Chapter 3

AGRICULTURE

Chapter 3.—AGRICULTURE

TABLES

FIGURES

Chapter 3

AGRICULTURE

Introduction

Agriculture was originally developed to provide a reliable source of food. Later feed was included in farm production and animals provided large parts of the population's energy needs. Although animals are rarely used for energy on U.S. farms today, agriculture has expanded to include the production of nonfood commodities, including cotton, tobacco, paint solvents, specialty chemicals, and various industrial oils. In 1977, these nonfood products accounted for over 13 percent of total farm production.

Many of the food and feed crops as well as farming byproducts can also be used to produce fuels or be combusted directly. In this chapter, the technical aspects of conventional agriculture are considered, leading to estimates of its potential for supplying energy.

Plant Growth, Crop Yields, and Crop Production

Harvested yields of many crops have increased dramatically over the past 30 years as a result of the development of genetically improved crop strains, as well as increased use of fertilizers and irrigation. Also, increased application of chemicals for control of insects, diseases, and weeds; further mechanization so that operations can be timely; improved tillage and harvesting operations; and other forms of improved management have also helped to raise yields.

Photosynthesis is the basic process providing energy for plant growth. Solar energy is absorbed by the green chlorophyll in the leaf and used to combine carbon dioxide (CO_2) from the air with water from the soil into stored chemical energy in the form of glucose. Glucose is used in the formation of compounds like adenosine triphosphate which provides energy for the synthesis of the various materials needed in the plant such as cellulose and lignins for cell walls and the structural parts of the plant and various amino acids (protein components). Glucose is respired to provide energy for production of other compounds, plant growth, and absorption of nutrients from the soil. As the plant matures, carbohydrates are stored in the seed to provide energy for the growth of new plants.

Sixteen nutrients are essential for plant growth and two or three more may increase yields but are not essential for the plant to complete its growth cycle. Of the 16, nitrogen, phosphorus, and potassium are the 3 main nutrients needed in large quantities to supplement the soil supply in order to obtain high crop yields. Calcium and magnesium are applied where needed as finely ground limestone. Sulfur is added as elemental sulfur or as sulfates when needed. Carbon, hydrogen, and oxygen come from the air and water and the remaining seven are used in extremely small amounts and are absorbed from the soil. All of these nutrients play essential roles in the growth processes within the plant.

Theoretical Maximum Yield

The theoretical maximum photosynthetic efficiency can be estimated as follows:

Ten percent of the light striking a leaf is reflected. Only 43 percent of the light that penetrates the leaf is of a proper energy to stimulate the chlorophyll. The basic chemical reactions (10 photon process) which use stimulated ("excited") chlorophyll to convert CO_2 and water to glucose have an overall efficien-

cy of 22.6 percent. The net result of these factors is, in theory, a maximum photosynthetic efficiency of about 9 percent. A summary of the various cases of photosynthetic efficiency is presented in table 14.

Table 14.–Photosynthotic Efficiency Summary

	Average PSE[a] during growth cycle (percent)
Maximum theoretical	8.7
Highest laboratory short-term PSE[a].	- 9
Laboratory single leaves, high CO_2 or low O_2, C-3 plants, c 7% full sunlight.	6.3
Same as above, for C-4 plants.	4.4
Corn canopy, single day, no respiration	5,0
Record U.S. corn **(345** bu of grain/acre, 120-day crop)	3.0
Record sugar cane (Texas)	3.0
Record Napier grass (El Salvador)	2.5
Record U.S. State average for corn (128 bu/acre, Illinois, 1979).	1.1
Record U.S. average for corn (108 bu/acre, 1979	0.9

[a] PSE-photosynthetic efficiency

SOURCE Office of Technology Assessment

An efficiency approaching the theoretical maximum appears to have been achieved for a short time under laboratory conditions using an alga or single-celled water plant. These results are controversial, however, and in practice there are always several other factors that limit the efficiency of photosynthesis, and the transformation of glucose into plant material. The most important of these factors, many of which are interdependent, are listed in table 15. For example, light saturation can be influenced by the CO_2 concentration, which is affected by other things. The key factors are light saturation, soil productivity (its ability to hold water, supply oxygen, release nutrients, and allow easy root development), weather (amount and timing of rainfall, absence of severe storms, length of growing season, temperature and insolation during the growing season), and plant type (leaf canopy structure, longevity of the photosynthetic system, sensitivity to various environmental stresses, etc.).

Table 15.–Factors Limiting Plant Growth

- Water availability,
- Light saturation–a tendency for the photosynthetic efficiency to drop as the incident light intensity increases above values as low as about 10% of peak solar radiation intensity.
- Ambient temperature, especially wide fluctuations from ideal.
- Mismatch between plant growth cycle and annual weather cycle.
- Length of photoperiod (hours of significant illumination per day).
- Plant respiration,
- Leaf area index–completeness of coverage of illuminated area by leaves or other photosensitive surfaces.
- Availability of primary nutrients–especially nitrogen, phosphorus, and potassium,
- Availability of trace chemicals necessary for growth.
- Physical characteristics of growth medium.
- Acidity of growth medium.
- Aging of photosynthetically active parts of plants.
- Wind speed.
- Exposure to heavy rain or hail or icing conditions.
- Plant diseases and plant pests.
- Changes in light, absorption by leaves due to accumulations of water film, dirt, or other absorbers or reflectors on surfaces of leaves or any glazing cover.
- Nonuniformity of maturity of plants in crop.
- Toxic chemicals in growth medium, air, or water, such as pollutants released by human activity.
- Availability of CO_2.
- Adjustment to rapid fluctuations in insolation or other environmental variables —i. e., "inertia' of plant response to changing conditions.

SOURCE. Off Ice of Technology Assessment

In an untended system, the environmental factors are left to chance. Consequently, in any given year, some areas of the country will experience a favorable combination of factors, resulting in more plant growth, while in other areas environmental factors will be unfavorable, resulting in less plant growth. The exact places where the growth is favorable or unfavorable will also change from year to year, as will the exact growth at the most favorable area in each year. In the absence of long-range environmental changes, however, such as weather changes or soil deterioration, the average growth over a very large area and for many years will remain relatively constant.

Some of the environmental factors can be controlled, while others cannot within the present state of knowledge. Managing a plant and soil system consists of artificially maintaining some of the environmental factors, such as nutrients or water, at a more favorable level than would occur naturally. The many remaining factors, however, are still left to chance. Furthermore, there is a limit to how

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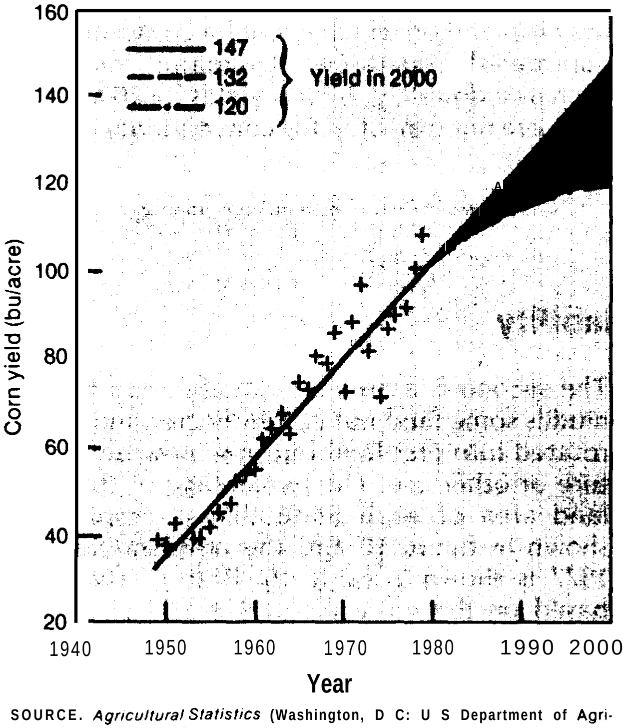
[1] V C Goedheer and J W Kleinen Hammans, Nature, vol 256, p 333, 1975

much plant growth (or other characteristics such as grain yield) can be influenced by changes in given environmental factors. Once some of the factors have been optimized for plant growth (or, e.g., grain yield) the plant's performance will not be improved by further changes of these factors. Too much water or fertilizer, for example, could actually inhibit growth rather than increase it.

Because plants vary in their sensitivity to growth-limiting factors yields can be improved by selecting or breeding for plants that are relatively insensitive to environmental factors that cannot be controlled and/or that respond well to factors that can.

A dramatic example of the success of breeding and management is corn. The history of U.S. average corn yields from 1948-78 is shown in figure 7. While the national average yields have not been analyzed in detail, Duvick has analyzed the changes in yields from hybrids grown in various Midwestern locations.[2] He concluded that 60 percent of the increase on these plots was due to genetic improvements while 40 percent was attributed to improved management. The management tends to reduce the environmental stresses, while hybrids were developed that are less sensitive to adverse environmental factors and more responsive to the factors that can be controlled (e. g., fertilizers, weed control, insect control, etc.).

Figure 7.—U.S. Average Corn Yield



SOURCE. *Agricultural Statistics* (Washington, D C: U S Department of Agriculture. 1978)

Historical Yield Trends

Past yield trends can be used as a guide for projection of future yields. A period of at least 15 years should be considered because of weather fluctuations since the desired value is the yield trend if weather remained constant. A period of dry years from 1973 to 1976 tended to exert some influence on data variability. During the 1948-78 period, corn yields increased an average of 2 bu/acre-yr giving a 1978 yield just over 100 bu/acre. Similarly soybean yields showed an increase of about 0.4 bu/acre-yr and a 1978 yield of 29.2 bu/acre. National wheat yields are somewhat more variable since wheat is grown primarily in areas that are more affected by drought than is corn. Nonetheless, the yield trend indicates an increase of 0.5 bu/acre-yr and a 1978 average yield of 31.6 bu/acre. The U.S. Department of Agriculture (USDA) has calculated a summary of all crop yields per acre using a relative value of 100 for the 1967 yield. The trend for increase over this period was 1.4 units per year, but the uncertainty in this number is large (see figure 8).

Yield increases in the future as in the past will come from a combination of improved crop varieties and improved cultural practices. Since current fertilization practices have reached near optimum rates, increases in yield due to increases in fertilization rates will be less than for the past 20 years. As yield potentials of varieties are increased, however, increased rates of fertilization will be needed to keep pace with the increased yields. Since yield increases result from a combination of practices, it is difficult to attribute yield increases to any one practice.

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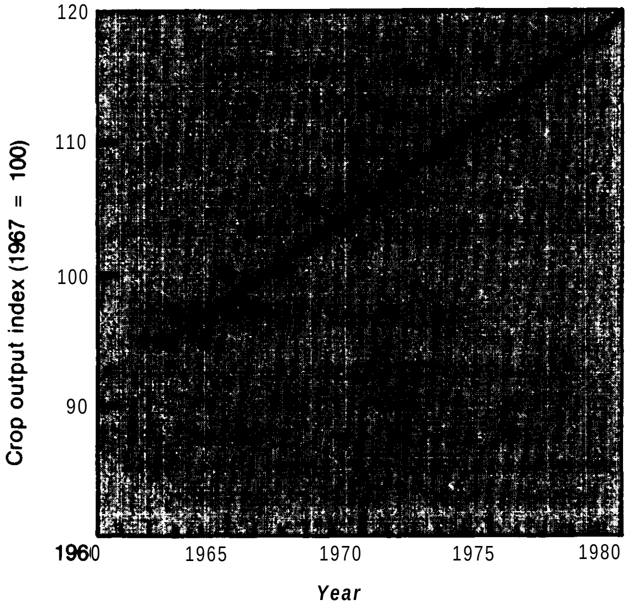
[2] D N Duvick, *Maydica XXII,* p 187,1977

Figure 8.—U.S. Average Crop Output



SOURCE: *Agricultural Statistics* (Washington, D. C.: U.S. Department of Agriculture, 1978).

Record Yields

Projection of yields and determination of where yield increases will diminish may be judged on the basis of yields that have been obtained. For example, the average U.S. corn yield has reached over 100 bu/acre, but the average yield in Illinois in 1979 was 128 bu/acre and in Iowa in 1979 it was 127 bu/acre. * If county averages within a State are examined, average yields are found to approach 140 bu/acre. If individual farms of 500 acres of corn are considered, yields of 175 bu/acre have occurred. And on selected areas of 2 or 3 acres yields of 345 bu/acre have been noted.

Future Yields

Over the past 30 years corn yields have increased at an average rate of about 2 bu/acre-yr. One would not expect this rate of increase to rise, and it may decline. Therefore, in projecting corn yields in the year 2000, 140 bu/acre would be optimistic. A less optimistic projection, based on annual average yields increasing at one-half the rate that they have in the recent past, is 120 bu/acre in 2000. A study by the National Defense University in 1978 gave a projected corn yield for 2000 of 132 bu/acre.

Future increases in the yields of other crops are also expected, but each crop together with the cropland on which it will be grown must be considered separately. Dramatic increases, such as a doubling in crop yields by 2000, however, are not expected for conventional crops.

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*The weather in 1979 was ideal for corn growing

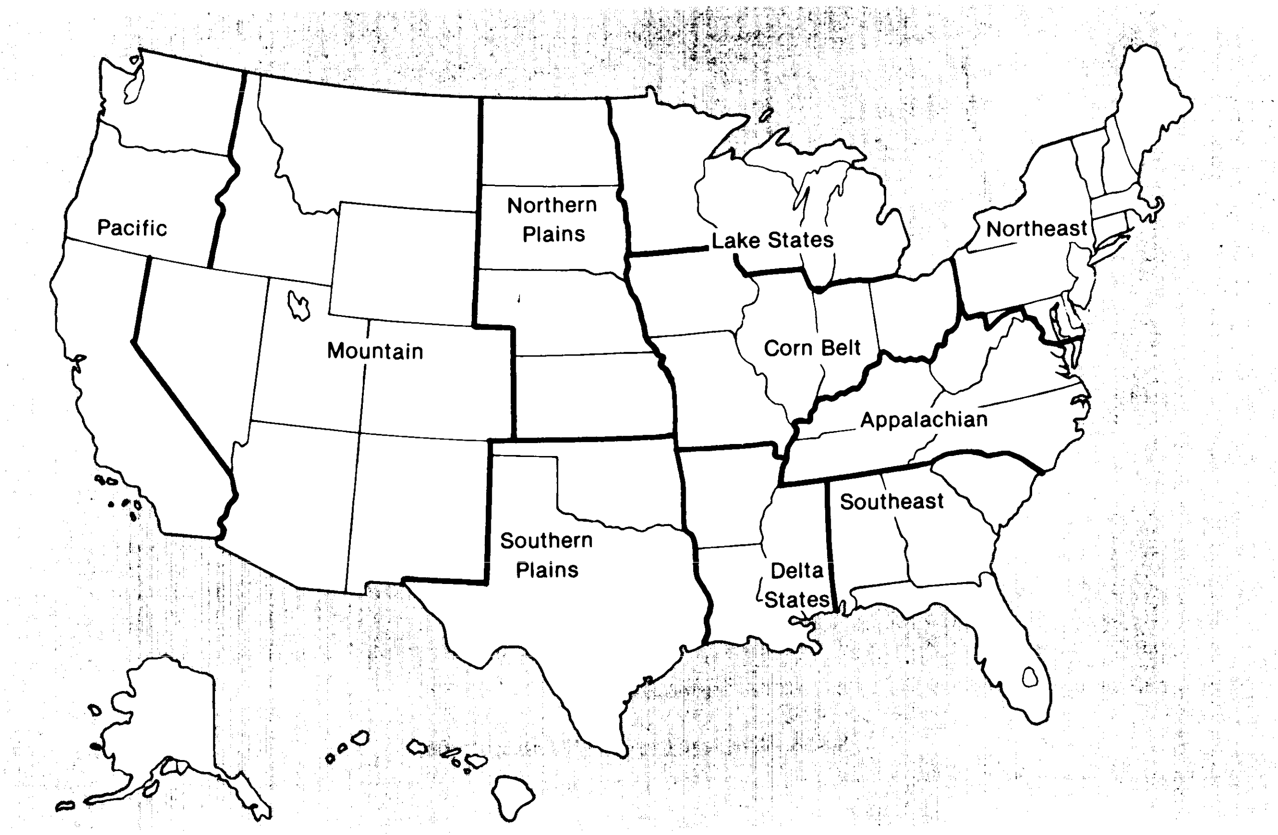
Land Availability

Cropland is land used for the production of adapted crops for harvest, alone or in a rotation with grasses and legumes, and includes row crops (e. g., corn), small grain crops (e. g., wheat), hay crops, nursery crops, orchard crops, and other similar specialty crops. Cropland is generally categorized into the agricultural production regions shown in figure 9.

