3.1 Nutrients

Nutrients need to be applied to most fields to maintain high crop yield. Most nutrients applied are from commercial fertilizer. Commercial fertilizer use in the United States has declined from a peak in 1981 because of fewer planted acres and stable or falling application rates. Fertilizer prices paid by farmers were relatively stable from 1989 to 1993, but increased dramatically in 1994 and 1995.

Contents

Crops take up nutrients—primarily nitrogen (N); phosphate (P_20_5), the oxide form of phosphorus (P); and potash (K_20), the oxide form of potassium (K)—from the soil as they grow (see Glossary for more on the roles of nutrients in food and fiber production). Plants require other nutrients than nitrogen, phosphate, and potash, but in smaller amounts. Magnesium, calcium, and sulphur are also essential nutrients for plant growth and development. Sulphur, for example, is important to plants for protein formation. Nutrients that plants need in only small or trace amounts (called micronutrients) include boron, chlorine, copper, iron, manganese, molybdenum, cobalt, sodium, and zinc. Commercial fertilizers are applied by farmers to ensure sufficient nutrients for high yields.

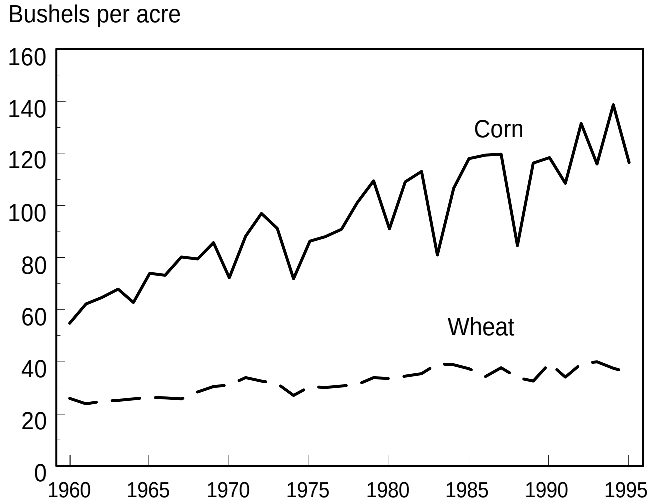
Lime is also applied to some soils as a soil conditioner, rather than as a nutrient. Lime reduces soil acidity (pH) so that crops can better utilize available nutrients and micronutrients.

From the settlement of the United States until the 19th century, increased food production came almost entirely from expanding the cropland base and mining the nutrients in the soil. However, the expanding demand for agricultural commodities required soil nutrient replacement to maintain or expand crop yields. First, manure and other farm refuse were applied to the soils. Later, applications of manure were supplemented with fish, seaweed, peatmoss, leaves, straw, leached ashes, bonemeal, and Peruvian guano, materials that contained a higher percentage of nitrogen, phosphate, and potash than did manure (Wines, 1985). As manufacturing developed, production of chemical fertilizers like superphosphates and, later, urea and anhydrous ammonia (see Glossary) replaced most fertilizers produced from recycled wastes. Commercial fertilizers provided low-cost nutrients to help realize the yield potential of new crop varieties and hybrids (Ibach and Williams, 1971). Since 1960, yields per unit of land area for major crops have increased dramatically. For example, average corn yield has increased from 55 bushels per acre in 1960 to 139 bushels in 1994 and average wheat yield from 26 to 38 bushels per acre (fig. 3.1.1). If nutrients were not applied, today's crops would rapidly deplete the soil's store of nutrients and yields would plummet.

Nutrient Sources

Commercial fertilizer is by far the major source of applied plant nutrients in the United States, followed by animal manure. Treated or composted municipal and industrial wastes are applied as sources of plant nutrients in some areas, but little data are available and overall use is likely limited, although increasing. Specific aspects of these three sources of nutrients are described in the following sections.

Figure 3.1.1--Average corn and wheat yields per harvested acre, 1960-95



Source: USDA, ERS, based on Agricultural Statistics, 1994 and earlier issues; and ERS, Agricultural Outlook, 1995.

Commercial Fertilizer

The U.S. commercial fertilizer industry is essentially composed of three separate industries (nitrogen, phosphate, and potash). Each has different material and process requirements but both are horizontally and vertically integrated (Andrilenas and Vroomen, 1990).

