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Implications for Resource Use, Supply Vulnerability and Farm Structure

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Technology adoption in U.S. production agriculture continues to be heavily dependent on the abilities of individual technologies to either (a) save resources or (b) increase output. This is true because individual producers must adhere closely to principles of cost minimization and profit maximization. But public interests in technology development and adoption include the broader issues of avoidance of negative externalities (soil erosion, toxic pollution, depletion of natural resources, displacement of labor, adverse structural impacts and others). In addition, the long-term viability of the production system itself is of public concern. For example, what are the impacts of specific production technologies on the vulnerability of future corn supplies? In this paper we draw on results from a broad-based technology assessment of commercial corn production in the U.S. (17) to address some of the above listed set of public issues relating to the impacts of corn production technologies.

Technology Impacts on Resource Use

(i) Energy

Per acre energy requirements for corn production have increased dramatically over time. The overall energy output/input ratio has, however, remained fairly constant since 1945 as energy outputs (yield/acre) have risen in roughly the same proportion as energy inputs per acre (Figure 1).[1/] Moreover, the overall energy output/input ratio (Kcal output/Kcal input) remains much in excess of unity at a magnitude of around three.

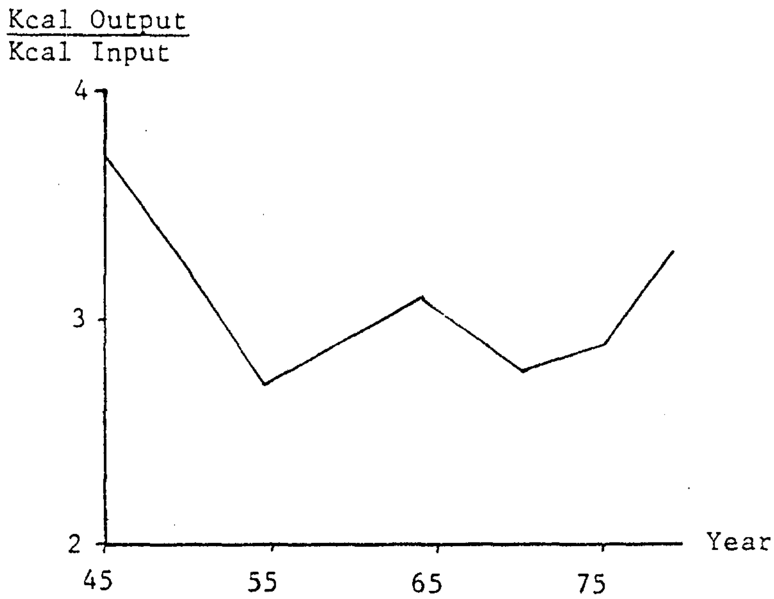

Figure 1. U.S. Corn Energy Output/Input Ratio Over Time.

Source: Pimentel et al. (12); Pimentel and Pimentel (14); and Pimentel (13).

The major energy intensive inputs in dryland corn production are fertilizers (over 50% of the total) and grain drying (13%). Irrigation of corn is particularily energy intensive with energy used in irrigation making up about 30 percent of total energy costs for production under irrigation. Where deep well pumping of water is involved, energy costs for pumping alone may be 60 percent of total energy costs (5, 23).

At present, corn production is energy intensive relative to other field crops. Compared to soybeans in the Corn Belt, it requires three times more energy per acre, and twice as much energy per dollar of output (6). Thus increases in real energy prices or energy shortages will ration energy use and enhance the competitive position of soybeans (and some other crops) vis-a-vis corn. As a consequence, public sector research to improve the energy efficiency of corn production technology should be a continuing area of high priority.

(ii) Land

Acreage of corn harvested for grain peaked at 97.2 million acres in 1932 followed by a long term decline which took harvested acreage down to around 55 million acres in the mid 1960s (20). By the mid 1970s harvested acreage had increased to more than 70 million. The amount of land required to produce a bushel of corn has fallen rapidly in line with increased corn yields. In 1945-59, 0.028 acres of land were required to produce a bushel of corn, but by 1975-79, this requirement had fallen by almost two-thirds to 0.010 ac/bu. Clearly the changes in technology which have taken place (such as plant breeding, fertilizer, chemical pesticides and management of soil moisture) have been heavily "land augmenting" in character.