Of the U.S. total land area of 2.3 billion acres, 413 million or 467 million acres are currently classified as cropland depending on whether one uses the Soil Conservation Service (SCS) or the other USDA classification system. The second is a broader classification that includes some land not currently cropped that is rotated into cropland but may now be in pasture or other use. The percentage of the total land area of each State that is cropland is shown in figure 10 and the cropland used in 1977 is shown in table 16. Both of these are based on the more restrictive SCS classification of cropland.

Cropland, however, is not a static category. The location of cropland may shift even though the quantity of cropland remains rela-

Figure 9.—Farm Production Regions of the United States



SOURCE Soil Conservation Service, U S Department of Agriculture

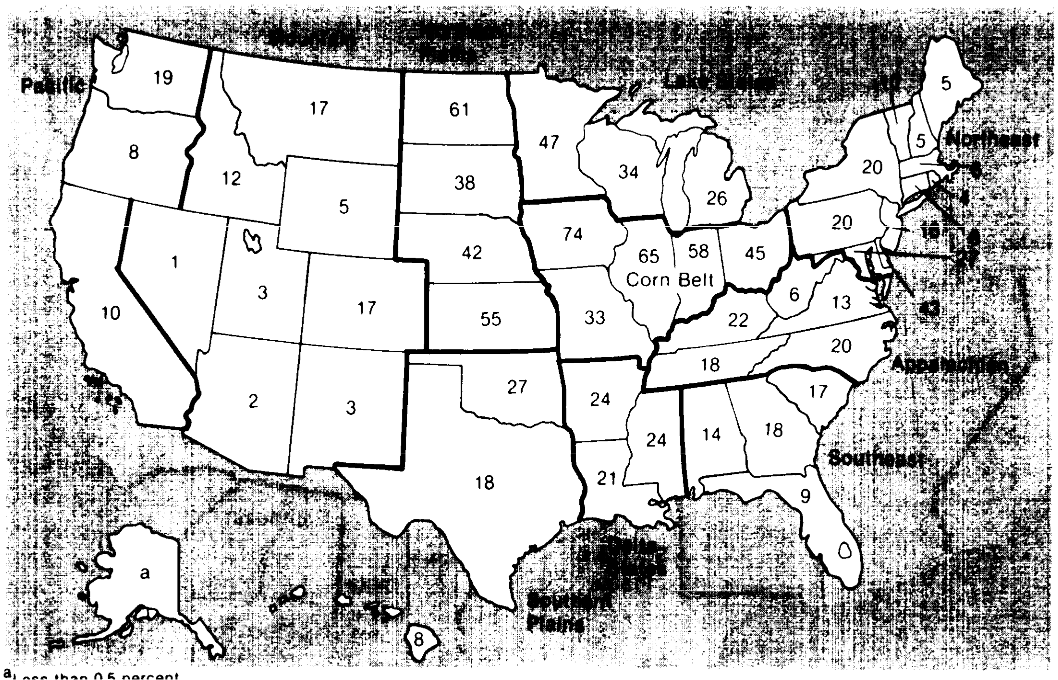
tively constant. Over time there are both additions and deletions to the cropland inventory.

The quality of land and cropping systems may shift as well. One such change has been the increase in irrigation, in areas like the Texas high plains, from 1.2 million acres in 1948 to 6.4 million acres in 1976. This represents both a trend in improving the productivity of existing cropland and a trend towards opening new, marginal land that is only productive and economic with irrigation. To some extent, the United States has been replacing rainfed arable land that is lost to agriculture with irrigated land in dry areas. This trend, however, is likely to change due to increasing energy costs and depletion of some Western ground water.

Over time, the content of a land inventory can be influenced by the way that a given statistic is enumerated. For example, up to 1964 the agricultural census was personally enumerated and in 1969 it was done by mail. According to the broader USDA classification, cropland pasture increased by over 30 million acres between these surveys, and the suspicion is that the farmer applied a less strict definition to cropland pasture which resulted in the inclusion of 30 million acres of pastureland and grassland into the cropland pasture category even though the actual usage had not changed.

One strong influence on the land inventory has been the Government's agricultural programs. The land retirement programs of the 1960's reduced planted cropland and had the net effect of moving less productive land out of crop production temporarily or even permanently in the case of very low-quality land. As

Figure 10.—Cropland as a Percentage of Total Land Area by Farm Production Region



[a]Less than 0.5 percent.

SOURCE: Soil Conservation Service, U.S. Department of Agriculture.

Table 16.-Cropland Use in 1977 (thousand acres)

	Row crops		Close-grown crops		Rotation hay		Occasionally improved hayland	
Region	Irrigated	Nonirrigated	Irrigated	Nonirrigated	Irrigated	Nonirrigated	Irrigated	Non irrigated
Northeast	254	6,771		1,033	9	3,339	5	3,286
Appalachian	349	14,445	33	543	7	1,248	10	3,151
Southeast	1,681	12,108	23	342	24	74	8	604
Delta States	2,294	15,358	1,489	285	170	299	0	397
Corn Belt	1,035	70,291	31	7,228	8	5,987	4	4,116
Lake States	799	20,930	80	9,140	36	7,753		2,802
Northern Plains	8,641	18,062	920	40,007	690	5,387	325	3,885
Southern Plains	5,935	13,908	2,354	15,784	33	802	286	725
Mountain	4,117	962	3,316	14,021	2,269	380	3,821	1,276
Pacific	4,477	132	2,757	5,556	1,124	502	1,092	295
Total[a]	29,750	173,493	11,025	93,865	4,398	25,818	5,559	20,839

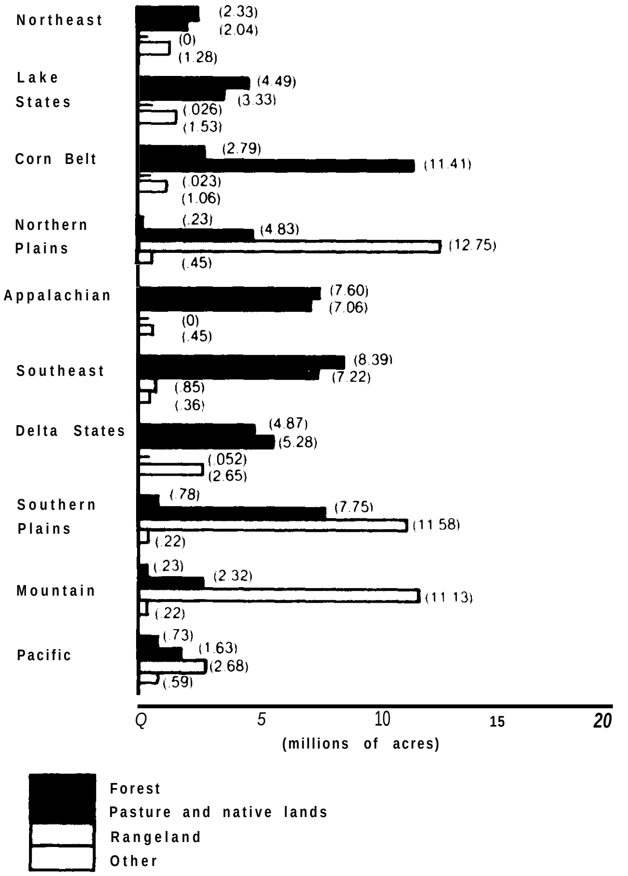
	Native hay			Orchards, etc.			All cropland	
Region	Irrigated	Nonirrigated	Summer fallow	Irrigated	Nonirrigated	Other	Irrigated	Nonirrigated
Northeast	0	789	24	84	508	493	372	16,534
Appalachian	0	86	112	0	149	690	406	20,339
Southeast	0	0	54	699	661	1,324	2,449	15,053
Delta States	0	84	179	6	136	489	3,979	17,207
Corn Belt	0	117	749	22	72	876	1,115	88,739
Lake States	0	719	466	42	291	1,073	972	43,167
Northern Plains	33	2,493	13,825	0	15	268	10,790	83,733
Southern Plains	0	405	1,061	33	153	755	9,011	33,223
Mountain	1,460	320	9,449		0	641	17,208	26,111
Pacific	261	208	4,082	2,242	183	277	12,261	10,927
Total[a]	1,754	5,221	28,319	3,295	2,225	6,806	57,647	355,520

[a]Also includes Caribbean and Hawaii

SOURCE Soil Conservation Service, U S Department of Agriculture programs were terminated in the early 1970's, some of these acres came back into crop production.

USDA'S SCS surveyed non-Federal lands in 1977 and identified the land that potentially could become cropland. [3]The survey classified potential croplands according to whether the land was judged to have a high, medium, low, or zero potential for conversion. Figure 11 summarizes the quantities of land that have a high or medium potential for conversion to cropland. Of the total potential cropland in 1977, 40 million acres have a high probability to be converted and another 95 million acres are classified as having medium probability. *

Figure 11.—Present Use of Land With High and Medium Potential for Conversion to Cropland by Farm Production Region



SOURCE: 1977 National Erosion Inventory Preliminary Estimates, Soil Conservation Service, U.S. Department of Agriculture, April 1979.

The breakdown of the potential cropland into high and medium potential for conversion is an attempt to define a crude cost curve for the availability of new cropland. It was judged by SCS that the land with a high potential will enter agriculture as a matter of course, if price relationships are somewhat more favorable to the farmer than the 1976 prices on which the survey was based. The medium potential, however, is a category involving lands with a wide variety of problems but which cannot be categorically excluded from conversion if farmland prices increase sufficiently.

The SCS survey, however, does not include a quantitative measure of the price increases necessary to bring potential cropland under cultivation. A conservative approach would be to assume that only land with high potential can be included in the cropland base without excessive inflation in food prices above that which would occur normally due to increased demand for food. A more optimistic approach would be to include those types of medium-potential land that probably will be considered high potential in the future, as increased demand for food raises cropland prices. This is the approach that was taken.

Two major factors, mentioned above, that affect crop productivity are water availability and soil quality. Therefore, land was included from the medium-potential category that has greater than 28 inches of annual rainfall and potentially has good productivity (capability classes 1 and 2 of the eight agricultural land capability classes). These land types are the most likely to be brought into cultivation if demand exceeds the high-potential category.

With these assumptions, the potential cropland is shown in table 17. This together with existing cropland provides the cropland base, to-

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[3] 1977 Soil Conservation Service *National Erosion Inventory Estimate* (Washington, D C Soil Conservation Service, U S Department of Agriculture, December 1978)

*As of November 1979, these numbers were 36 million and 91 million acres, respectively

Table 17.-Potential Cropland (thousand acres)

Region	Source Forest	 Pasture	 Rangeland	 Other
High potential with over 28 inches rainfall				
Lake States. , ...	868	1,206	22	443
Delta	1,482	1,781	0	129
Corn Belt	664	4,451	23	368
Northeast ..,.....	268	562	0	371
Southeast	2,111	2,926	133	151
Appalachian	1,981	2,974	0	183
	7,374	13,900	178	1,645
Total of forest pasture, and rangeland: 21,452				
Medium potential, class I&2 land only with over 28 inches rainfall				
Lake States. .... . ., ...	1,463	723	0	*315*
Delta	*986*	*1,423*	0	
Corn Belt	974	2,590	0	356
Northeast	656	433	0	306
Southeast	2,082	1,256	0	17
Appalachian	2,012	1,157	0	119
	8,137	7,582	0	1,113
Total of forest, pasture, and rangeland: 15,755				
High potential with less than 28 inches rainfall				
Arid regions	312	5,503	9,549	—
Total of forest, pasture, and rangeland: 15,364				

SOURCE: Otto C. Doermg III, "Cropland Availability for Biomass Production," contractor report to OTA, August 1979.

taling 520 million acres. (This is based on the broader cropland classification as used in USDA's Agricultural Statistics and all Economics, Statistics, and Cooperatives Service publibations) Although it is impossible to predict exactly how the cropland base will develop in the future, one plausible scenario is shown in table 18 based on continuation of past trends to 1984 and on USDA's National Interregional Agricultural Projections System (NIRAP) for 1990 and 2000.[4]

By examining the detailed demand forvarious crops from NIRAP and the land available, Doering has derived baseline estimates for the quantity of cropland that could be available for bioenergy production, which are shown in table 19.[5] Doering, also derived high and low food demand scenarios for 1984 based on extrapolation of trends in the recent past and increased this demand range proportionately to the increase in baseline crop demand from the NIRAP projections for 1990 and 2000. Finally these demand ranges were combined with

Table 18.-Cropland Balance Sheet (million acres)

Year	1977[a]	1979	1984	1990	2000
Cropland (except cropland pasture and hayland)	393	395	404	407	439
Cropland pasture and hayland	74	72	65	80	60
Noncropland pasture	27	27	22	10	2
Other potential cropland	26	24	22	13	4
Total	520	518	514	510	505
Total land lost to other uses to date	0	2	6	10	15
Total . . . . , ... , ...	520	520	520	520	520

[a] With SCS acreage counting system, the 1977 acreages (in millions of acres) would be as follows, cropland except cropland pasture and hayland, 343; cropland pastaure and hayland, 63; noncropland pasture which is potential cropland or is periodically rotated into cropland, 88; and other potential cropland, 26 The major differences are that the cropland categories total 406 million acres with the SCS classification rather than 467 million acres and the noncropland categories are increased accordingly. In both classification schemes there are additional noncropland pature categories which are neither potential cropland nor periodically rotated into cropland, primarily because the terrain is too rocky or rough to allow mechanized harvests

SOURCE. Deduced from Otto C Doering III, ''Cropland Availability for Biomass Production, " contractor report to OTA, August 1979

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[4] L Quance, A Smith, K. Liu, and L. Yao-Chi, "Adjustment Potentials m U.S Agriculture," *Vol. 1—National Interregional Projections System* (Washington, D.C.: Economics, Statistics, and Cooperatives Service, U.S Department of Agriculture, May 1979)

[5] Otto C Doering III, "Cropland Availability for Biomass Production," contractor report to OTA, August1979,

NIRAP high and low productivity (yield/acre) estimates to determine plausible ranges of demand for cropland for food and feed production and thus the ranges of land available for bioenergy production. These estimates are shown in table 19.

Table 19.–Cropland Available for Biomass Production

	Million acres
1984	
From cropland pasture	10
From high potential	10
From medium potential	10
	30
Range of uncertainty, ...	30-70
1990	
From cropland pasture	25
From high potential	5
From medium potential	5
	35
Range of uncertainty	***9-69***
2000	
From cropland pasture	10
From high potential	NA
From medium potential	NA
	10
Range of uncertainty.	0-65

NA=none available

SOURCE” Otfo C Doering III, ''Cropland Availability for Biomass Production, ” contractor report to OTA, August 1979

It should be emphasized that these are not predictions, but rather plausible estimates given the current state of knowledge. The ranges are less than ± 10 percent of the cropland base, so it is unlikely that more accurate estimates can be made. Furthermore, unexpected increases in crop productivity, in world food demand, or in demand for cropland for nonagricultural uses could increase or decrease the quantity of cropland available for bioenergy production beyond the ranges shown. Also, since this only refers to cropland capable of producing more or less conventional crops, the development of unconventional crops could open new land categories not considered here.

In addition to the physical availability of cropland, one must consider the cost of bringing it into production. Four major factors influence this cost. First the land is currently being used for some purpose that the owner considers to be more valuable. than crop production. Second an investment is sometimes necessary to convert the land to crop production, such as installation of drainage tiles or removing trees occupying the site. These costs can vary from virtually nothing to as much as $600/acre.’ Third, the land that can be brought into production is generally less productive, on the average, than cropland currently in production. Finally, this land also typically suffers from problems of drought or flooding that make crop yields extremely sensitive to weather (particularly the rainfall pattern). Consequently, farming this land involves a larger cost and risk than with average cropland; and, from the national perspective, using it will increase the year-to-year fluctuations in food supplies and prices.

As a result of these added costs and risks, farm commodity prices will have to rise before it will be profitable to bring new land into crop production. Eventually this raises the cost of all farmland, the cost of farming, and food prices. The exact price rise needed to increase the cropland in production by a given amount is unknown, but some things can be deduced from this analysis. During the next few years, bioenergy production from cropland is not likely to be constrained by the availability of cropland. However, the quantity of land that can be devoted to energy production without reducing food production is likely to decrease in the future. Furthermore, since the marginal cost of bringing new cropland into production increases as the quantity of cropland in production expands, the added cost in terms of higher food prices needed to keep a given amount of cropland in energy production is likely to increase with time. In other words, it is likely to be increasingly expensive to produce energy crops, even if the energy output remains constant.