Anhydrous ammonia is the source of nearly all nitrogen fertilizer. It may be applied directly to the soil or converted into other nitrogen fertilizer such as ammonium nitrate, urea, nitrogen solutions, synthetic ammonium sulfate, and ammonium phosphate. Anhydrous ammonia is synthesized through a chemical process that combines atmospheric nitrogen with hydrogen. Nitrogen can be obtained from the air, but the hydrogen is derived from natural gas.

U.S. capacity to produce anhydrous ammonia and other nitrogen fertilizers increased since 1950 in response to rising demand. Capacity increased from 7.8 million tons in 1964 to 20 million tons in 1981, but has declined to about 17 million tons due to plant closures and lack of new plant construction (International Fertilizer Development Center, 1995). Plants built before 1960 were scattered around the country in areas of high market demand. However, plants built since then are located near natural gas regions of the Delta (Mississippi, Arkansas, and Louisiana) and the Southern Plains (Texas and Oklahoma).

The United States is a net importer of nitrogen. In 1995, the United States exported more than 3 million nutrient tons of nitrogen and imported over 5 million nutrient tons; however, imports are understated because anhydrous ammonia imports from the former Soviet Union are not reported by the Department of Commerce due to a disclosure claim. The major fertilizer import is anhydrous ammonia while the major export is diammonium phosphate, which contains nitrogen.

Nearly all phosphate fertilizer is produced by treating phosphate rock with sulfuric acid to produce phosphoric acid, which is further processed into various phosphatic fertilizer materials such as superphosphates and diammonium phosphates. The United States has become the world's largest phosphate fertilizer exporter. Approximately 3.3 tons of phosphate rock and about 2.8 tons of sulfuric acid are required to produce a ton of phosphate fertilizer. U.S. annual phosphoric acid capacity is over 14 million tons. Phosphate rock is obtained from mines mainly in Florida and North Carolina, with annual capacity estimated at 65 million tons.

Potash can be used as a fertilizer with less processing or refining than nitrogen or phosphate. Most potash deposits in the United States are located near Carlsbad, New Mexico. However, these deposits supply less than 10 percent of U.S. demand. Vast potash deposits in Saskatchewan and New Brunswick, Canada are cheaper to mine than the dwindling U.S. reserves because of the large size, uniformity, and high quality of the Canadian deposits, and the modern mining techniques used. The United States currently imports over 5 million tons of potash and over 95 percent of these imports come from Canada. U.S. and Canadian annual potash capacity is about 1.6 and 13.9 million tons, respectively.

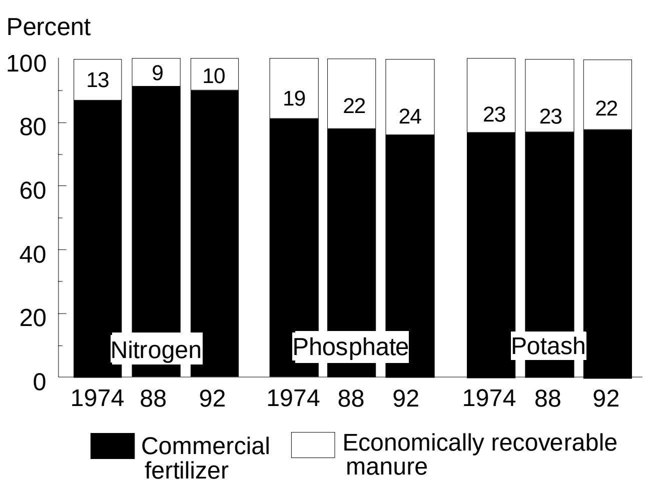
Calcium, magnesium, and sulfur are often added to soils to correct plant conditions such as empty peanut shells due to the failure of fruit to develop, failure of new emerging corn leaves to unfold, yellowing between veins of older leaves, and pale yellow or light green leaves. Applying lime to bring soil pH into proper range for optimum plant growth usually supplies sufficient calcium. Primary sources of calcium are the liming materials and gypsum, which are considered soil amendments rather than fertilizers. The most common source of magnesium is dolomite limestone, which contains up to 12 percent magnesium (Fertilizer Institute, 1982). The main forms of sulfur in soil are inorganic sulfates and sulfur in organic matter. Atmospheric sulfur dioxide had been a major source of sulfur for crops, but as atmospheric emissions of sulfur dioxide are reduced by environmental controls the sulfur needs of crops must be supplied by fertilizer sources. Sulfuric acid, a byproduct in phosphate fertilizer manufacturing, provides an adequate amount of sulfur for many crop needs.