However, the potential for several key land augmenting technologies (agricultural chemicals in general, and nitrogen fertilizer in particular) appear to have been almost fully exploited (as of 1982). Mechanical technologies (tillage, planting, harvesting) which have made only modest contributions to land augmentation in the past will make only modest (at best) contributions in the future. Also, the potential increases in corn production attributable to land drainage have been mainly exploited and most new drainage installation will be to replace or augment existing systems. When their contributions are realized, the emerging biotechnologies will be strongly land augmenting. But, these contributions will probably not be significant until the mid 1990s.

In summary, among the land augmenting technologies only plant breeding appears likely to make a major continuing contribution to corn production increases in the near term. As a consequence, if such increases are needed, they will probably need to depend heavily on additional inputs of cropland as a key source.

(iii) Labor

A century ago (in 1880) corn production required about 1.8 hours of labor per bushel. Corn production remained labor intensive throughout the early decades of the 20th century. Since World War II, the labor required to produce a bushel of corn has fallen even more dramatically than the land requirement. In 1975-79, the labor required was less than 10 percent of that required in 1945-59. And, a modest decline in output per unit of labor input is continuing as producers adjust to available technology.

Past labor efficiencies in corn production resulted mainly from mechanization of tillage, planting and harvesting operations, combined with the extensive use of herbicides for weed control. Improved labor efficiency, coupled with per acre yield increases, has now reduced the labor input in corn production to less than 5 percent of total production costs. Moreover, at the present level of less than 0.04 hrs/bu, the likelihood of further major increases in labor efficiency appears low.

At the same time that the quantity of labor inputs for corn production has declined, skill requirements have increased. The handling of complex, science-based technologies and sophisticated financial management strategies require a better trained, higher skill labor force than formerly. Thus, improvement of management information systems and upgrading the technical training of producers appear of higher priority for future public sector research and education than does a further reduction in labor inputs.

(iv) Water

Subsurface drainage has long been an important technology in corn production. Development of small diameter plastic tubing in the 1960s was augmented by use of high speed, trenchless laser-leveling installation equipment. This technology reduced the real cost of drainage and spurred adoption rates so that most land used in row crop production is now drained rather effectively.

Sprinkler irrigation of corn was virtually revolutionized by the development of lightweight aluminum tubing in the 1940s and the subsequent development of labor efficient "center pivot" technology in the early 1950s. Use of the center pivot system expanded rapidly through the 1960s, and in response to extensive drought in the mid 1970s. By 1980 an estimated 11.5 million acres of corn were being irrigated (4), mostly for grain (see Table 1 for the 13 states with largest acreage of irrigated corn). Irrigation now contributes 700 million bushels or more to annual corn production and reduces annual production variability by about one-half of that amount (17).

Despite a declining water table in some areas (particularly in the Southern Plains), higher expected energy prices and more intensive competition for water in nonagricultural uses, irrigated corn acreage is expected to increase significantly over the near-term.[2/] Increased irrigation in Nebraska (where large underground water supplies remain) alone will more than off-set decreases in the Southern Plains.

But, environmental hazards will be increased in the process of further irrigation development on marginal and fragile soils (15). And, continuation of the current practice of heavy "mining" of subsurface water supplies is an adverse externality of likely great future importance.

Table 1. Estimated Acreage of Corn Irrigated in Slected States[a/], 1980

State	Irrigated Corn Acreage[b/] (thousand acres)
California	440
Colorado	1,110
Georgia	390
Idaho	121
Iowa	185
Kansas	1,209
Michigan	156
Minnesota	355
Missouri	148
Nebraska	4,950
South Dakota	215
Texas	984
Washington	155
Total (13 states)	10,418

a/ Includes those states reporting 100,000 acres or more of irrigated corn in 1980.

b/ The 1977 National Resource Inventory conducted by SCS placed the total U.S. irrigated acreage at 58 million acres compared to 61 million acres estimated in the Irrigation Journal Survey for 1980 (19). Thus, the Irrigation Survey data are probably reasonably accurate for the purposes of our use.

Source: Irrigation Journal, 1980 Irrigation Survey (4).