The above comments are particularly applicable to grains and sugar crops. Considerable quantities of land, however, already are devoted to forage grass production and the yields can be raised through increased fertilization (see below). Furthermore, grass yields tend to be less sensitive to poor soil quality than grains

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[c] Ibid

and sugar crops. Consequently, the economic barriers to increased grass production are considerably lower than for increased grain or sugar production, and one would expect the indirect costs of grass production to be less than those of grains and sugar crops.

Nevertheless, in the long term, there may be little cropland suitable for food/feed production that can be devoted to energy, and any energy crops would have to be grown on land totally unsuited to food and feed production.

Types of Crops

There are over 300,000 plant species in the world, but less than 100 are grown as crops in the United States. Of the various crops, three basic types are currently of interest for immediate energy production: starch, sugar, and forage.

The major starch crops are corn (for grain) and wheat, accounting for 21 percent each of the total acreage of harvested crops, or about 70 million acres each. The annual production and disposition of corn and wheat are shown in tables 20 and 21. In addition, oats, barley, grain sorghum, and rice are other important starch crops.

The main sugar crops currently grown in the United States are sugarcane and sugar beets. About 760,000 acres are devoted to sugarcane (in Florida, Louisiana, Texas, and Hawaii) and sugar beets were grown on 1.2 million acres in 1977. Also, a smaller acreage is devoted to sweet sorghum production, primarily for sorghum syrup. The sugar yields averaged about 3.7 ton/acre for sugarcane (some growing seasons were 18 to 24 months) and 2.6 ton/acre for sugar beets. The very limited commercial acreage of sweet sorghum has yielded about 1.9 ton/acre of sugar, however, the acreage is too small to accurately reflect the yields that would occur from large-scale production of this crop.

Forage crops are grown for feed and bedding. Including alfalfa, the area under forage crop production is about 60 million acres.[7] Forage crops include orchard grass, brome grass, tall fescue, alfalfa, clover, and reed canarygrass. Yields average about 1.5 to 2.5 ton/acre but could be increased to 4 to 5 ton/acre by relatively straightforward changes in management practices.

Table 20.–Annual Production and Disposition of Corn for Grain in the United States, 1966-75 (million bushels)

Year	Production	Domestic consumption	ExPorts	Stocks
1966	4,167	3,697	487	826
1967	4,860	3,885	633	1,169
1968	4,450	3,966	536	1,118
1969	4,687	4,189	612	1,005
1970	4,152	3,977	517	667
1971	5,641	4,387	796	1,126
1972	5,573	4,733	1,258	706
1973	5,647	4,631	1,243	483
1974	4,664	3,641	1,149	359
1975	5,797	4,049	1,711	398

SOURCE *Agricultural Statistics* 1977(Washington. D C U S Department of Agriculture, 1977)

Table 21.-Annual Production and Disposition of Wheat in the United States, 1966-75 (million bushels)

Year	Production	Domestic consumption	Exports	Stocks
1966	1,967	683	771	513
1967	2,202	626	765	630
1968	2,188	740	544	904
1969	2,350	764	603	983
1970	2,336	772	741	823
1971 .., .	2,442	848	610	983
1972, . . .	2,530	798	1,135	597
1973, . . .	2,305	748	1,217	340
1974	2,140	686	1,019	435
1975	2,572	735	1,173	664

SOURCE *Agricultural Statistics* 1977(Washington, D C U S Department of Agriculture, 1977)

Most crops can be grown in several different areas of the country. However, each crop has unique characteristics that enable it to do well under certain combinations of soil type, growing season, rainfall, etc. Since these parameters vary widely throughout the United States, it is unlikely that any one crop could prove to

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[7] *Agricultural Statistics* (Washington, D C.: U S Department of Agriculture, 1978).

be the correct energy crop for a given product. Rather, the available cropland can best be utilized for energy by growing various different crops suited to the various soil types, climates, and other conditions. Nevertheless, there are some striking differences when national average yields are compared. (See "Energy Potential From Conventional Crops" below.)

The crops mentioned here do not exhaust the possibilities, even for starch, sugar, and cellulosic products. Other crops may be superior to these under certain circumstances. But these crops do serve to illustrate U.S. agriculture's energy potential, costs, and impacts.

Current Agricultural Practices and Energy and Economic Costs

As mentioned above, the purpose of managing a plant system is to provide an artificially favorable environment for plant growth. Since increasing the intensity of management costs money, there is always a tradeoff between the increased cost and the expected increase in yields. As price relationships change, the intensity of management will also change. A summary of some current agricultural practices and their costs and energy usage is given below.

Aside from weather and soil type, the planting date, planting density, weed, disease, and insect control, and tillage practices can all affect crop yield. Different plants have different sensitivities to these various factors. Practices also have to be suited to the climate and soil type that is being farmed. Consequently, the direct costs of farming will vary depending on the crop and region. There can even be significant differences for the same crop within a given region (e. g., erosion control measures, irrigation, etc.).

A "typical" farming operation for annual crops such as corn and soybeans, however, might be as follows: After harvest of the crop in the fall the residues are chopped or the soil is disked to reduce the size of the residues and to level the soil. Phosphate and potassium fertilizer are broadcast and the residues and fertilizer are plowed under. In the spring, surface tillage to level the soil is done soon after the soil becomes suitable for tillage. Nitrogen fertilizer — anhydrous (dry) ammonia, etc. — if needed, is applied to the soil. Five to ten days later the soil is surface tilled with a cultivator or disk and the crop planted. During planting some additional fertilizer may be added, an insecticide may be applied, and herbicides may be broadcast on the soil surface. The crop may be cultivated for weed control once or twice within the first month of growth. No additional operations occur until the crop is harvested with a harvestor that separates the grain and leaves the residue on the field. If the grain has a moisture content above that needed for storage without spoilage, it is dried. The grain may be fed on the farm, stored and sold later, or sold directly to a grain company at harvest.

Minimum or reduced tillage operations are used to reduce soil erosion. With their use the soil may be chisel-plowed rather than moldboard-plowed so that much of the residue remains in the surface. Herbicides may be used to give complete weed control so that no further cultivation is needed.

Forage crop management is considerably simpler. Since forage crops are usually perennials, crop planting is done only once every 4 to 5 years, or longer. Aside from planting, the only management is the application of fertilizers and the harvesting of the forage crop.

The estimated costs for producing corn (a row crop) and wheat (a close-grown crop) are shown in table 22. These costs are fairly representative of what can be expected for the production costs per acre for annual crop production, with intensive agriculture. Costs will vary from place to place, but where costs other than land costs are higher and/or yields are lower, the land will be worth less and land costs will be lower.

Table 22.-Estimated per Acre Production Costs in Indiana, 1979

Production cost item	Corn	Wheat
Yield per acre	110 bu	50 bu
Direct cost per acre		
Fertilizer and lime[a]	$32.00	$22.50
Seed and chemicals	20.00	10.00
Machine operating and drying	25.50	11.25
Interest on operating capital	9.00	7,00
Total direct costs	$86.50	$50.75
Indirect costs per acre		
Machinery and equipment	$43.00	$18.00
Labor and management	31.00	20.00
Grain storage (bin only)	11.00	–
Land cost[b]	92.00	92.00
Total indirect costs	$177.00	$130.00
Total costs per acre	$263.50	$180.75
Cost per bushel	2.40	3.62

[a] Nitrogen prices at $0.12/lb for corn and $020 for wheat Phosphorus pentoxide priced at $0.18/lb; potassium monoxide priced at $009 for all crops A corn-soybean rotation is assumed Thus soybeans produce a nitrogen credit for corn production and no insectide is used

[b] Land costs approximate current cash rental rates

SOURCE Barber, et al , "The Potential of Producing Energy From Agriculture, " Purdue University, contractor report to OTA, May 1979

Table 24.-Energy Inputs and Outputs for Corn in U.S. Corn Belt

	Energy units	
	Nonirrigated[a] (10' Btu)	Sprinkler (10^5Btu)
output		
Grain	543.7	666.4
Residue	543.7	666.4
Total output	1087.4	1332.8
Input		
Irrigation pumping	–	60.0
Fertilizer	47.0	57.6
Drying fuel	19.4	23.8
Equipment fuel	10.0	10.5
Pesticides	6.0	6.0
Total input	82.4	157.9

[a] Grain yield, 139 bu/acre; residue yield: 7,770 lb/acre.

[b] Pump irrigated 15 inches water, 100 ft depth Grain yield and residue yield are 170 bu/acre and 9,520 lb/acre, respectively.

SOURCE Barber, et al , ' 'The Potential of Producing Energy From Agriculture, ' Purdue University, contractor report to OTA, May 1979.

The energy used for farming varies considerably. Typical energy inputs per acre for various crops are shown in table 23. These energies are for cultivation without pumped irrigation. A comparison of the energy inputs for irrigated and nonirrigated corn is shown in table 24. Overall, the energy per ton of grain can vary at least from 1.2 million Btu/ton for oats in Iowa to 6.5 million Btu/ton for grain sorghum in Texas. For corn the variation is at least from 2.6 million Btu/ton of grain (Illinois average) to 4.6 million Btu/ton (Nebraska). The U.S. average for corn is 3.1 million Btu/ton of corn grain.

These differences reflect not only differences in cultivation practices and, yields, but also the presence or absence of pumped irriga-

Table 23.-Energy Inputs for Various Crops (10^5 Btu per acre)

	Corn					
	Conventional tillage	Minimum tillage	No tillage	Soybeans	Wheat	Alfalfa
Nitrogen [a]	43.75	43.75	43,75	—	20,00	1.25
Phosphorus pentoxide + potassium monoxide[b]	3.20	3.20	3.20	2.70	3.00	6.56
Drying [c]	19.35	19,35	19.35	—	—	
Diesel[d]						
Ground preparation	7.36[e]	5.13[f]	2.21[g]	5.67[h]	3.15[i]	—
Planting	1.34	1.34	1.34	1.34	1.34	–
Cultivation	1.34	1.34	—	1.34	–	21.07
Harvest	2.15	2.15	2.15	1,69	1.54	–
Herbicides	4.20	4.65	6.00	4.80	–	–
Insecticide	1.80	1.80	1.80	—	—	5.60
Total	84.49	82.71	79.80	17.54	29.03	34.48

[a] 25.000 Btu/lb nitrogen.

[b] 3.000 Btu/lb phosphorus pentoxide and 2,000 Btu/lb potassium monoxide

[c] 93,500 Btu/gal LP-gas, 3,414 Btu/kW-hr electricity.

[d] 132,250 Btu/gal diesel fuel

[e] Spread fertilizer, plow, disk, apply anhydrous ammonia, disk

[f] Spread fertilizer, chisel plow, apply anhydrous ammonia, field cultivate

[g] Spread fertilizer, spray, apply anhydrous ammonia.

[h] Spread fertilizer, plow, disk, disk

[i] Disk, disk, spread fertilizer in spring

11211,000 Btu/lb active ingredient

SOURCE: Barber, et al , ''The Potential of Producing Energy From Agriculture, " Purdue University, contractor report to OTA, May 1979, tion and the fuel used for irrigation. Examples of energy-intensive crops range from corn grown in Nebraska which is irrigated with ground water brought to the surface by electric pumps and is dried with liquefied petroleum, to grain sorghum which has relatively low yields compared to energy inputs throughout the United States. Other crops, such as rice, can be even more energy intensive (7.8 million Btu/ton, U.S. average).

For most corn cultivation, over half of the energy input comes from fertilizer, principally nitrogen. However, without nitrogen fertilizers, average corn yields would drop from about 100 bu/acre to less than 30 bu/acre. In the example in table 23, the energy used would increase from 3.0 million to 4.9 million Btu/ton if nitrogen fertilizers were not used, assuming the above yield change.

The other big energy input for some areas—irrigation—can have the opposite effect. In the example given in table 24, the use of irrigation raises the energy input from 2.2 million to 3.4 million Btu/ton. And in some areas (e.g., west Texas and southern Arizona), the energy required for pumped irrigation is more than twice that shown in table 24.[8] In all, 85 percent of the 58 million acres of irrigated cropland are in the West (Northern Plains, Southern Plains, Mountain, and Pacific farm production regions) and 94 percent of the 0.26 Quad/yr used for pumped irrigation in the United States in 1974 was in the West.[9] On the average, the energy needed to pump the equivalent of 22 inches of rainfall in the West is 6 million Btu/acre. Consequently, this is a reasonable average figure for the energy input due to irrigation.

Another possible type of energy crop is forage grass. Currently, little or no fertilizer is used to cultivate forage grass; and yields are about 2 ton/acre. However, if fertilizers were used and the crops harvested more times per year, additional biomass could be obtained. Table 25 shows the costs of producing grass

Table 25.–Estimated Costs of Producing Grass Horbage at Three Yield Levels

	Yield level (ton/acre)		
	2	3	4
Growing costs ($/acre)			
Fertilizer	—	19.45[b] - 24.42[c]	41.59 [d] - 50.70[e]
Seed and seeding	2.30	2.30	2.30
Interest and miscellaneous	0.22	2.07 - 2.54	4.17 - 5.04
Total	2.52	23.92 - 29.26	48.06 - 58.04
Harvest costs ($/acre)			
Machine operating	8.00	12.00	16.00
Interest and miscellaneous	0.76	1.14	1.52
Machine investment	34.06	34.06	34.06
Hay storage[g]	0 - 8.72	0 - 13.08	0 - 17.44
Labor @ $4/hr[h]	3.68 -11.04	5.52 - 16.56	7.36 - 22.08
Total	46.50 -62.58	52.72 - 76.84	58.94 - 91.10
Total non-land costs			
$/acre	49.02 -65,10	76.54 -106.10	107.00 -149.14
$/ton [i]	27.23 -32.55	28.35 - 35.37	29.72 - 37.29

[a] Includes cost of application
[b] 60 lb nitrogen, 20 lb phosphorous pentoxide, 50 lb potassium monoxide/acre.
[c] &I lb nitrogen, 30 lb phosphorous pentoxide, 90 lb potassium monoxide/acre
[d] 150 lb nitrogen, 30 lb phosphorous pentoxide, 60 lb potassium monoxide/acre
[e] 150 lb nitrogen, 50 lb phosphorous pentoxide, 150 lb potassium monoxide/acre.
‘9-percent interest = O 5% miscellaneous costs
[g] Range from no cost if large hay package stored outside to new barn costs for rectangular bales
[h] High labor values for rectangular bale handled by hand, low labor bales for large hay packages
[i] Assumes 10% additional storage loss if hay stored outside (average storage period).

SOURCE. Barber, et al , “The Potential of Producing Energy From Agriculture, “ Purdue University, contractor report to OTA, May 1979

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[8] D. Dvoskin, K. Nicol, and E. O. Heady, “ Irrigation Energy Requirements in the 17 Western States,” *Agriculture and Energy,* W, Locheretz, ed. (Academic Press, 1977)

[9] G. Sloggett, “Energy Used for Pumping Irrigation Water in the United States, 1974,” *Agriculture and Energy,* W. Locheretz, ed (Academic Press, 1977).

herbage at various levels of fertilization and grass production. The additional production is estimated to cost $28 to $37/dry ton. Note particularly that no land charges are included in these cost calculations, because the use of the land has not changed. Only the output has been increased. Nevertheless, some farmer profit in addition to the labor charge may be needed to induce farmers to increase production. Furthermore, obtaining the full potential from this resource would require a 50- to 100-percent increase in fertilizer use in agriculture.

With no fertilization the energy used to produce the grass is about 0.1 million Btu/ton of grass at the present estimated level of 2 ton/acre. At 3 and 4 ton/acre, the additional energy use is about 1.9 million Btu for the third and 2.4 million Btu for the fourth ton. About 0.1 million to 0.2 million Btu/ton should be added to these energy inputs for a 15-mile transport of the grass.

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[10] S. Barber, et al., "The Potential of Producing Energy From Agriculture," Purdue University, contractor report to OTA, May 1979.

[11] Ibid

Energy Potential From Conventional Crops

Aside from crop residues, the two major near- to mid-term sources of bioenergy from conventional crops are grains and sugar crops for liquid fuels production and increased forage grass production, On the land capable of supporting grain and sugar crop production, grasses could also be grown; and a comparison of these choices is considered first.

The mechanism through which food and fuel production compete is the increase in farm commodity prices. Since farm commodity prices must rise in order to make it profitable for farmers to increase the quantity of land under intensive production, it is important to examine the net quantities of premium fuels that can be displaced, through liquid fuels production, by each of the alternatives when new cropland is brought into production. (For details of the energy balances, see ch. 11.)

The calculations for sugar crops and grasses are relatively straightforward, since these feedstocks have very little protein in them and, consequently, the byproduct probably has little value as an animal feed (see "Byproducts" in ch. 8). The distillation of grains, in contrast, produces a protein concentrate byproduct that can displace significant quantities of soybean meal and thus soybean production. Additional grains could then be grown on the land formerly devoted to soybean production. Estimates of the effect of this substitution are calculated below.