Availability of micronutrients to plants is related to soil pH. Availability of boron, copper, iron, manganese, and zinc generally decrease as soil pH increases from 5 to 7; availability of molybdenum increases. Micronutrients are involved in cell division, photosynthesis, fruit formation, carbohydrate and water metabolism, chlorophyll formation, protein synthesis, and seed development in plants. Micronutrient needs during different stages of plant growth must be better understood by both research scientist and farmer so that appropriate amounts are made available.

Animal Manure

Animal waste is primarily manure, but on some large poultry operations, dead chickens are also a disposal problem and a source of nutrients if properly composted. In recent years, animal wastes have provided 9-24 percent of total nutrients available for crop production (fig. 3.1.2). Actual application of animal wastes as nutrients is less than this (table 3.1.3). Because of transportation costs, use of animal waste as fertilizer is economically feasible only if onfarm or nearby sources exist, and thus occurs on relatively few acres.

Figure 3.1.2--Availability of nutrients for application, 1974, 1988, and 1992



Source: USDA, ERS, based on U.S. EPA, 1979; USDA, unpublished data, 1977; and USDA, 1992.

In 1992, there were 435 million acres of cropland, of which 124 million or 28 percent were operated by farmers having confined animal units. These 511,000 farms had 60.7 million animal units of beef, dairy, swine, turkey, and poultry (Letson and Gollehon, 1996), producing an estimated 1.23, 1.32, and 1.44 million tons of economically recoverable nitrogen (N), phosphate ($P_2 0_5$), and potash ($K_2 0$). Letson and Gollehon (1996) also determined that large specialized animal production farms produce most animals but have little cropland. Facilities with fewer animals produce a minor share of the animals but have a large share of the cropland associated with confined livestock farms. Concentration of increasing numbers of animals on fewer farms has been a long-term trend (see fig.1.2.7 in chapter 1.2, *Land Tenure*). The significance of the shares of animals and acres is emphasized by the fact that around 90 percent of manure does not leave the farm where it is produced (Bosch and Napit, 1992). High-density areas like dairy farms in southern California, beef feedlots in the Southern Plains, large hog operations in the Corn Belt, and the broiler belt across the Delta, Southeast, and Appalachian States provide large quantities of manure that is likely underused as fertilizer. However, some areas have both high manure nutrient densities and high fertilizer spending per acre, suggesting redundant nutrient applications that may be an avoidable farming expense and that could impair water resources (Letson and Gollehon, 1996).

Environmental degradation, particularly of water, can occur from excessive use or improper handling or application of nutrients (Achorn and Broder, 1991; Bosch, Fuglie, and Keim, 1994; Kanwar, Baker, and Baker, 1988; and Kellogg, Maizel, and Goss, 1992: see also chapter 2.2, *Water Quality*). Large livestock operations are already under regulation as point sources of pollution, requiring installation of certain facilities and practices. In many critical areas, USDA is helping smaller livestock operations efficiently manage animal and commercial nutrients to reduce their loss to the environment (for more information, see chapter 4.5, *Nutrient Management*, and chapter 6.2, *Water Quality Programs*).

Municipal and Industrial Wastes

Municipal wastes include municipal solid wastes (MSW) and sewage sludge (SS). America's cities generated 200 million tons of MSW in 1990 (Millner and others, 1993). MSW includes paper and paperboard, glass, metals, plastics, rubber, leather, textile, wood, food wastes, yard trimmings, miscellaneous inorganic wastes, and other residential, institutional, and industrial wastes. The three major methods for MSW disposal in 1990 were land filling (61 percent), recoveries for recycling (17 percent), and incineration (12 percent). SS is collected at municipal wastewater plants. The three major methods of SS disposal in 1988 were land application (36 percent), surface water disposal (10) percent, and incineration (3 percent) (the rest of SS disposal is either not regulated or unknown). Agricultural land application was about 27 percent. A small portion (about 1.2 percent) of SS was used for composting in 1988. The number of municipal wastewater plants producing SS compost increased from 90 in 1983 to 318 in 1994 (Golstein and others, 1994). The outlets for SS compost are public works applications; wholesale marketing to soil blenders, landscapers, and nurseries; and give-away to the public.