(v) Capital Intensity

Expenditures for corn production--both investments in durable items (e.g., land, machinery and equipment) and costs of annual production inputs (e.g., fertilizer, fuel, seed, machinery repairs, etc.)--have experienced dramatic growth in recent years. The cost of credit to finance these expenditures has also risen rapidly. Annual costs of servicing all production inputs (including capital investments) are illustrated in Table 2 for the period of 1975-79 and for 1980. From 35 to 40 percent of these costs are those associated with land transfer or ownership which are mainly intrasectoral financial transactions (and for some producers, they are opportunity costs - not cash costs). Although lower land prices would reduce production costs for some producers significantly, the asset values of those with equity in farm real estate would also be reduced. Thus any cost reduction via lower land prices has serious distributional implications.

One impact of high current capital costs has been to drive the per bushel differential between costs and revenues down dramatically over time (Table 3).[3/] A second impact has been that of inducing increased size in order to spread the cost of expensive, lumpy capital inputs, particularly machinery, over a larger acreage base. Yet another practical impact has been to limit entry into commercial corn production to those with access to substantial capital. For example, a modern technology farm of only 300 acres in the Central Corn Belt now requires a capital base of about $1 million (including land).

Impacts of Technology on Structure of Farming

Technology has generated major impacts via increases in the size and a decrease in the number of firms producing corn. Historical data on the average size of farms growing corn, and on the size of the corn enterprise, are available

Table 2. U.S. Corn Production Costs, $ Per Bushel, 1975-79 and 1980.

	1975-79	1980
VARIABLE:		
Seed	0.11	0.16
Fertilizer	0.38	0.53
Lime	0.01	0.02
Chemicals a/	0.12	0.17
Custom operations b/	0.05	0.05
Labor	0.11	0.14
Fuel and lubrication	0.09	0.19
Repairs	0.08	0.11
Drying	0.06	0.07
Interest	0.03	0.07
Total	1.04	1.51
MACHINERY OWNERSHIP:		
Replacement	0.20	0.28
Interest	0.09	0.22
Taxes and Insurance	0.03	0.04
Total	0.32	0.54
Farm Overhead	0.09	0.10
Management c/	0.15	0.21
TOTAL, EXCLUDING LAND	1.60	2.36
TOTAL, INCLUDING LAND d/	2.49	3.82
TOTAL, EXCLUDING LAND, DEFLATED e/	1.57	1.69
TOTAL, INCLUDING LAND, DEFLATED e/	2.43	2.73
YIELD/PER PLANTED ACRE	94.3	90.5

a/ Includes herbicides, insecticides and rodenticides not otherwise included under custom operations

b/ Includes custom application of crop chemicals, the cost of chemicals in some cases, and custom harvesting and hauling.

c/ Based on 10% of the above costs.

d/ Weighted current value composite of owned and rented land.

e/ Deflated by USDA Prices Paid Index, which in the respective years was 89, 95, 100, 109, 125, and 140.

SOURCE: Committee on Agriculture, Nutrition and Forestry, U.S. Senate (various years), Costs of Producing Selected Crops in the U.S., 1975 through 1979. Data for 1980 are unpublished, USDA.

Table 3. Historical Real Net Returns for Corn - Central Illinois

Period	Real Net Returns (Prices - Costs in $/bu)[a/]
1941-42	$3.15
1951-52	$2.61
1959-60	$0.61
1964-73	$0.61
1974-80	$0.12

a/ 1980 dollars (nominal prices - costs, deflated by CPI).

from the U.S. Census of Agriculture. However, this data source is misleading in that it averages all units identified in the Census as "farms", rather than providing a more valid "operating unit" inventory of farm size. Moreover, it is to operating units rather than to Census farms that production technology is actually applied. Fortunately, an operating unit measure which is "acreage weighted" is available from a recent cost of production survey reported by Lagrone and Krenz (7). But, it is based on a small sample and it has no historical counterpart against which to measure change over time.

Table 4 illustrates the difference in size of corn enterprise between Census farms and the Lagrone-Krenz (L-K) operating units for Minnesota, Iowa and Illinois in 1978. The differences are crucial ones since it would be difficult for producers to justify investments in expensive 6- and 8- row planting and harvesting machinery for corn acreages of the size enumerated by the Census. Moreover, the L-K survey data indicate that the corn enterprise typically represents only about one-third to two-thirds of the cropland acres for operating units. Thus, much of the machinery, equipment, and other technology (as well as the labor complement) for individual operating units is spread over crop

Table 4. Comparison of Corn Enterprise Size (Census vs. Operating Unit Definitions) for Three States, 1978.