First, let X represent the number of acres of average soybean production that can be displaced by growing 1 acre of average corn production, converting the corn to ethanol, and feeding the byproduct to livestock. Assuming that the corn yield on marginal cropland (i.e., the new cropland that can be brought into production) is y times as great as on average cropland, then 1 acre of marginal cropland grown with corn for ethanol production results in a byproduct that can displace yX acres of soybean production. Planting this yX acres with corn for ethanol and using the distillery byproduct for animal feed displace an additional yX^2 acres of soybeans, etc. In all, the total acreage of average soybean production displaced by this marginal acre of corn is:

$$yx + yx^2 + yx^3 \ldots . = \frac{yX}{1 - x} \qquad (1)$$

If Nm and Na are the net premium fuels displacement per acre of marginal and average corn production, then the total net premium fuels displacement attributable to bringing 1 marginal acre into corn production is:

$$N = Nm + Na \left(\frac{yX}{1 - x}\right) \qquad (2)$$

The ideal crop switching technique would be where X =1, i.e., where one can simply switch to another crop which produces all of the products of the first crop and liquid fuels as well, without expanding the acreage under intensive cultivation. Several imaginative suggestions for crop switching have achieved this ideal but none are proven.[2]The closest to this ideal that has been demonstrated is the corn-soybean switch, in which X = 0.77, based on national average yields of the respective crops.*[13] Nevertheless, even this switch is limited by the quantity of land suitable for corn production and the fact that the corn distillery byproduct is not a perfect substitute for soybeans in all of its uses. As a fuel ethanol industry is first developing, however, these limitations are probably of minimal importance.

Assuming, then, that the distillery byproduct is fully utilized and that marginal cropland produces 75 percent of the yield of average cropland, OTA has calculated the net premium fuels displacement per acre of marginal (new) cropland brought into production for various liquid fuels options. These include ethanol from various grains and sugarcane and both methanol and ethanol from grass. The energy inputs were assumed to be national average energy inputs for the various grains and sugarcane and 1 million Btu/dry ton for grass** and the alcohols are assumed to be used as octane-boosting additives to gasoline. The results are shown in figure 12. Although the exact numbers cannot be taken too literally because of the various assumptions required to derive them, the relative values are fairly insensitive to the assumptions chosen, provided the alcohols are used as octane-boosting additives. * Also, utilization of crop residues does not substantially change the results.

Among the grain and sugar crops, corn appears to be the best choice, as long as the distillery byproduct is fully utilized to displace soybeans. In this calculation, 2.5 acres of average soybean land plus 1 acre of marginal land, all grown in corn for ethanol production, can produce an equivalent amount of animal feed protein concentrate as 2.5 average acres grown with soybeans, and provide the ethanol as well. However, as the utilization (i. e., X in equation 2) drops, then grass quickly becomes a superior alternative. If, for example, 1 lb of distillery byproduct displaces 0.5 lb of soybean meal instead of the maximum of 0.67 lb (see ch. 8), then grass and corn would be roughly equivalent. Similarly if grass yields increase to 8 dry ton/acre-yr, then grass would be as good or better than corn regardless of the byproduct utilization. (It should be noted, however, that these calculations do not take the economics of producing ethanol from grass or the difficulties of using methanol as an octane-boosting additive into consideration.)

Sugarcane appears to be roughly equivalent to grass, but sugarcane can be grown on only a limited amount of U.S. cropland and the ethanol produced from it would be considerably more expensive than corn-derived ethanol. Other sugar crops have considerably lower yields than sugarcane.

The exact point where the byproduct utilization will drop is unknown. Some analyses have put it at 2 billion to 3 billion gal/yr of ethanol when distillers' grain is the distillery byproduct.[14] Producing corn gluten meal could, however, increase this to as much as 7 billion gal/yr, based on the total domestic use of soybean meal for animal feed. 's As mentioned above, however, the byproduct is not equivalent to the soybean products, so it is unlikely that one can reach this level with full byproduct utilization to displace other crops. For the purposes of these estimates, it is assumed that 2 billion to 4 billion gal/yr of ethanol from corn

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[12]R Carlson, B Commoner, D Freedman, and R Scott, "Interim Report on Possible Energy Production Alternatives In Crop-Livestock Agriculture," Center for the Biology of Natural Systems, Washington University, St. Louis, Mo , Jan 4, 1979

● The byproduct of 1 bu of corn can displace the meal from about O 25 bu of soybean. See "Byproducts" under "Fermentation "

[1] '*Improving* Soils With *Organic Wastes,* op. cit

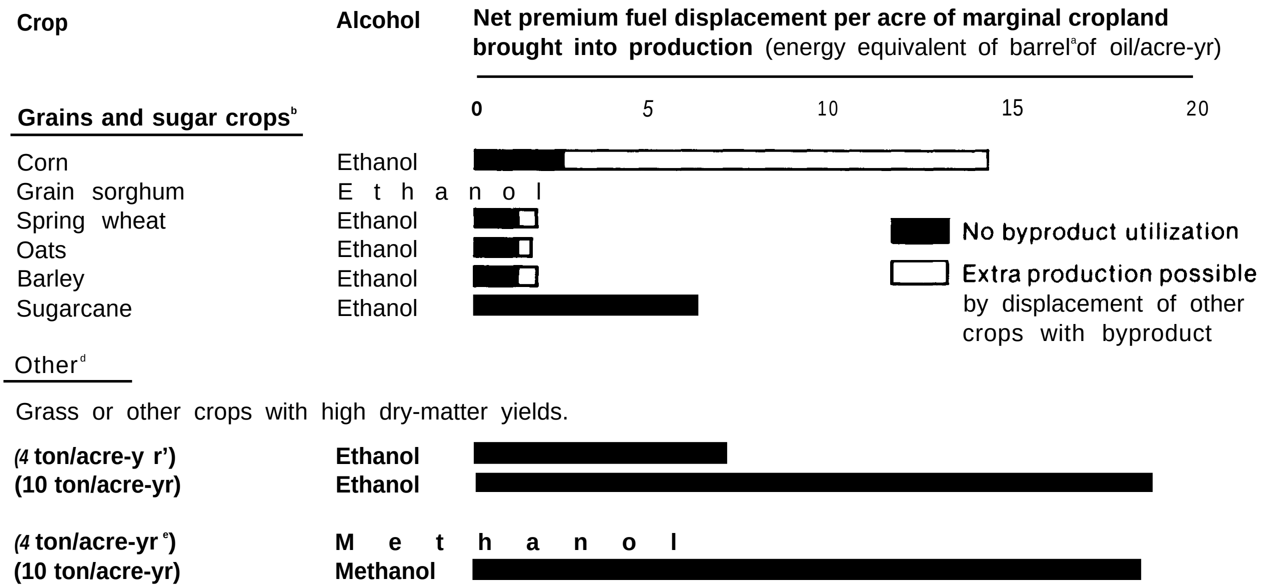
* *One-half that denved above for Increased grass production, because here it is assumed that the entire grass production goes to energy

*If the alcohols are used as standalone fuels, the relative values are similar, but the net displacement is about half that shown ın figure 12

[14]R C. Meekhof, W E. Tyner, and F. D Holland, "Agricultural Policy and Gasohol," Purdue University, May 1979. This reference reports a 3-billion-gal limit based on a 2-lb substitution of distillers' grain for 1 lb of soybean meal. Other studies, however, have put the feed ratio at 1 5:1, which would reduce the limit to 2.25 billion gal/yr

"improving Soils *With Organic Wastes,* op cit.

Figure 12.—Net Displacement of Premium Fuel(oiland naturalgas) per Acre of New Croplnd Brought into Production



[a] Based on 59 million Btu/bbl alcohol used as octane-boosting additive to gasoline

[b] Assumes national average energy inputs per acre cultivated and yields (on the marginal cropland) of 75% of the national average yields between 1974.77 Yields on average cropland are assumed to be the average of 1974-77 national averages This methodology is internally consistent, raising the average cropland yield to 1979 yields would not significantly change the relative results If usable crop residues are converted to ethanol. the lower value (no distillery byproduct utilization) would be increased by about 1 2 bbl/acre-yr or less for the grains and 26 bbl/acre-yr or less for sugarcane

[c] Economic and physical opportunities for full byproduct utilization diminish with greater quantities of by Product production

[d] Uncertainty of ± 30% for methanol and more for ethanol from grass, since the ethanol processes are not well defined at present Assumes 1 million Btu/dry ton of grass needed for cultivation harvest and transport of the grass and conversion process yields (after all process steam requirements are satisfied with waste heat or part of the feedstock) of 84 gal/dry ton of grass for ethanol and 100 gal/dry ton of grass of methanol

[e] Four ton/acre-yr can be achieved with current grass varieties grown on marginal cropland

SOURCE Office of Technology Assessment yields from USDA *Agricultural Statistics.* 1978

Data Used in Figure 12

Crop	Average 1974-77 national average yields (gal of ethanol/acre)	National average farming energy (10^3 Btu/gal of ethanol): Average land	National average farming energy (10^3 Btu/gal of ethanol): Land that is 75 percent as productive as average	Net premium fuels displacement[a] (bbl of oil equivalent/acre): Average land: With byproduct credit	Average land: Without byproduct credit	Land that is 75 percent as productive as average land: With byproduct credit	Land that is 75 percent as productive as average land: Without byproduct credit
Corn	220	33.3	44.4	4.4	4.0	3.0	2.7
Grain sorghum.	130	54.5	72.7	2.1	1.9	1.3	1.1
Spring wheat ...	73	23.8	31.7	1.6	1.5	1.1	1.0
Oats	74	24.2	32.3	1.6	1.5	1.1	1,0
Barley	79	29.4	39.2	4.6	1.5	1.1	1.0
Sugarcane .	504	30.3	40.4	NA	9.7	NA	6.4
Grass ...	400[b]	NA	10	NA	NA	NA	7.3

NA =-none available

[a] Assumes gross displacement of 140,000 Btu/gal of ethanol, byproduct credit of 10,500 Btu/gal, and 5.9 million Btu/bbl of Oil. For methanol, 117,000 Btu/gal gross displacement.

[b] Assumes 4 ton/acre on marginal land and 100 gal methanol Peton.

Crop	Displacement of soybean production[c] (average acres of soybeans displaced per average acre of grain = x)	$\frac{0.75X}{1-x}$ (total acres of soybeans displaced by 1 marginal acre of grain and additional cultivation of grain on former soybean land	Net premium fuels displacement from 1 acre of marginal land plus $\frac{0.75X}{1-x}$ acres displaced soybean land (bbl oil equivalent/acre of marginal land)
Corn.	0.77	2.5	13.9
Grain sorghum	0.46	0.64	2.7
Spring wheat.	0.26	0.26	1.5
Oats.	0.26	0.26	1.5
Barley	0.28	0.29	1.6
Sugarcane,	0	0	6.4
Grass.	0	0	7.3

[c] Assumes average soybean yield of 27.1 bu/acre, a displacement of 1 lb of soybean meal per 1.5 lb of distillers' grain, and 48 fb of soybean meal per bushel of soybeans.

SOURCE: S. Barber, et al., "The Potential of Producing Energy From Agriculture," Purdue University, contractor report to OTA; and *Agricultural Statistics, 1978* (Washington, D. C.: U.S. Department of Agriculture, 1978).

(about 0.2 to 0.4 Quad/yr) can be produced while utilizing the byproducts fully. This would require about 2 million to 5 million additional acres in intensive crop production and expansion of corn production by over three times this acreage. It is not certain that cropland will be available for energy production by 2000; but if it is, it is assumed that any further production above this level will use grass as the energy crop.

In the near to mid-term, increased production of forage grass can be obtained on about 100 million acres of hayland, cropland pasture, and noncropland pasture. Assuming a 1- to 2-ton/acre-yr increase in yields, this would result in 100 million to 200 million tons of grass or about 1.3 to 2.7 Quads/yr. Deducting the energy needed to cultivate and transport the grass reduces the output to about 1.1 to 2.2 Quads/yr.

By 2000 anywhere from zero to 65 million acres could be used for energy crops. Assuming that grasses with average yields of 6 dry ton/acre-yr on this cropland have been developed, then the energy potential would be zero to 5 Quads/yr.

Although adding this to the ethanol yield from corn involves a small amount of double counting, the uncertainty in the actual cropland availability and future grass yields is too great to warrant a detailed separation. Consequently, OTA estimates that 1 to 3 Quads/yr can be obtained in the near to mid-term and zero to 5 Quads/yr in the long term from the production of conventional crops for energy.

The above mix of corn and grass was chosen as the one that appears to be the least inflationary to food prices in the long term per unit of liquid fuel produced. However, if 65 million acres are available for energy production in 2000, one could conceivably produce over 15 billion gal of ethanol from corn* or about 1.3 Quads/yr of liquid fuel. Grass production, on the other hand, would yield about 2.5 Quads/yr** of liquid fuel from this same cropland and with the same or lower inflationary impact.

Judging when the emphasis should shift from corn to grass is likely to be difficult. As a fallible rule of thumb, however, any significant increase in corn prices relative to the other grains would be an economic signal to distillers and/or animal feeders to use grains other than corn, which would make grass a superior option for energy production. Similarly a significant drop in the price of distillery byproduct, relative to the alternatives, would be an economic signal that the distillery byproducts are not being fully utilized and, again, grass would be superior. Consequently, if there is a significant rise in corn prices or drop in distillery byproduct prices, relative to the alternatives, then these could be indications that the cropland could better be utilized by producing grass.

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*Seven billion gal with complete substitution of soybean meal and requiring about 10 million of the 65 million acres. The remaining 55 million acres, with yields of 65 bu/acre, could produce an additional 9 billion gal/yr of ethanol.

**5 Quads/yr of grass could yield slightly less than 25 Quads/yr of methanol

Energy Potential From Crop Residues

Crop residues are the plant material left in the field after a crop harvest. Their major function is to protect the soil against wind and water erosion by providing a protective cover, and they have a modest fertilizer value[16] and a soil-conditioning value through maintenance of soil organic matter. (See also "Environmental Impacts.")

Barber, et al., have calculated the total quantities of residues by multiplying the crop yields reported by USDA by residue factors, i.e., the ratio of residue to the yield of tradi-

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[16] Residues are about O 7 percent nitrogen, O 2 percent phosphorus, and 4 percent potash See Barber, et al., op cit.

tional crop for the various types of crops.[17] The results of these calculations are shown in table 26. The total quantity of residues generated is about 400 million ton/yr or about 5 Quads/yr.

Table 26.-Total Crop Residues in the United States for 10 Major Crops (based on 1975-77 average production)

	Acres k acres	Total residue k tons
Corn.	69,530	171,084
Wheat	68,789	99,890
Soybeans	53,616	67,556
Sorghum	14,714	21,123
Oats. ., ...	12,831	20,677
Barley	8,772	13,341
Rice.	2,515	8,584
Cotton	10,990	3,578
Sugarcane	660	4,700
Rye	715	708
U.S. Total	243,132	411,240

SOURCE. Barber, et al, "The Potential of Producing Energy From Agriculture," Purdue University, contractor report to OTA, May1979

During fall plowing many farmers turn under the residues, rendering them useless as a protection against erosion. These residues could be collected and used for energy without worsening the erosion on these lands. However, current agriculture policy is to encourage farming practices that limit soil erosion to the soil-loss tolerance levels, or the levels of erosion that are believed not to impair the long-term productivity of the land (see “Environmental Impacts”). Consequently, a more detailed consideration of crop residues is appropriate.

Using data supplied by Dr W. Larson,[18]* the total crop residues were calculated for each of the major land resource areas or subregions of States. Using standard equations for soil erosion,* the quantities of residues that could be removed without exceeding standard soil-loss tolerance values were calculated. These were then modified to take into consideration the quantities that can be physically collected with current harvesting equipment (about 60 percent in field trials at Purdue University). In addition, a 15-percent storage loss was assumed. The results of these calculations are shown in table 27 as the usable crop residues, which are about 20 percent of the total crop residues.

Table 27.–Total Usable Crop Residue by Crop

Crops	Amount (k tons)	Harvestable acres (k acres)	Average yield (ton/acre)
Corn.	37,098	39,122	0.95
Small grains	33,623	36,324	0.93
Sorghum.	1,452	4,100	0,35
Rice	5,457	2,516	2.17
Sugarcane.	590	331	1.78
Total ... , ...	78,220	82,393	0.95

SOURCE Barber, et al., "The Potential of Producing Energy From Agriculture, " Purdue University, contractor report to OTA, May 1979

Harvesting crop residues would typically consist of moving the residues into windrows, or long thin piles of residues. The windrows would then be collected with baling machinery and the bales dumped at the roadside. The windrows would be collected and transported to a place where they would be stored or used.

Crop residues typically contain 40- to 60-percent moisture 2 days after the grain harvests. In favorable weather conditions, the residues dry to about 20-percent moisture in 18 days.[20] With these moisture contents, bacteria will gradually consume the residues. If the residue bales are compacted too tightly, the heat generated from the bacterial action can cause the material to spontaneously combust. However, with relatively loose bales, the bacterial heating will dry the material to a moisture content at which the bacteria do not consume the material. Some loss, however, is inevitable (15-percent loss has been assumed in table 27).

The extra fertilizers necessary to replace the nutrients in the residues removed cost about $7.70/ton of residue removed.

In addition, one of the main problems with harvesting residues is that it delays the fall ground preparation. If winter rains come too soon, there may not be sufficient time to collect the residues and prepare the ground for the spring planting. The spring planting is then

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[17] Ibid

[18] W. E. Larson, “Plant Residues–How Can They Be Used Best,” paper No. 10585, Science Journal Series, SEA-AR/USDA, 1979

* Universal soil-loss equation and wind erosion equation.

[20] Barber, et al., op. cit.

delayed and yields for the following year may suffer. Using computer simulations of farming operations and the actual weather conditions in central Indiana between 1968 and 1974, it was found that residue harvests reduced corn yields by an average of 1.6 bu/acre-yr.[20] If this cost is attributed to the residues, then it raises the residue costs by $2.70/ton. This factor is less of a problem with most other grains, however, since they are less sensitive to the exact planting time.

Adding these various costs and assuming a markup of 20 percent above costs gives the State average costs for various residues (table 28). Care should be exercised when using this table, however, since the costs within a State can vary considerably. In favorable cases the costs might be as low as $20/dry ton and, in unfavorable cases, as high as $60/dry ton or more.

Table 28.–State Average Estimated Usable Group Residue Quantities and Costs

State	Total usable crop residues (million tons/yr)	Delivered cost[a] ($/ton) (estimated uncertainty: 20%))
Corn		
Illionois	8.0	32.16
Indiana	4.6	32.42
Iowa	6.9	32.77
Minnesota	4.2	38.67
Nebraska	1.8	41.68
Ohio	2.6	35.18
Small grains		
California	1.8	28.29
Illinois	1.0	31.53
Minnesota	6.1	30.54
South Dakota	1.8	33.05
Washington	3.0	31.01
Wisconsin	2.0	26.93
Sorghum grain		
Colorado	0.12	*35.60*
Kansas	0.72	*57.62*
Missouri	0.28	*36.87*
Rice		
Arkansas	1.9	36.32
California	1.1	34.82
Texas	1.2	36.08
Sugarcane		
Florida	0.53	30.93

[a] Including 15-mile transport, labor at $5/hr, $0 80/gal diesel fuel, yield penalty of $2 70/ton of residues for corn, additional fertilizers for $7 70/ton of residues, and profit of 20 percent of costs

SOURCE Barber, et al , ' 'The Potential of Producing Energy From Agriculture, Purdue University, contractor report to OTA, May 1979

Crop residues contain about 13 million Btu/ton. The energy costs for harvesting and transporting the residues are about 0.9 million Btu/ton for a 15-mile transport and 1.8 million Btu/ton for a 50-mile transport. (With integrated residue and crop harvests the energy costs would be slightly less, but this may not be a practical alternative because it delays the harvest.) In addition, the energy content of the additional fertilizer needed to replace the nutrients lost in the residues is about 0.6 million Btu/ton. Thus, the total energy use associated with collecting and transporting the residues is about 1.5 million to 2.5 million Btu/ton of residue.

National average crop yields can fluctuate by ± 5 percent or more from year to year and the usable crop residues will fluctuate by about ± 10 percent, since an absolute quantity of residue should be left regardless of the crop yield. On a local basis, usable crop residues can vary considerably. Within a county located in a humid region of the country, the fluctuation may be ± 20 percent and for crops that are not irrigated in dry regions, the year-to-year variations can reach ± 100 percent. The areas with the largest fluctuations, however, also have the lowest quantities of usable residues.

In summary, the total crop residue production in the United States is about 5 Quads/yr, of which about 3 Quads/yr can be collected with current harvesting equipment. The quantity that can be collected while maintaining current soil erosion standards is about 1 Quad/yr. Considerations of a reliable supply, however, would reduce this to roughly 0.7 Quad/yr* of reliable feedstock, if soil erosion standards are strictly adhered to. By 2000, increases in crop production could raise this by 20 percent to 0.8 to 1.2 Quads/yr.

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[20] Ibid

● Calculated by assuming that the total quantity of residue can fluctuate by ± 20 percent at the local level; i.e , by subtracting 20 percent of the total residues from the usable residues on a State-by-State basis

Environmental Impacts of Agricultural Biomass Production

Introduction

American agriculture, with its astonishing productivity and reliability, bestows critically important benefits on the economy and general well being of the United States. Unfortunately, it also has serious negative environmental impacts. Any substantial increase in land cultivation or intensification of present crop production to produce energy crops—biomass–will cause an extension and intensification of many of the impacts of the present system.

There are substantial uncertainties in the understanding of the consequences of relying on agricultural feedstocks for energy production. These uncertainties stem from a lack of complete understanding of present impacts, the potential for changes in crop production methods in the future, and uncertainty as to the pace of development. This section attempts to place the potential impacts of large-scale biomass production from agriculture into perspective by briefly describing what is known of the impacts of food crop production (the energy feedstock production system should resemble the food production system), describing how the pace of development may intensify impacts, and finally identifying those differences between food and energy feedstock production that are most critical in determining impacts.

Table 29.-Environmental Impacts of Agriculture

Water
- Water use (irrigated only) that can conflict with other uses or cause ground water mining.
- Leaching of salts and nutrients into surface and ground waters, (and runoff into surface waters) which can cause pollution of drinking water supplies for animals and humans, excessive algae growth in streams and ponds, damage to aquatic habitats, and odors.
- Flow of sediments into surface waters, causing increased turbidity, obstruction of streams, filling of reservoirs, destruction of aquatic habitat, increase of flood potential.
- Flow of pesticides into surface and ground waters, potential buildup in food chain causing both aquatic and terrestrial effects such as thinning of egg shells of birds.
- Thermal pollution of streams caused by land clearing on stream banks, loss of shade, and thus greater solar heating.

Air
- Dust from decreased cover on land, operation of heavy farm machinery.
- Pesticides from aerial spraying or as a component of dust.
- Changed pollen count, human health effects.
- Exhaust emissions from farm machinery.

Land
- Erosion and loss of topsoil from decreased cover, plowing, increased water flow because of lower retention; degrading of productivity.
- Displacement of alternative land uses–wilderness, wildlife, esthetics, etc.
- Change in water retention capabilities of land, increased flooding potential.
- Buildup of pesticide residues in soil, potential damage to soil microbial populations.
- Increase in soil salinity (especially from irrigated agriculture), degrading of soil productivity.
- Depletion of nutrients and organic matter from soil.

Other
- Promotion of plant diseases by monoculture cropping practices.
- Occupational health and safety problems associated with operation of heavy machinery, close contact with pesticide residues and involvement in spraying operations.

SOURCE Office of Technology Assessment

The Environmental Impacts of American Agriculture

Agriculture is a major source of pollution and causes serious environmental impacts. Table 29 lists the major environmental impacts associated with present forms of large-scale mechanized agricultural production. Most of the impacts apply to the majority of farming situations (although with varying magnitude), but some impacts are negligible or nonexistent in certain situations. Also, most of the impacts are more or less controllable, but for a variety of reasons (a high perceived cost or negative effect on crop yields are almost certainly the most important) many control techniques are rarely used.

Water pollution and land degradation due to erosion are American agriculture's primary problems, and the two impacts are intimately linked. The action of wind and water strips farmland of its productive topsoil cover, and much of this soil ends up in the Nation's waterways. Thus, estimates of soil erosion are critical to understanding the effects of agriculture on both soil productivity and on water ecosystems.

SCS has recently revised downward its estimates of cropland erosion. Its 1977 National Erosion *Inventory* estimates average annual sheet and rill erosion from all cropland to be 4.77 ton/acre-yr (or a total of about 2 billion ton/y.[21] Previously, it had estimated cropland sheet and rill erosion at about 9 ton/acre-yr,[22] and other sources had estimated total erosion (including wind erosion) from croplands to be as high as 12 ton/acre-yr.[23] SCS attributes the decrease to the greatly improved data base recently made available by the 1977 *Inventory.* Also, the original 9-ton/acre-yr estimate apparently referred only to land in row crops, close-grown crops, and summer fallow, whereas the more recent estimate includes lands that are in less intensive (and less erosive) uses such as rotation hay and pasture, or native hay.

Data from the 1977 *Inventory* has only recently begun to be released to the general public, and it seems likely to generate controversy — especially because its estimate of average erosion is under the 5 ton/acre-yr that SCS generally considers to be a tolerable level (i. e., a level that will not affect long-term productivity) for much U.S. cropland. However, the lower estimate is not especially comforting for a number of reasons:

- National (sheet and rill) erosion rates for cropland in intensive production are estimated by SCS to be 6.26 ton/acre-yr.
- The national estimate tends to hide several important food-producing areas with uncomfortably high erosion rates (e. g., Missouri averages 11.38 ton/acre-yr; Iowa averages 9.91 ton/acre-y r).
- The estimates do not include wind erosion and alternative forms of water erosion. Cropland wind erosion in 10 western States averages 5.29 ton/acre-yr. Thus, although Texas cropland has a sheet and rill erosion rate of only 3.47 ton/acre-yr, its total erosion rate is greater than 18 ton/acre-yr because of wind erosion.
- Although SCS generally considers 5 ton/acre-yr as an (average) annual erosion at which long-term productivity on good soils will not suffer, it is not certain that soil is actually replaced this fast. Authoritative estimates of soil replacement rates do not exist, but average rates of as low as 1.5 ton/acre-yr have been claimed.[24] However, the SCS rates do represent the general consensus of the agronomy community.
- Even the new lower erosion rate implies that about a billion or more tons of sediment from croplands are entering the Nation's waterways each year.[25]
- Erosion rates from croplands are many times higher than those of natural ecosystems. Forests typically erode at a rate of less than one-tenth of a ton/acre-yr, and grassland at less than half a ton/acre/yr.[26]

As a result of the mismatch between erosion and soil replacement, the United States has lost a considerable portion of its topsoil and, some have claimed, its production potential. Pimentel estimates that U.S. cropland has lost about one-third of its topsoil and 10 to 15 percent of its production potential over the last 200 years.[27] Bennett estimates that, during the period prior to 1935, 100 million acres of cropland were lost to erosion and an additional 100 million acres were stripped of more than half of their topsoil.[28] At best, however, these values represent extremely rough estimates, and the new SCS erosion inventory may cause their downward revision.

It appears likely that the process of land degradation will continue for the immediate future. Although USDA has spent nearly $15 billion in its soil conservation programs since their inception in 1935,[29] only 36 percent of the

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[21] 1977 *SCS National Erosion Inventory Estimate,* op. cit.

[22] Ibid

[23] D Pimentel, et al , "Land Degradation, Effects on Food and Energy Resources, " Science, vol 194, Oct 8, 1976

[24] Ibid

[25] *Environmental Implications of Trends in Agriculture and Silviculture—Volume I: Trend Identification and Evolution* (Washington, D C Environmental Protection Agency, October 1977), EPA-60013-77-I 21

[26] Ibid

[27] D Pimentel, op cit

[28] H H Bennett, *Soil Conservation* (New York. McGraw-Hill, 1939),

[29] *To Protect Tomorrow's Food Supply, Soil Conservation Needs Priority Attention* (Washington, D C : General Accounting Office, Feb 4, 1977), CED-77-30

472 million acres of cropland in 1967 were judged to have adequate conservation treatment[30] and the programs have been criticized as inadequate by the General Accounting Office.[31]

A reason for the inability of USDA conservation programs to satisfy their critics may be the difficulty of demonstrating to the farmer (in all but the more severe cases) the benefits of additional conservation measures. Because an inch of topsoil weighs about 150 ton/acre, a net loss of 5 ton/acre-yr would result in a loss of 1 inch of soil every 30 years. During that time, farming procedures would be gradually changing, obscuring the effects of any soil loss. For example, during the past *30* years, more intensive use of fertilizers, pesticides, and other inputs, better information on future weather and other critical factors, and improved crop varieties more than compensated for erosion-caused losses on most lands. Also, the actual effect on productivity may not be large in some circumstances because the effect of soil loss is very sensitive to soil conditions: while loss of soil from a very shallow soil over rock in Kentucky may cause the land to be withdrawn from production, on some deep loess soils of Iowa, the loss of several inches of topsoil may have little effect on productivity. Few if any agricultural scientists would argue that net soil loss can continue indefinitely without major losses in productivity. However, on many lands the damages of erosion may never become visible to the farmer; rather they will be perceived by his children or grandchildren. Moreover, short-term economic constraints may compel a farmer to discount the future benefits of conservation by much more than he would personally prefer.

Aside from the long-term consequences in land degradation, soil erosion represents a severe water pollution problem. Not only is soil itself a serious pollutant, it also acts as a carrier of other pollutants: phosphorus, pesticides, heavy metals, and bacteria.[32] The soil lost to agricultural erosion represents more than half of the sediment entering the Nation's surface waters.[33] [34] Sediment causes turbidity, fills reservoirs and lakes, obstructs irrigation canals, and destroys aquatic habitats. Yearly material damages have been estimated at over $360 million,[35] not including damage to aquatic habitats and other noneconomic costs. Adding the flooding damage caused by the decrease in storage capacity of reservoirs and streams would increase annual costs to over $1 billion.[36]

The effects on aquatic ecosystems of the enormous flow of sediments into the Nation's waterways have never been satisfactorily estimated. Research on the impacts of "nonpoint" sources of water pollution—agriculture, construction, etc. –has not been given a high priority within the Environmental Protection Agency (EPA) or USDA, and the result is a scarcity of information from which to draw conclusions about either present impacts or future impacts associated with the devotion of millions of additional cropland acres to biomass production.

The other major water pollution problems of agriculture involve the toxic effects of pesticides and inorganic salts and the nutrient influx into the Nation's waterways associated with American agriculture's increasing use of fertilizers.

Pesticide use in American agriculture has grown from 466 million lb in 1971[37] to 900 million lb in 1977.[38] By 1985, American farmers are expected to be using as much as 1.5 billion lb.[39] Much of this increase can be traced to the growth in minimum tillage practices[40] which substitute increased herbicide use for tillage to control weeds. These practices include leaving crop residues on the soil surface, and these residues harbor plant pests and pathogens and generally increase pesticide requirements (al-

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[30] *"Potential Cropland Study," Statistical Bulletin No. 578,* Soil Conservation Service, U.S. Department of Agriculture, 1977.

[31] *To protect Tomorrow's Food Supply,* op. cit.

[32] *Environmental Implications of* Trends, op. cit.

[33] Ibid.

[34] Pimentel, op. cit.

[35] *1977 SCS National Erosion Inventory Estimate, 0p. cit.*

[36] Ibid.

[37] *Environmental Implications of Trends,* op. cit.

[38] *1977 SCS National Erosion Inventory Estimate,* op cit.

[39] Ibid,

[40] *Environmental* Implications *of Trends,* op. cit.

though they offer substantial benefits in erosion control). Recent growth in the practice of single- and double-cropping may also account for some of the increase. Although less than 5 percent of the pesticides enter the surface and ground water systems, ” pesticide use has been associated with fish kills and other damage to aquatic systems as well as reproductive failures in birds and acute sickness and death in animals. Under conditions of high exposure—in accidental spills, improper handling by applicators, etc. —pesticides have been associated with the sickness and death of humans. Recent research has implicated some widely used pesticides as possible carcinogenic agents when ingested or inhaled, and EPA has removed certain of these— including Aldrin, Dieldrin, and Mirex–from the marketplace under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Amendments to FIFRA have considerably tightened the requirements for testing and registering pesticides. However, the tremendous variety of pesticide compounds [“1 ,800 biologically active compounds sold domestically in over 32,000 different formulations”[42]) and the difficulty of detecting damages in human populations and in the environment will greatly complicate successful enforcement of the Act. At present, the long-term impacts of pesticides on the environment and on man are poorly understood.

The problems of pesticide use in agriculture are becoming particularly visible because of a recent rash of instances where pesticides thought to be safe have been accused of causing severe injuries — including birth defects, miscarriages, and other acute physical disorders–and death to exposed populations, The controversy surrounding the use of the herbicide 2, 4, 5-T in Oregon and its suspension by EPA is a widely publicized– but by no means unique —example of rising national concern. Resolution of the conflicting claims about the safety (or lack of it) of these pesticides is well beyond the scope of this report. Based on current interest, however, it is likely that a major public concern associated with any large increase in crop cultivation will be the concurrent increase in pesticide use on the new lands. There is a distinct possibility that rising public concern over pesticide usage could put a severe constraint both on the continuing increase in this usage and on the expansion of crop production for energy feedstocks.