State	Cornland (acres)	
	Census Units	Acreage Weighted a/ Operating Unit
Minnesota	91	218
Iowa	125	262
Illinois	140	372

a/ Data are from statistical samples ranging from 48-73 farms per state. Sample stratification sought to provide equal probability of including each acre of corn. Thus it is an acreage weighted sample of corn producing units which is depicted by the data.

Source: 1978 Census of Agriculture and 1978 survey by Lagrone and Krenz (7).

enterprises other than corn. Miller *et al.* (11) indicate that costs per dollar of gross income decline by about $.06 (or about 13 percent) on Corn Belt farms as cropland acreage is increased from 272 to 630 acres. Unfortunately, they included no farm size units of between 272 and 630 cropland acres or of more than 630 acres.

In order to put together operating units of adequate size to spread the cost of modern mechanical technology, many farmers now rent cropland in addition to that which they own. For example, the average percentage of land rented by sample corn producers ranged from about one-third in Minnesota to almost 60 percent in Illinois (L-K).

In summary, among the impacts of technological change in corn production have been increases in size of operating units and in the incidence of land renting. But, nonfamily corporations remain an insignificant component of the corn production sector.

Our conclusion is that adoption of modern production technology generates economic pressures which are probably strong to increase the amount of cropland per Corn Belt operating unit to 600 acres or more.[4/] Although somewhat larger operating units (over 750 acres in Nebraska and 2400 acres in Colorado) were observed by L-K in the production of irrigated corn, there is no obvious reason to suggest that additional size economies are present for irrigated production. It is more likely that these irrigated units are larger mainly because of their business organization and their access to larger amounts of capital.

Supply Vulnerability

Our purpose in this section is to discuss briefly the vulnerability of the aggregate supply of U.S. produced corn over the period between now and the year 2000. In order to place the following discussion of supply vulnerabilities in perspective, we have assumed that aggregate corn acreage harvested for grain can be expected to remain generally in the 70-80 million acre range (as it has since 1976).[5/] Also, assuming a continuation of about the 1980 level of real research funding for corn, we have projected average annual marginal yield increases of around 1.5 bu/ac/yr through the 1980s (Table 5). This expected increase represents only two-thirds of the average annual yield increase which occurred over the period from 1954-80, mainly because of the reduced marginal impacts of fertilizer. From 1990-2000, yield increases, though more speculative, are expected to be signficiantly higher than 1.5 bu/ac/yr as some emerging biotechnologies begin to be applied commercially. The several major potential sources of supply vulnerability are discussed individually in the sections which follow.

(i) Weather and Climate

Plant breeding, irrigation, drainage, grain drying and mechanization technologies have all reduced the vulnerability of aggregate corn production to both intra-season and inter-season weather fluctuations. Yet, weather vulnerability continues to have a major impact on aggregate corn supplies mainly via variance in

Table 5. Projected Marginal Impacts on Corn Yields of Various Technologies, 1981-2000. (Bu/Ac/Yr)

Year	Technology Trend	Additional Nitrogen	Production Management Technologies	Emerging Biotechnologies	Total[b/]
1981	1.0	.4	.2		1.5
1982	1.0	.3	.2		1.5
1983	1.0	.3	.3		1.5
1984	1.0	.2	.3		1.5
1985	1.0	.2	.3		1.5
1986	1.0	.2	.3		1.4
1987	1.0	.2	.3		1.4
1988	1.0	.1	.3		1.4
1989	1.0	.1	.3	.1	1.5
1990	1.0	.1	.3	.2	1.6
1991	1.0	.1	.2	.3	1.5
1992	1.0	.1	.2	.5	1.7
1993	1.0	.1	.2	.8	2.0
1994	1.0	.1	.2	.9	2.1
1995	1.0		.2	1.2	2.4
1996	1.0		.2	1.4	2.6
1997	1.0		.2	1.5	2.7
1998	1.0		.2	1.7	2.9
1999	1.0		.2	1.7	2.9
2000	1.0		.2	1.7	2.9
Total	20.0	2.5	4.8	12.0	38.5

a/ Includes conventional plant breeding and other highly correlated trend factors such as plant population and moisture control.

b/ May not add due to rounding.

average annual yields. A recent study by the Research Directorate of the National Defense University (16) reported a standard deviation in corn yields of 10 bu/ac for a historical base period when adjusted to 1976 levels of technology. That study did not, however, account for "price induced" yield effects, principally via changes in the fertilizer/corn price ratio. Our own analysis, which did account for changing fertilizer levels resulted in a "mainly weather related" standard deviation of about 5 bu/ac over the past 27 years. This totals to over 350 million bushels on the current corn crop from more than 70 million acres. A larger deviation from trend of almost 16 bu/ac (or about 1.05 billion bushels total) occurred in 1974. Interyear production variability of even this magnitude, however, can be dealt with via effective grain reserve-type strategies so as to minimize its adverse impacts on annual corn supplies.