Salinity increases caused by irrigated agriculture present another substantial impact. Irrigated land produces one-fourth of the total value of U.S. crops, mostly in the 17 western States. ’J Increased salinity in streams in these areas is caused by the salts added to irrigation water from upstream farms and by the concentrating effect of the high evaporation rates in arid climates (evaporation leaves the salts behind). The same mechanisms can lead to increasing salt concentrations in the soils of downstream farms unless sufficient water can be obtained to periodically flush excess salts out of the soil profile. Damages associated with increased salinity of soils and irrigation water include reduced crop yields, inability to grow salt-sensitive crops, increased industrial treatment costs, and adverse effects on wildlife, domestic animals, and aquatic ecosystems. Trends in irrigated agriculture are leading to improvements in irrigation efficiency and decreased salt loadings in streams, but these trends could be overwhelmed by substantial increases in irrigated acreage either to grow crops for energy or to compensate for competition between food and biomass production in other areas.

Fertilizer use is of extreme importance in calculating the environmental impacts of agriculture. Large amounts of energy— one-third of the energy consumed by the agricultural sector and its suppliers— are needed to produce fertilizer. The Haber-Bosche process for the synthesis of anhydrous ammonia fertilizer requires around 21 ft^3 of natural gas to produce 1 lb of nitrogen in fertilizer (and more for other forms of nitrogen);[44] current U.S. nitrogen fertilizer production is 10 million metric

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[41] Ibid

[42] 1977 *SCS National Erosion Inventory Estimate, op.* cit.

[43] Ibid

[44] C.H. Davis and G M Blouin, “Energy Consumption in the U.S. Chemical Fertilizer System From the Ground to the Ground,” *Agriculture and Energy,* W. Lockeretz, ed. (New York: Academic Press, 1977), pp 315-371

tonnes per year consuming 3 percent of total U.S. natural gas production. If current trends of increased rates of fertilizer applications continue and food demands increase by 3 percent per year, natural gas requirements for fertilizer production will triple by 2000.[45]

The application of large quantities of chemical fertilizers also represents a water pollution problem because much of the nutrient value ends up in the Nation’s waterways. Wittwer estimates that only 50 percent of the nitrogen and less than 35 percent of the phosphorus and potassium applied as fertilizer are actually recovered by crops;[46] other estimates for nitrogen range from 46 to 85 percent.[47] Although a portion of that which is lost is due to volatilization (and consequent loss to the atmosphere), much is lost to surface and ground waters via runoff, leaching, and erosion processes. The amount of nitrogen and phosphorus (potassium is not considered to have significant environmental impacts[48]) entering the waterways from agricultural lands in the early 1970’s has been estimated at 1,500 million to 15,000 million lb/yr and 120 million to 1,200 million lb/yr, respectively.[49]

This nutrient pollution from fertilizers may be toxic to humans and wildlife in high concentrations; nitrate poisoning of wells from contaminated ground water is not unusual in some agricultural areas. The more common impact, however, is to speed up eutrophication of streams and the problems of oxygen demand and algae growth associated with eutrophication.

The remaining major water-associated impact of agriculture is water use. The appropriation water rights system in the West offers little incentive to use water efficiently. * The combination of artificially low prices for water and the requirement of the appropriation doctrine that the holder of a water right must maintain that right through use (“use or lose”) has led to the cultivation of water-intensive crops in arid climates. This has led to water shortages in many Western basins and to aggravation of salinity problems in several major rivers.

Several water use trends will affect agricultural production capabilities in the near future. First, large-scale energy development—especially electrical generating stations and, possibly, synthetic fuel plants–will consume substantial quantities of water and, in some cases, compete directly with agricultural interests for the limited supply. Second, expanded acreage for food production will occur, including projects on Indian land that may have priority rights to the limited water supply. On the other hand, improvements in irrigation efficiency will have some conserving effect on water consumption even though this is not a primary goal of efficiency increase (the primary goal is to reduce water withdrawals and ‘return flows and to improve water quality rather than to reduce consumptive use). For example, SCS estimates that irrigated acreage in the critical Upper Colorado River Basin could increase from 1,370,000 acres in 1975 to 1,442,000 acres in 2000 while water consumption declines by 93,000 acre-ft with a concerted program to improve irrigation practices.[50] Further decreases in water consumption are possible by “crop switching” — shifting to less water-intensive crops where markets are available—and removing marginal, low-productivity land from cultivation.[51] Also, substantial potential for water conservation exists in energy production.

Much of the agricultural land in the United States was’ obtained by forest clearing or plowing native grasslands, and the consequent replacement of natural ecosystems with intensively managed monoculture must be consid-

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[45] S. H Wittwer, “The Shape of Things to Come, ” *Biology of Crop Productivity*, P. Carlson, ed. (New York: Academic Press, 1978),

[46] Ibid

[47] *Environmental Implications of Trends,* op. cit.

[48] I bid,

[49] Ibid.

*For an excellent review of Western water law see E. Radosevitch, “Interface of Water Quantity and Quality Laws in the West, in ***Proceedings of the** National **Conference** Irrigation **Return Flow Quantity Management,*** **J.** P. Law and G V. Skogerboe, eds. (Fort Collins, Colo.: Colorado State University, 1977).

[50] *Conservation **Needs Inventory*** (Washington, D. C.: Soil Conservation Service, U.S. Department of Agriculture, 1976).

[51] S. E Plotkin, H. Gold, and 1. L. White, “Water and Energy in the Western Coal Lands,” ***Water*** Resources *Bulletin,* vol. 15, No. 1, February 1979.

ered a major environmental impact of agricultural production. (This process is not a one-way street. A combination of changing crop patterns, alternative producing areas, increasing average productivity, and, especially in the South, depletion of soils has led during this century to the abandonment of considerable farmland acreage and, in many cases, reversion to second-growth forest. Principle areas involved in this transformation include the Piedmont areas of the Southeast, the hillier areas of the Northeast, and the upper lake States. However, farm abandonment no longer appears to be a significant force.[52]) Aside from the loss of esthetic and recreational values, this replacement represents a substantial decline in wildlife diversity, loss of watershed protection, and the loss of the alternative wood (or other) resource. At present, this loss involves a bit over 400 million acres of designated cropland[53] and will probably increase unless crop production efficiency can keep pace with the rising demand for food. Also, because millions of acres of cropland are lost each year to roadbuilding and urban development, merely the maintenance of the status quo demands continued clearing of unmanaged and lightly managed lands for crop production.

1973=74: A Case Study in Increased Cropland Use[54]

In 1973, USDA told American farmers that they would be free to plant as many acres of wheat, corn, and feed grains as they wished during the 1973-74 season. In response, 8.9 million additional acres were planted and harvested during that season:

- 3.6 million acres from grassland,
- 0.4 million acres from woodland, and
- 4.9 million acres from idle cropland and set-aside land.

The results of this new agricultural production may provide a basis on which to predict the potential impact of a surge in production caused by incentives to grow crops for biomass energy production.

Of the 8.9 million acres, SCS estimated that 5.1 million acres had inadequate conservation treatment and water management, and 4 million acres had inadequate erosion control. These problems in land selection and environmental planning were soon translated into severe erosion losses. Although poor weather conditions (fall and winter drought in the southern high plains, spring floods in the northern Great Plains, torrential spring rains followed by drought in the Corn Belt) aggravated these losses, most observers appear willing to place a major blame on the farmers' land selection and inattention to erosion control practices.

Soil losses on the additional acreage during the 1973-74 season averaged over 6 ton/acre over and above expected losses without production. Those lands designated as suffering from inadequate conservation treatment lost an average of more than 12 ton/acre above expected losses. First-year erosion losses are expected to be lighter than subsequent years because the root structures of the original cover crops are not totally destroyed by tilling and provide some protection to the soil until they decompose; thus, erosion rates would be expected to rise still further unless conservation practices were begun.

The hardest hit of the agricultural regions were the Corn Belt (390,000 acres, 15 to 100 ton/acre additional soil loss on the new land), western Great Plains— North Dakota, Montana, Wyoming, eastern Colorado (325,000 acres, 5 to 40 ton/acre), eastern Great Plains — Nebraska, Kansas, South Dakota (260,000 acres, 5 to 55 ton/acre). Great Lakes (195,000 acres, 5 to 55 ton/acre), and the southern Coastal Plains of Florida, Georgia, Louisiana, Alabama, and Mississippi (210,000 acres, 5 to 70 ton/acre). In addition, a number of other producing regions experienced high soil losses on the additional acreage.

High as these soil losses were, however, they are not unusual when compared to losses suf-

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[52] M Clawson, "Forests in the Long Sweep of American History, " *Science,* vol 204, June 15, 1979

[53] *Potential Cropland Study,* op cit

[54] Adapted from K E Grant, *Erosion 1973-74: The Record and the Challenge.*

fered by land in continuous production. As noted previously, many areas that are critically important to U.S. grain production routinely lose soil at rates well above the 5-ton/acre-yr maximum recommended by SCS. Assuming that much of the converted land was taken out of relatively nonerosive uses (the 4 million acres of grassland and woodland, nearly half the total, would have suffered virtually no erosive losses if left undisturbed), the erosion experienced on the additional acreage was only slightly worse than the average erosion rates on all U.S. cropland. On the other hand, the lands designated as inadequately protected did have much higher erosion than average. The conclusion appears to be that a rapid increase in land under production will not necessarily cause proportionately more erosion than our current experience would lead us to expect, but that conservation planning and treatment will be required to keep erosion rates from escalating beyond current rates.

Potential Impacts of Production of Biomass for Energy Feedstocks

Most proposals for using the agricultural system to produce energy feedstocks do not contemplate growing and harvesting systems that appear to be radically different from current large-scale mechanized food-growing systems found in the Corn Belt and other centers of American agriculture. Proposals centering around gasohol, for example, assume that at least the near-term feedstock (after food wastes and spoiled grains are used up) will be corn and other conventional starch or sugar crops. Even the more radical systems—for example, tree plantations — can be viewed as variations of common agricultural systems.

The key to identifying the impacts of implementing the various approaches to energy feedstock production is to identify those differences from today's systems that are most critical to causing differences in the impacts. These differences in impacts primarily depend on differences in:

- quality and previous use of the land,
- production practices, and
- type of crop grown.

Land Quality and Previous Use

The land available for growing biomass crops consists of cropland that is presently not in intensive use— for instance, land used to grow native hay— and land currently in range, forest, or other use that can be converted to cropland. Table 30 presents SCS estimates of cropland not currently being utilized to its maximum production potential, and land available for conversion to cropland in 1977. (The acreage "not in intensive use" includes land where the current use meshes with the farmers' desired mix of livestock and crops and thus is unlikely to be converted to more intensive use; thus, the table may overestimate the acreage available for switching to biomass production.) Table 31 presents SCS estimates of the rates of erosion on these lands, by land use and capability class.

The data shows that there is a very substantial amount of land available for biomass production that could be cultivated with few environmental problems. For example, table 30 shows well over 3 million acres of the highest quality (class I) land with high and medium conversion potential. Over 10 million acres of high-quality class I I (for brief definitions, see table 30) land requiring some drainage correction is available. However, there currently is no guarantee that land for biomass production will be selected for its environmental characteristics. Erosion potential, which is of critical environmental importance, is only one of several characteristics used by farmers to decide whether to put land into production. Characteristics such as contiguity of land, current ownership, and the cost of conversion may be the deciding factors.

According to table 30, farmers currently have biased their choice of land for row crop cultivation somewhat in favor of the less erosive lands. Over 11 percent of land in row crops is prime class I land with both high productivity and minimal erosion. In contrast, other land uses typically have about 4 or 5 per-

Table 30.–1977 Cropland and Potential Cropland Erosion Potential (in thousand acres, % of total acreage)

Class	Present cropland in intensive use		Present cropland not in intensive use (rotation hay and pasture, occasionally improved/native hayland)	Potential cropland	
	Row crops	Close-grown crops		High potential	Medium potential
1. Excellent capability, few restrictions.	23,034	4,471	2,389	2,186	1,412
	(11.3)	(3.4)	(4.2)	(5.5)	(1 .5)
II. Some limitations, require moderate conservation practices					
Erosive	45,954	23,463	11,718	*10,543*	13,921
	(22.6)	(22.4)	(20.8)	*(26.3)*	(14.8)
Other problems	58,657	22,762	9,855	*8,278*	10,750
	(28.9)	(21 .7)	(1 7.5)	*(20,7)*	(11 .3)
III. Severe limitations, reduced crop choice and/or special conservation practices required					
Erosive	28,054	***26,997***	12,561	7,893	25,142
	(13.8)	***(25.7)***	(22.3)	(19.7)	(26.7)
Other	27,676	***10,811***	6,557	4,797	12,703
	(13.6)	(10.3)	(1 1.6)	(12.0)	(13.4)
IV. Severe limitations, more restricted than above					
Erosive	9,159	9,324	5,701	1,896	11,531
	(4.5)	(8.9)	(10.1)	(4.7)	(12,3)
Other	5,436	2,933	3,154	1,601	7,210
	(2.7)	(2.8)	(5.6)	(4.0)	(7.6)
V-VIII. Generally not suited.	5,728	345	4,479	2,888	12,248
	(2.6)	(0.3)	(7.9)	(7.2)	(13.0)
Total,	203,243	104,890	56,414	40,082	94,917
Percent of land that is erosive	40.9	57.0	53.1	50.7	53.4

SOURCE *1977 Soil Conservation Service National Erosion Inventory Estimate* (Washington, D C Soil Conservation Service, U S Department of Agriculture, December 1978)

Table 31 .–Moan National Erosion Rates by Capability Class and Subclass (rates are in ton/acre-yr)

Class/subclass	Row crop	Close grown	Nonintensive	Potential	
				High	Medium
Class 1. Excellent capability, few restrictions	3.46”	1.75	0.66	0.31	0.35
Class II. Some limitations, require moderate conservation practices/erosive	6.51	3.67	0.96	0.67	0.71
Class n/other	3.46	2.55	0.43	0.30	0.31
Class III. Severe limitations, reduced crop choice and/or special conservation practices required/erosive	12.39	6.62	1.51	1.08	1.28
Class Ill/other.	3.41	2.51	0.51	0.21	0.28
Class IV. Severe limitations, more restricted than Ill/erosive	17.88	12.20	2.93	2.01	2.28
Class IV/other.	4.52	1.85	0.45	0.46	0.43
Classes V-VIII. Generally not suited/erosive	46.82	19.61	5.42	2.38	4.15
Classes V-VIll/other.	14.26	3.27	0.80	1.51	0.38

SOURCE *1977 Sod Conservation Service National Erosion Inventory Estimate* (Washington, D.C Soil Conservation Service, U S Department of Agriculture, December 1978)

cent of their land classified as class 1. In land quality classes I through IV, 43 percent of the row-cropped acreage is erosive, whereas over 50 percent of every other land use category is erosive. Because row crop cultivation is generally the most vulnerable to erosion, this bias towards use of less erosive land is not surprising.

Close-grown crop cultivation is considerably less erosive than row cropping. Apparently in response to this, farmers have placed close-grown crops on lands that are more vulnerable to erosion; 60 percent of close-grown cropland acreage is erosion-prone.

It is important to look beyond these overall percentages and examine the percentage of land in each land use capability class. The erosivity of lands categorized as E (erosive] by SCS appears to be a strong function of the capability class. For example, the average *1977* annual sheet and rill erosion rates on erosive croplands in intensive use were estimated to be (from table 31):

Class I	3.18 ton/acre-yr
Class IIE	5.55
Class IIIE	9.56
Class IVE	15.02
Class V-VIIIE	34.70

Thus, the erosion danger appears to increase markedly as land capability declines. If the erosive portions of the land with future biomass potential (present cropland not in intensive use and land with switching potential) were skewed towards the lower quality classes, then an examination of the overall erosive potentials would underestimate the erosion danger presented by massive shifts to intensive cultivation. An examination of table 30 indicates that the erosive portions of the present cropland not in intensive use and the high-potential land are somewhat skewed towards the lower quality lands when compared with present cropland, but the differences do not appear to be substantial. For example, whereas 53 percent of erodible land in intensive use is class IIIE or below, 60 percent of erodible land with high biomass potential is in this erosivity range.

The surprising implication of the statistics presented in table 30 is that the land available for agricultural biomass production is not radically different in its erosion qualities from land currently being utilized for intensive agricultural production. Although clearly some selection has been made in utilizing the best lands and keeping idle the worst, this selection process appears to have been skewed by other physical attributes and economic and social factors that are as important or more important than erosion potential. It appears that erosion problems will be significant in adding new lands to intensive agricultural production, but it does not appear on a national basis that these problems will be very much worse than those that could be predicted by extrapolating from current erosion rates.

It is possible to estimate quantitatively the general erosion danger from an expansion of intensive production by utilizing the data in tables 30 and *31* and by making the following simplifying assumptions:

- The 1977 erosion rate for land under intensive production, for each land capability subclass, is representative of the erosion that would occur if additional land in that subclass were to be put into intensive production.
- Given a desire to place additional land into intensive production, farmers will select land mainly from cropland not now in intensive production and "high potential" land, and their selection will be random (this is probably a "worst case" assumption but may not be seriously in error judging from the discussion above).
- A mix of row and close-grown biomass crops will be grown, with the mix being about the same as the 1977 food crop mix.

Under these conditions, the average *erosion rate on the new land put into intensive production will be* about 7.5 ton/acre-yr. For comparison, the 1977 erosion rate on intensively cultivated lands was 6.26 ton/acre-yr. In other words, erosion from additional acres devoted to growing biomass crops may be about 20 percent worse than similar acreages of food crops in production today (this assumes no Government action to improve land selection). Given the substantial uncertainties in this estimate, the 20-percent differential is well within the range of possible error. It is, however, consistent with what is known about agricultural land selection and the quality of available (but undeveloped) farmland.

Because land quality is affected by net rather than gross erosion — i.e., by the difference between erosion and soil replacement–the effect on the land of relatively small changes in erosion rates may be greater than would be apparent at first glance. For example, if the average topsoil replacement rate is 5 ton/acre-yr,* the 7.5 ton/acre-yr biomass erosion rate yields a 2.5 ton/acre-yr net soil loss, versus 1.26 ton/acre-yr net loss from food production. Thus, while a large-scale expansion of acreage for biomass production may have effects on waterways that are similar in magnitude to the effects of present intensive agriculture, this acreage may lose its topsoil layer at twice the rate of current agricultural land. However, it should be noted that the rate of loss is (on the average) fairly low.

Aside from new biomass cropland's capability to resist erosion and its productive potential, an important factor determining the environmental impact of the conversion to intensive production is the nature of the previous land use. For example, the conversion of land in rotation hay and pasture to intensive crop production would clearly be valued differently from a conversion from forest. Because different groups value alternative land uses differently, it is difficult to place more or less weight on the conversion of one land use relative to another. It seems likely, however, that most environmentally oriented groups would prefer to see the conversion of lands that are manmade monoculture (e. g., improved haylands) before more natural and diverse ecosystems were converted.

The cost of conversion will play an important role in determining which lands will be chosen. At the present time, conversion of pastureland and hayland is likely to be less expensive than conversion of forest, and land conversions may be expected to be skewed away from forests. Least expensive of all to convert are lands currently in set-aside, and these are likely to be the first to be taken. The cost of forest conversion may, however, be lowered significantly if the demand for wood-for-energy rises with the demand for energy crops (because the value of the now-worthless cull wood and slash can be traded off against clearing and site preparation costs). Thus, there is no guarantee that forests—which make up about one-quarter of the high- and medium-potential cropland[55]— will not be cleared in significant quantities if large-scale conversion to biomass crop production occurs.

Production Practices

A variety of practices are available to control the erosion and other impacts of farming. These range from crop rotation to conservation tillage to scouting for pest infestations. Table 32 provides a partial list of these practices. Their future use will play a critical role in determining the environmental impacts of biomass energy production.

Table 32.–Agricultural Production Practices That Reduce Environmental Impacts

Runoff and erosion control
Contour farming or contour stripcropping
Terraces and grass waterways
Minimum tillage and no-till
Cover crops
Reducing fall plowing

Reducing chemical pollution
Scouting (monitoring for pest problems)
Disease- and insect-resistant crops
Crop rotation
Integrated pest management
Soil analysis for detecting nutrient deficiencies
Nitrogen-fixing crops
Improved fertilizer and pesticide placement, timing, and amount
Improving irrigation efficiency-trickle irrigation, etc.
Incorporating surface applications into soil

SOURCE Office of Technology Assessment

The availability of these controls should not be confused with the probability that impacts will not occur. in fact, it is unwise to assume that the use of many of the practices listed in table 32 will be widespread. There are a number of reasons for this.

First, the costs of the controls may considerably exceed the farmer's perceived benefits. The effects of erosion on water quality are largely "external" effects; although the farmer may benefit from the control efforts of others, he is unlikely to benefit from any water quality improvements caused by his own efforts. This

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*This is almost certainly very optimistic, but SCS guidelines define 5 ton/acre-yr as an acceptable rate for many lands

[55] *National Erosion Inventory Estimate,* op cit

problem of "external" benefits is endemic to American agricultural practices. It is, in fact, merely one aspect of the "tragedy of the commons" that hinders voluntary environmental control in virtually all of man's activities. Also, any success in delaying or preventing productivity declines from erosion effects may be masked by improvements in other production practices and in any case would be very long term in nature. The farmer must balance these benefits against very high erosion control costs. SCS has examined the effects on farm production costs of requiring reductions in current erosion rates on croplands. For example, requiring a 10-percent reduction in each of 105 producing areas would raise corn production costs by $0.07/bu in 1985. Requiring all acreage to conform to a maximum allowable erosion rate of 10 ton/acre-yr (twice the "no productivity loss" rate) would cost $0.31/bu or a 16-percent increase over the projected 1985 cost without controls. Further constraints could raise costs astronomically (a 5-ton/acre-yr constraint leads to a $23.70/bu production cost) because heroic efforts must be made on some acreage in order to meet the constraints.[56] Although these estimates are sharply dependent on a number of critical assumptions (e.g., the role of Federal soil conservation assistance is ignored), they demonstrate the large potential cost (and price) increases that erosion control requirements could cause.

Second, there are substantive scientific disagreements about the actual environmental benefits achieved by these controls. Some of the controls may reduce one environmental impact at the expense of increasing others. A primary example of this is the effect of some erosion controls— reductions in fall plowing and conservation tillage —on pesticide use. These controls leave crop residues on the surface, and the residues in turn act to break the force of raindrops on the soil and drastically decrease erosion and runoff. Because the residues harbor plant pathogens and insect pests, pesticide requirements will go up sharply. Also, increased applications of herbicides are used for weed control to compensate for the reduced tillage. The net effect on the environment is not entirely clear because a large source of pesticide entry into surface waters — adsorption on soil particles and transport in runoff — is considerably reduced by the controls, but EPA has identified increased pesticide use with conservation tillage as a significant problem.[57] Tables 33 and 34 identify in greater detail the environmental tradeoffs involved in erosion controls.

Third, some of these controls may appear to be incompatible with the present agricultural system and may not be accepted by farmers. For example, the use of nitrogen-fixing crops, cover crops, and crop rotations conflict with today's large-scale, highly mechanized, chemical-oriented farming although they were widely practiced in the past. Although some scientists argue that the economic advantages of present methods will evaporate (or have already evaporated) in the face of rising prices for energy and energy-intensive agricultural chemicals, and that the long-term environmental viability of the methods is questionable, the relative advantages and disadvantages of the present system and its alternatives are a subject of intense controversy in the agricultural community— with defense of the present system having the upper hand at present. It appears virtually certain that in the absense of Government intervention the provision of feedstocks for energy production will rely primarily on a mechanized, chemical-oriented philosophy modified only by any economic pressures arising from increases in energy prices. Any substantive changes from this philosophy would represent essentially a revolution from established practice and would be unlikely because the present system has clearly succeeded in providing a reliable supply of food at (comparatively) moderate prices.

Crop Types

The environmental impacts of growing and harvesting agricultural crops for energy will vary strongly with the type of crop grown, since different crops have different fertilizer and pesticide requirements, water needs, soil

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[56] G. English, Iowa State University, personal communication, June 15,1979.

[57] *Environmental Implications of Trends*, op. cit.

Table 33.-Environmental Pollution Effects of Agricultural Conservation Practices

Extensiveness	Resource use	Pollutant changes m media: surface water sediment	Nutrients	Pesticides	Pollutant changes m media: ground water–nutrients–pesticides	Pollutant changes m media: soil	Pollutant changes in media: air
Contour farming/contour stripcropping							
Acreage of crops farmed on the contour or strip-cropped decreased 25% between 1964 and 1969 and continued to decrease slightly to 1976, Contour farming is more widely used in nonirrigated crop production than m irrigated crop production.	Fertizer and herbicide use remain constant Insecticideuse will remain constant to very slight increases.	Sediment loss can be reduced substantially on moderate slopes, but much less on steep slopes, Reductions up to 50% are possible, but average reductions will be about 35%. Contour stripcropping can reduce sediment losses more than contour alone. (Note: research shows substantial loss can occur with contour watersheds with some soil types, with long slopes and/or with steep slopes.)	Nutrients associated with sediment will be reduced, but reductions may be proportional to the amount of sediment lost,	Pesticlie reductions will be less than that for nutrients since a greater amount of pesticide IS lost through surface water than bound to sediment.	Loss of nutrients and pesticides through ground water will remain constant or decrease slightly. However the amount of N leached IS small compared to amount that can be lost in runoff and loss of pesticides to ground water IS minor with proper application rates.	Erosion losses can be reduced up to 50% with average reductions of 12Y0 (see conclusions on sediment).	Pesticide losses through volatilization will decrease if they are incorporated into the soil by mechanical means
Terraces and grass waterways							
Terraces and-grass waterways **are** not important in irrigated production, but are Important for nonirrigated crops. However, only **6% of all acres in 1969 had terraces** The acres with terraces in 1976 could have increased or decreased slightly.	Fertilizer, herbicide, and insecticide use is not expected to increase (fertilizer could increase if production per cropped acre is expected to increase to compensate for land taken out of production). However, terrace practices will not require more fertilizers. Costs and maintenance increase for terraces,	Substantial reductions in sediment and runoff can usually be expected.	Reductions in nitrates and phosphates are expected with decreased soil loss and surface runoff. Reductions could be substantial with some soils and cropping systems.	Reduction of pesticide residues in surface water could be substantial with terrace systems, since both surface runoff and soil loss are reduced.	N m ground water may be reduced, based on limited research data. Leaching of pesticides IS not likely to result in significant loss with normal applications rates	Substantial reductions m erosion can result.	No change.

SOURCE U S Environmental Protection Agency, *Environmental Implications of Trends in Agriculture and Silviculture, Volume II Environmental Effects of Trends,* EPA-600/3-78-102, December 1978

Table 33.–Environmental Pollution Effects of Agricultural Conservation Practices-continued

Extensiveness	Resource use	Pollutant changes m media: surface water sediment	Nutrients	Pesticides	Pollutant changes in media: ground water—nutrients—pesticides	Pollutant changes m media: soil	
Conservation tillage; no-till							
Approximately 2.6% of all cropped land was no-till in 1977. While this Practice is expected **to increase to limited use in 2010, current projections (up to 55% of crops under no-till in 2010) seem high. Extensiveness may only be 10 to 20% in 2010.**	Fertilizer and herbicide use increases by 15%, insecticide use by 11%. “An estimated 5 million acres of land could be shifted to crop production with no-till and reduced-till methods. Labor costs are reduced, More water will be conserved with no-till, as much as 2 inches per year.	Sediment reductions of 50 to 90% will result.	While larqe soil loss reductions will tend to reduce nutrient losses, fertilizer use will increase by 15%. There will probably still tend to be reductions in total nutrient loss, but reduction will not be proportional to reductions in soil loss. N content of soil may also increase from weathering of crop residues.	Effect of no-till on pesticide losses is not well documented. Loss to surface water is greater when the compound is surface applied and not incorporated in the soil, and 11‘Yo more insecticides and 15% more herbicides will be used for no-till. While reductions of pesticides in surface water could occur, current research does not prove this. Increased use and surface application, even with reduced soil loss with no-till, could even cause slight increases in pesticide losses.	Nitrates in ground water will show no change to slight increases. Pesticide loss to ground water will not be significantly changed with no-till practices.	Erosion losses will be decreased 50 to 90%. Crop residues will increase which may result in increased N loss to the soil or available for runoff. Additionally, residues may provide a hiding place for pests and increase the incidence of pests.	With some pesticides, increased volatilization will occur with surface applications. The vapor pressure, molecular weight, and other properties of a pesticide will determine the extent of vaporization.
Conservation tillage; reduced tillage							
In 1977, an estimated ***58.8*** million acres (19% of total cropped acres) will be reduced tilled. An additional 40 million acres will be classified as less tilled. Less till includes chisel plowing, disking once instead of twice, and planting in rough ground. In 2010, a total of 40% of all cropland may be classified as reduced tilled.	Fertilizer use will increase slightly. Herbicide use is up (0.6%) and insecticide use increases by 8.6%. An estimated 5 million acres of land will be shifted to crop production with reduced and no-tillage methods. Labor output will decrease. Energy to plant crops decreases, but increased energy will be used in manufacture of increased fertilizers and insecticides. Some soil moisture will be conserved with reduced tillage.	Sediment will be reduced an average Of 14%. Reduced tillage is less effective than no-till in controlling soil loss,	There will probably be reductions in **total nutrient** loss to surface water, but reduction will not be proportional to reductions in soil loss (14%),	Effect of reduced tillage on pesticide loss IS not well documented. Loss to surface water is greater when a pesticide is surface applied and total pesticide use IS 9% greater for reduced till. While reductions of pesticides in surface water could occur, there is not enough research data to support this.	Nitrates in ground water will show no change to slight increases. Pesticide levels in ground water will not be significantly changed with reduced tillage.	Erosion losses decrease an estimated 14%. Wind erosion losses will also decrease slightly. Crop residues increase, which lead to increased N available to the soil for leaching and runoff. Residues on soil also increase the incidence of pests.	**Surface** applications of some pesticides types leads to increased volatilization losses. The vapor pressure, molecular weight, and other chemical properties of a pesticide will determine the extent of vaporization.

SOURCE U S. Environmental Protectlon Agency, *Environmental Implications of Trends in Agriculture and Silviculture, Volume II: Environmental Effects of Trends*, EPA-600/3-78-102, December 1978.

Table 34. -Ecological Effects of Agricultural Conservation Practices

Contour farming/contour stripcropping

Extensiveness of contouring in 1985 (over 1976 use) will be low, but will increase by 2010. Beneficial aquatic effects result from decreased turbidity and pesticide residues in surface water. Species diversity will also increase in the aquatic ecosystem. Decreased erosion and retention of soil nutrient cycles will have long-term beneficial terrestrial effects. Since pesticide residues at current levels in drinking water are not known to be a human health hazard, reduction of pesticide residues will have no significant human health effects. However, if pesticide residues are later determined to be dangerous at current levels, then human health effects would be beneficial.

Terraces and grass waterways

Terraces are more effective than contouring in reducing pollutants, but extensiveness of use is tower for terraces. Aquatic effects are decreased turbidity, increased species diversity, and decreased pesticide residues. Terrestrial effects are beneficial, resulting from increased vegetation on terraces and grass waterways, increased diversity of wildlife, and more pathways for animal populations to travel. Valuable topsoil will also be retained. Based on present knowledge, there is no known human health effect. Decreased sediment in water might result in an unpleasant taste or odor in drinking water.

Reduced tillage

Reduced tillage (with crop residues remaining) is less effective than no-till in reducing soil loss, but extensiveness of reduced tillage will be greater. Therefore, the intensity of ecological effects are comparable for the two practices. Sediment reductions will reduce turbidity and increase species diversity. However, the potential for increased pesticide residues in surface water could have adverse effects on the aquatic ecosystem. Crop residues remaining on the soil and decreased soil loss are beneficial to the terrestrial system, but increased pesticide use will have adverse effects on nontarget organisms. Human health effects will not be significant.

No-till

Aquatic and terrestrial effects are both beneficial and adverse. Aquatic systems will benefit from reduced turbidity and increased species diversity. However, pesticide residues in surface water could potentially be increased with no-till and create adverse effects in the aquatic ecosystem. Increased pesticide use can also have adverse effects on nontarget terrestrial life. Retention of crop residues and reductions in erosion will have beneficial terrestrial effects. Human health effects will not be significant since pesticide residue in surface water should still be within safety limits even if they increase slightly with no-till.