(ii) Genetic Resources

There may have been some improvements in increasing the genetic diversity of corn in the ground in a given year since 1970 (3) and such improvements may continue as more private sector resources are devoted to the development of parent inbred lines. Nevertheless, disease or insect pest attacks of the magnitude of the 1970 corn blight could reoccur. The prospect of such a problem existing for a period of more than one to two years is small, since genetic resources in breeding pools and in gene banks appear to be adequate.

Taking a longer-term view of the situation, however, it appears that the total world supply of genetic resources is diminishing. Yet there will be a continuing demand for new and exotic germplasm. Present government efforts to collect, preserve and describe corn germplasm appear to be inadequate (2). This poses a threat to corn supplies in the long-term which should be addressed via effective programs and policies in both the public and the private sectors.

(iii) Environmental Externalities

In the short-term, environmental considerations are not likely to pose any major threats to the supply of corn. In the long-term, soil erosion from water runoff could pose a serious threat, if unchecked.[6/] However, voluntary changes in tillage systems by farmers, assisted by modest "targeted" incentives from government can greatly reduce this threat (10).

Other adverse environmental externalities associated with current production technologies (principally nutrient and toxic pollutants) can probably be controlled at acceptable levels by improved management and local regulation. Eventual reversion of some irrigated cornland to dryland farming upon depletion of local water supplies and/or because of high energy prices will constitute a serious environmental impact when it occurs. But, because the total acreage involved is only a small percentage of total corn land acreage (not more than 2-3%) it will probably not greatly jeopardize the aggregate supply of corn. Caution should be taken, however, in developing additional "environmentally fragile" land for irrigation.

(iv) Resource Supplies and Prices

Of the important resources used in corn production, only the supplies of energy (including agricultural chemicals with their high energy embodiments), and irrigation water appear vulnerable to short supplies in the near term.

In the case of agricultural chemicals, including nitrogen fertilizer, a strong financial incentive exists to conserve inputs. Indications are, however, that corn yields are now less responsive to changes in input prices (particularily fertilizer prices) than they were in the mid-1950s and 1960s (9). This is true because the marginal value productivity for current high levels of fertilizer (125-130 lbs/ac/yr) is only about one-fifth of that in the 1950's. Thus a reduction in fertilizer application rates from their present levels would have less impact on yield and total supply than a similar reduction at the earlier, lower rate levels.

Although fuel for field machinery and grain drying may be in short supply and may experience price rises in the future, the conservation of fuel in field operations and the use of substitute fuels for grain drying will probably prevent shortages from impacting significantly on aggregate corn supplies. Of the several technologies which are heavy users of energy, only deep well irrigation appears seriously threatened by "high priced" energy. Even in this case, a combination of energy conservation, adoption of more energy efficient technology and a shift to some shallower well water supplies will likely postpone the vulnerability of aggregate corn supplies to energy prices until after the year 2000.

In the near term, water resource shortages will limit corn production below current levels only in the Southern Plains. This source of vulnerability for aggregate corn supplies will be more than offset by expanded water use for irrigating corn elsewhere. Though competition from non-agricultural water users is rising rapidly, it does not appear that this competition will be intense with most water used for corn irrigation before the year 2000. This situation could change, however, with an extended drought in the central portion of the U.S. Moreover, current heavy mining of water resources does constitute a vulnerability for corn production in the next century.

(v) Farm Structure

Concern has been expressed regarding the impact of large farms (particularly those operated by large corporations) on the vulnerability of supply for farm products. Although this may well be a legitimate concern in the long-term it does not appear to be a source of near-term vulnerability for aggregate corn production. Only a small portion (about 5% in 1978) of the U.S. corn production was from farms with annual sales of $500,000 or more and most of these farms were not corporate units (1). A continuation of the past upward size adjustment in operating units can be expected as corn producers continue to move toward that size of unit (600 acres of cropland or more) which more efficiently utilizes available mechanization technology for tillage, planting, and harvesting.

Probably of significant vulnerability is the current and future financial solvency of some corn producers who have borrowed heavily to invest in durable capital for corn production (land, machinery, irrigation equipment and drying and storage facilities) at high prices. However, this financial vulnerability for individual producers does not translate into vulnerability for aggregate corn production. Cornland will likely continue in production under a high level of technology even though individual producers experience financial problems severe enough to create business insolvency. There is a strong incentive to keep productive cropland in use and the land resources of any insolvent producers would be quickly incorporated into existing, high-technology production units. Although land prices might decline significantly in the face of such adverse financial conditions,[7/] productive cropland will still be put to use.

In Conclusion

The U.S. corn production sector has evolved to a labor efficient and a capital and energy intensive one. The major yield gains available from chemical technologies (fertilizers and pesticides) have now been exploited, in the main, as have the productivity gains associated with labor saving mechanization. Yield gains from conventional plant breeding continue at the rate of about 1/bu/ac/yr. Also, improved management technology will reduce some of the gap between experimental and farm-level yields. But, it will probably be into the 1990s before the emerging biotechnologies provide a significant contribution to corn yields. Thus, productivity gains in the 1980s and early 1990s for corn can be expected to be slower than in the past 30 years unless R & D activities achieve unexpected break throughs (the potential for which can be enhanced by effective research targeting).[8/] Aside from this slowing in productivity rate, the high energy intensiveness of corn production technology, a high incidence of soil erosion, particularly on the steeper slopes of the Corn Belt, the mining of subsurface water supplies in the Southern Plains, and declining real returns to producers are major issues to which future public attention needs to be addressed.

Footnotes

1/ The data presented in Figure 1 must be regarded as being approximate only, although a comparison between the figures for 1975 (from Pimentel, as quoted in Sundquist et al.) (17) and those of USDA for 1974 (18) showed a close correspondence. Furthermore, these data should not be applied to specific corn production systems. Energy inputs per unit of output vary greatly between production systems. Production systems using deep well sprinkler irrigation, for example, are much more energy intensive than dryland systems.

2/ In 1975, 77 percent of the consumption of water withdrawals in the U.S. was for agriculture, with only 23 percent for all other uses. The latter percentage was up from 10 percent in 1955 and 15 percent in 1965 (22). Non-agricultural water use is probably now in the 26-28 percent of total usage range, and rising. Despite this phenomenon, and primarily because most corn irrigation is not in the arid west where competition for water is greatest, irrigated corn acreage will probably expand by an additional several million acres by 1990 (17).

3/ Several factors make these or other estimates of real net returns subject to potential error. These include data comparability over time and the procedure by which land costs are estimated. Even after discounting for these problems, however, the trend in real net returns per bushel (and even per acre) has been strongly downward.

4/ Not all operators have adopted or will adopt modern mechanization technology as represented by 6 to 8 row planting and harvesting machinery, etc. For those who do, however, there will be economic pressure to operate this expensive machinery at or near full capacity.

5/ In years during which land retirement programs reduce acreage levels substantially below 70 million acres (such as is the case with the PIK program in 1983) average corn yields can be expected to exceed trend yields and the marginal impacts of technologies on yield (Table 5) will not be applicable.

6/ The current situation with respect to soil erosion in the U.S., though serious, is not as bad as represented by some. Mayer (1), while warning that the methodology differs somewhat between the two surveys, compares results of a survey conducted in 1934 with the 1977 National Resources Inventory. "The 1977 survey found 77 percent of cropland with only slight erosion compared to 47 percent in the 1934 survey; 13 percent with moderate erosion compared to 38 percent in the 1934 survey; and 10 percent with severe erosion compared to 15 percent in 1934." Moreover, in order for corn yields to increase as dramatically as they have over the past several decades, one concludes that soil resources used for corn production are still in fairly good condition.

7/ Such declines have, in fact, already occurred. Among the largest declines in farmland prices between February 11, 1981 and April 1, 1982 were those in Ohio, 15 percent, Indiana, 13 percent, and Illinois, 9 percent (21). This decline was due, at least in part, to the cost-price squeeze experienced by corn producers in 1981 and that cost-price squeeze continues.

8/ Such targeting would, for example, emphasize such technologies as plant breeding, the emerging biotechnologies and more effective moisture control while deemphasizing additional increases in labor efficiency.

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