SOURCE U S Environmental Protection Agency, *Environmental Implications of Trends in Agriculture and Siliviculture, Volume II Environmental Effects of Trends*, EPA-600/3-78-102, December 1978

preparation methods, harvesting times, and other factors that may potentially affect impact. Some of the more important crop-determined factors are:

- *Annual or perennial,* — Perennial crops (trees, sugarcane, perennial grasses, etc.) offer a substantive environmental advantage over annuals because their roots and unharvested top growth protect the soil from erosion year round, while annuals offer protection only during the growing season and require seasonal tilling (unless no-till is used) and planting.
- Row or *close-grown crops.* — Row crop cultivation is generally more erosive than cultivation of close-grown crops. For example, the average erosion rates of close-grown crops are significantly lower than those of row crops in every land capability class and subclass shown in table 34. In general, the rates of the close-grown crops appear to be about half those of the row crops.

  In the previous calculation of the expected average erosion rates from new biomass production, a mix of row and close-grown biomass crops (in the same proportion as existed in 1977 food production) would be expected to have an average (sheet and gully) erosion rate of about 7.5 ton/acre-yr compared with about 6.3 ton/acre-yr for food production. If the entire biomass crop were a row crop (e. g., corn for large-scale alcohol production), the average erosion rate from the biomass acreage is estimated to be 9.3 ton/acre-yr— almost 50 percent higher than the erosion rate from food production.
- *Water requirements.* — High irrigation water use means greater competition for water among competing uses, greater drawdown of streams and consequent loss of assimilative capacity, potential for entry of more salts into surface and ground waters, depletion of aquifers (ground water mining), and energy use for pumping. There are substantial differences in water consumption among different crops. For example, irrigation requirements for crops in Arizona during a dry year[58] are:

	Water use, acre-ft/ton of crop
Wheat	0.9
Oats	1.6
Barley	1.3
Alfalfa	0.7

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[58] *Conservation Needs* ***Inventory,*** op. cit

Most discussions of biomass energy assume that irrigation generally will not be used in growing feedstocks. However, an extension of the types of irrigation water subsidies now available to Western farmers, however unlikely, could lead to such use.

- *Soil* requirements. —The ability to utilize marginal lands can avoid the problem of competition with food production that is a major environmental and social/economic issue in evaluating biomass fuels. As discussed elsewhere in this chapter, however, the potential for high biomass yields under marginal soil, temperature, and water conditions has been exaggerated.
- Pesticide *requirements.* —The importance of reducing pesticide applications is a matter of considerable controversy. However, crops that have low pesticide requirements will be perceived as more environmentally benign. In some instances, present pesticide use may be a poor indicator of future requirements for energy crops because cropping practices and land characteristics may be altered significantly in going to a crops-for-energy system. For example, regulatory restrictions on soil erosion could force virtually universal use of conservation tillage and consequent increases in herbicide and (to a lesser extent) insecticide applications. The lack of esthetic requirements for biomass feedstocks might also lead to some decrease in pesticide requirements, but this effect may be small because minor insect damage can lead to further damage by fungal and viral infections (especially during storage). Finally, although pesticide requirements for grasslands currently are very low, pest problems conceivably may accelerate if productivity is pushed by expanded use of fertilizers.
- *Fertilizer requirements.* – In general, high fertilizer requirements are an environmental cost because of the energy used to produce the fertilizer and the nutrient runoff that results from applications. However, crop requirements for very high levels of nitrogen may be an environmental advantage; some high-nitrogen crops are compatible with land disposal of sewage sludge and effluents and thus can be an important component of urban sewage treatment strategy.
- *Yield.* — Because yield per acre determines the amount of land necessary to produce a unit of energy, it is one of the most important factors determining impact. Measurements of input requirements (water, fertilizer, pesticides, etc.) and measurable damages (such as erosion) on a "per acre" basis are inadequate measures of relative environmental impact because of the large variation in biomass yields from crop to crop. For example, corn is widely perceived as an extremely energy- and water-intensive crop, but its very high yields essentially cancel its high "per acre" fertilizer, pesticide, and water needs; it is, in fact, a relatively average crop on an "energy per ton of product" basis.

The importance of these factors in determining environmental impacts is extremely site and region specific. For example, water requirements clearly are more important in the arid West than in the wet Southeast, while factors affecting sheet and rill erosion potential are more or less important in the reverse order. Much of the data needed to assess the different potential crops are not available, and thus it is premature to suggest which crops would be the most environmentally benign in each region or subregion. There are sufficient data, however, to draw some rough sketches of some of the possible advantages or disadvantages of several of the suggested biomass crops.

Corn has been most often mentioned as the primary candidate for an ethanol feedstock. It is an annual row crop and thus a major contributor to erosion, but much of the land on which it is grown is relatively flat, a factor that limits the erosion rate. Corn's high yield rate—currently about 100 bu/acre, or about 260 gal/acre of ethanol —will minimize the land use impact of additional production, although yields on new lands will not be as high as the current average, and the land displaced would be of high quality.

Because the protein-rich residue from the fermentation (ethanol producing) process is a substitute (although not necessarily a perfect one) for soybean meal in cattle feed, switching existing cropland from soybean to corn production may allow large quantities of ethanol to be produced using far less acreage than would be needed if corn for ethanol production were planted only on new acreage. As discussed in the section on "Energy Potential From Conventional Crops," corn's effective yield per acre of new land could grow by over 300 percent (i.e., about three-fourths of the corn used for ethanol would be grown on land formerly planted in soybeans with no loss in national food and feed values) as long as the soybean meal market remained unsaturated. Significant uncertainties concerning the corn residue's nutritive value, potential corn yields on soybean land, soybean market response, and other factors must be overcome, however, before this crop-switching scenario can be accepted as valid. In the absence of the necessary research, the higher estimate of new land required for each gallon of ethanol produced should be used as a pessimistic measure of potential impact. At low levels of production, the more optimistic, lower acreage requirements are likely to be accurate, but the requirements may increase as production increases. Above 2 billion to 7 billion gal of ethanol produced annually, feed markets would be saturated even under the most optimistic assumptions and additional ethanol production would require cropland conversion at the higher rate.

Sweet sorghum has been praised as a crop of high biomass potential for fermentation and alcohol production. Although ethanol yields of 260 to 530 gal/acre have been projected, these projections are based on minimal — and clearly inadequate — experience. However, these high yields, if confirmed, would limit displacement of alternative land uses. Sweet sorghum may be more tolerant of marginal growing conditions than corn, which could lead to a lower level of displacement of the most productive ecosystems.

Sugarcane has been suggested as a biomass crop for alcohol production in Hawaii and the Gulf Coast. Because its cellulosic content is high enough to supply all of the heat energy necessary to ferment the sugar and distill alcohol from it, no coal or other fossil fuel use would be necessary to power the system. Sugarcane requires high-quality land and thus may displace particularly valuable alternative land uses.

Perennial grasses can be supplied in large quantities by increasing yields on present acreage with more intensive harvesting and fertilization; the present average yield is 1½ to 2 ton/acre, and this can be increased to 3 to 5 tons. Because perennials provide excellent erosion control, and because no additional acreage would have to be converted from alternative uses, the environmental impact of a grass-based biomass strategy should be far less than that of a strategy based on annual crops. Environmental impacts of some significance could occur because of the expanded use of fertilizer (150 lb N, 30 to 50 lb P_2O_5, 80 to 150 lb K_2 for an incremental production of 78 gal of ethanol on each acre) and pesticides. Recovery of added fertilizer is very high for grasses, however, so the potential for water pollution will be less than for annual crops. Also, there is uncertainty about changes in susceptibility to disease and insect damage because of the intensification of production, and substantial new use of pesticides conceivably could be required. Finally, the frequent harvesting and greater use of chemicals may disrupt the populations of wildlife that now flourish in the less intensively maintained grasslands.

Trees may be grown plantation-style and harvested by coppicing to supply significant quantities of biomass. A carefully designed tree plantation should have few problems of erosion unless cultivation is practiced (which appears unlikely); however, harvesting may conceivably create an erosion problem unless low-bearing-pressure machines are used to avoid damaging the soil. Tree plantations present basically the same ecological problems as do agricultural monocultures — higher potential for disease attack and displacement of alternative ecosystems. The spacing necessary for tree growth may also allow greater competition from weeds– and consequently larger herbicide requirements–but the sheltering effect of the tree canopy and the greater ability of some tree species to compete for water may counterbalance this effect.

Environmental Impacts of Harvesting Agricultural Residues

The residues from agricultural production have a number of significant effects –beneficial or otherwise—when left on the land. Understanding these effects is critical to understanding the potential environmental impacts of the collection and use of these residues as an energy feedstock.

Table 35.–Environmental impacts of Plant Residue Removal

Water

- Increased ***erosion and flow of sediments*** into surface waters if restrictions on removal are not observed, causing increased turbidity, obstruction of streams, filling of reservoirs, destruction of aquatic habitat, increase of flood potential; under circumstances where conservation tillage is encouraged by removal of a portion of the residues, erosion and its consequences will decrease,
- Increased ***use of herbicides*** and possible increased flow into surface and ground waters if conservation tillage is required for erosion control; in some situations, removal of a portion of the residues would increase herbicide efficiency and greater use may not occur.
- Increased ***flow of nutrients*** if more runoff results from decreased water retention of soil and greater erosivity of soil; if more fertilizer is applied to compensate for nutrient loss, flow of nutrients will change but the net affect is not certain.

Air

- ***Dust*** from decreased cover on land, operation of residue harvesting equipment (unless integrated operation).
- Added *herbicides from* aerial spraying or as a component of dust.
- ***Decreased insecticides, fungicides.***
- ***Reduction in pollution from open-burning*** of residues, where formerly practiced.

Land

- ***Erosion and loss of topsoil, degrading of productivity*** if restrictions on removal are not observed; the opposite, positive effect if conservation tillage is encouraged by residue removal.
- Decrease in ***water retention capabilities*** of land, increased flooding potential if restrictions are not observed.
- *Depletion of nutrients and organic matter from soil* (nutrients may easily be replaced),

Other

- ***Reduction in plant diseases and pests*** (if lowering of soil organic matter does not adversely affect this factor) because residues can harbor plant pathogens.

SOURCE: Office of Technology Assessment.

The effects of residues left on the land include (table 35):

- Control of wind and water erosion. – Retention of residues as a surface cover is a major erosion control mechanism on erosion-prone lands. For example, residue retention on land that is conventionally tilled (i.e., plow-disk-harrow) can cut erosion in half.[59]
- Retention of plant nutrients. – Residues from the nine leading crops in the United States contain about 40, 10, and 80 percent as much nitrogen, phosphorus, and potassium, respectively, as in total fertilizer use in U.S. agriculture.[60]
- Enhanced retention of water by soils and maintenance of ability of soil surfaces to allow water infiltration.
- Maintenance of organic matter levels (necessary to maintain soil structure, ion exchange capacity, water retention properties) in soils. –Croplands in the United States have lost major portions of their organic content. Reductions (in North Central and Great Plains soils) of one-half to two-thirds of what was present under native grassland have been cited.[61] Retention of crop residues is a critical factor in maintaining organic matter levels.
- A number of negative effects depending on the type of crop and amount of residue–" poor seed germination, stand reduction, phytotoxic effects, nonuniform moisture distribution, immobilization of nitrogen in a form unavailable to plants, and increased insect and weed problems."[62] In all cases, the residues harbor crop pests; this can be a particularly sig-

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[59] W. E. Larson, et al., "Residues for Soil Conservation, " paper No. 9818, Science Journal Series, AR S-USDA, 1978.

[60] Ibid.

[61] Ibid.

[62] *Improving Soils With Organic Wastes*, OP. cit.

nificant problem if single cropping is practiced (the same crop is grown in consecutive years). Because the residues shield the soil, they may hinder soil warming and delay spring planting (causing reduced yields in corn).

When the problems associated with crop residues outweigh the benefits, farmers will physically remove the residue (this practice is necessary in rice cultivation) or plow it under in the fall (a common practice in the Corn Belt). The collected residues may be burned, although they have alternative uses such as livestock bedding. Where removal is normally practiced, use of the residues as an energy feedstock is at worst environmentally benign and possibly beneficial (if air pollution from open burning is prevented). Because fall plowing negates much of the residues' value as an erosion control, collection of a portion of the residue is usually considered benign (full removal may affect soil organic content, the importance of which is somewhat in debate). Because an excess of residue may inhibit the effectiveness of herbicide treatments — especially preemergence and preplant treatments — and also leave large numbers of weed seeds near the soil surface, removal of a portion of the residues on land where they are in excess may promote the use of reduced tillage by allowing more effective chemical weed control, and thus be considered environmentally beneficial.

When residues are normally left on the soil surface as an erosion control, their removal potentially may be harmful. However, where substantial quantities of residue are produced on flat, nonerosive soils, a portion of these residues may be removed without significantly affecting erosion rates. SCS and the Science and Education Administration –Agricultural Research have sponsored extensive research designed to compute the effects of residue removal practices and other practices on soil erosion. USDA believes that it can identify the quantity of residues that can be safely removed from agricultural lands in all parts of the United States. Although controversy exists over the rate of creation of new topsoil, and thus the erosion rate that will maintain productivity over the very long term, it seems likely that errors in these computations will not cause significant harm as long as SCS maintains its monitoring efforts at the current level.

The key to preventing significant environmental damage while harvesting large quantities of residues is for the agricultural system to act in accordance with USDA's knowledge. The discussion of the impacts of U.S. agriculture presented previously seems to indicate a willingness among farmers to ignore warnings about using erosive practices or cultivating fragile land, in order to gain short-term benefits. In the absense of additional constraints, a significant number of farmers might be willing to remove their crop residues even when adverse erosion effects would occur. (interestingly enough, some farmers may ignore USDA with the opposite effect—they may be reluctant to remove any residues because of their fear of erosion and other negative consequences). Under these circumstances, the establishment of a market for crop residues could result in additional erosion from croplands that cannot afford it and add to the already significant sediment burden on surface waters caused by current farming practices.

Although the negative effects of any increase in erosion are straightforward, other effects that have been associated with residue removal are more ambiguous. For example, the removal of plant nutrients in the residues may be compensated for by the return of the conversion process byproducts or by chemical fertilizers (both of which may have some adverse effects on water quality). The removal of organic content has been identified as a significant impact[63] and soil scientists have long thought that soil organic content is a critical variable of the health of the agricultural ecosystem (e. g., increasing the organic content of soils can stimulate the growth and activity of soil micro-organisms that compete with plant pathogens). However, despite a variety of papers in the agronomy literature that treat yield

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[63] Pimentel, et al., op cit.

as a function of soil carbon level, there is insufficient experimental evidence to establish that any significant effects on crop yields would occur. Also, the much higher yields of today's agriculture means that removal of half of the residue will leave the same amount of organic material as would have occurred 25 years ago if all of the residue had been left on the land. This is an area that clearly deserves further research.

R&D Needs

Considerable research has been and is directed at improving agriculture for food, feed, and materials production. While much of this research is applicable to energy production, the specific goal of producing various types of energy crops has not been adequately addressed. Changing the emphasis to energy or energy and food production and the environmental concerns with agriculture suggest several R&D problems. Some examples are listed below.

- A wide variety of crops that are not used as food or feed crops could, potentially, be good bioenergy crops. The promising varieties should be developed. From a theoretical point of view, grasses appear to be promising candidates for high biomass producers and on marginal cropland (see ch. 4): and arid land and saline tolerant crops may enable the economic use of lands and water supplies that are otherwise unsuited for agriculture.
- Food and feed crops are usually quite specific as to their use. Corn, for example, is not interchangeable with wheat. Many different types of crops, however, can produce the same or interchangeable biomass fuels. Consequently, extensive comparative studies between various crops are needed to determine the promising bioenergy crops for the various soil types and climates.
- If both the residues and the grain can be sold, then the optimum plant may not be the one that produces the most grain. Farming practices and hybrids that can change the relative proportions of grain to residue in the plant while maintaining a high overall yield should be investigated.
- Various crop-switching possibilities that involve fuel production should be investigated further to determine the extent to which they can provide fuels and the traditional products from agriculture with-. out expanding the quantity of cropland cultivated. The extent to which the corn-soybean switch actually takes place should be studied, as should novel possibilities such as sugar beets used for animal fodder. Included in this should be investigations of the effect of substituting current feed rations with varying amounts of forage-distillers' grain, forage-corn gluten mixtures, and other feeds that may be involved in the crop-switching schemes.
- Large-scale biomass development will require the placement of millions of acres of land — now in low-intensity agriculture (e.g., pasture), forest, or other uses– into intensive production, coupled in many cases with very high rates of removal of organic matter. Environmental R&D that should accompany, and preferably precede, such development includes:
  - –further investigation of long-term effects of reduction in soil organic matter,
  - –determination of pesticide requirements for high-yield grasses in intensive production,
  - — intensification of breeding programs for insect/disease-resistant strains of crops with high biomass potential,
  - –determination of economically optimum strategies for minimization of soil erosion, and
  - –development of effective/ programs to improve farmer (environmental) behavior.