The potential for agricultural use of municipal wastes is large, but a number of issues need resolution (see box, "Potential for Agricultural Use of Municipal Wastes," p. 111).

Commercial Fertilizer Use and Product Change, 1960-95

Commercial fertilizer use depends on a variety of factors including soil, climate, feasible technology, weather, crop mix, crop rotations, technological change, government programs, and commodity and fertilizer prices (Denbaly and Vroomen, 1993). Total fertilizer use has fluctuated with planted acreage because application rates and percentage of acres treated have been less variable than planted acreage.

U.S. nitrogen, phosphate, and potash use for all purposes rose from 7.5 million nutrient tons in 1960 to a record 23.7 million tons in 1981 (table 3.1.1). Total nutrient use has dropped from this level, along with total crop acreage, to 21.3 million nutrient tons.

Nitrogen, phosphate, and potash all contributed to the dramatic increase in fertilizer use during the 1960's and 1970's (table 3.1.1, fig. 3.1.3), although nitrogen use increased most rapidly. In 1960, nitrogen use was about 37 percent of total commercial nutrient use; by 1981, nitrogen use had increased 335 percent and represented over 50 percent of total commercial nutrient use. Nitrogen use equaled 11.7 million tons in 1995, or 55.2 percent of total commercial nutrient use. This relative gain in nitrogen use is the result of

Table 3.1.1—U.S. commercial fertilizer use, 1960-95[1]

Year ending June 30[2]	Total fertilizer mate-rials3	Primary nutrient use			
		Nitrogen (N)	Phosphate (P_2O_5)	Potash (K_2O)	Total[4]
		Million tons			
1960	24.9	2.7	2.6	2.2	7.5
1961	25.6	3.0	2.6	2.2	7.8
1962	26.6	3.4	2.8	2.3	8.4
1963	28.8	3.9	3.1	2.5	9.5
1964	30.7	4.4	3.4	2.7	10.5
1965	31.8	4.6	3.5	2.8	10.9
1966	34.5	5.3	3.9	3.2	12.4
1967	37.1	6.0	4.3	3.6	14.0
1968	38.7	6.8	4.4	3.8	15.0
1969	38.9	6.9	4.7	3.9	15.5
1970	39.6	7.5	4.6	4.0	16.1
1971	41.1	8.1	4.8	4.2	17.2
1972	41.2	8.0	4.9	4.3	17.2
1973	43.3	8.3	5.1	4.6	18.0
1974	47.1	9.2	5.1	5.1	19.3
1975	42.5	8.6	4.5	4.4	17.6
1976	49.2	10.4	5.2	5.2	20.8
1977	51.6	10.6	5.6	5.8	22.1
1978	47.5	10.0	5.1	5.5	20.6
1979	51.5	10.7	5.6	6.2	22.6
1980	52.8	11.4	5.4	6.2	23.1
1981	54.0	11.9	5.4	6.3	23.7
1982	48.7	11.0	4.8	5.6	21.4
1983	41.8	9.1	4.1	4.8	18.1
1984	50.1	11.1	4.9	5.8	21.8
1985	49.1	11.5	4.7	5.6	21.7
1986	44.1	10.4	4.2	5.1	19.7
1987	43.0	10.2	4.0	4.8	19.1
1988	44.5	10.5	4.1	5.0	19.6
1989	44.9	10.6	4.1	4.8	19.6
1990	47.7	11.1	4.3	5.2	20.6
1991	47.3	11.3	4.2	5.0	20.5
1992	48.8	11.5	4.2	5.0	20.7
1993	49.2	11.4	4.4	5.1	20.9
1994	52.3	12.6	4.5	5.3	22.4
1995	50.7	11.7	4.4	5.1	21.3

[1] Includes Puerto Rico. Detailed State data shown in USDA, 1995. Fertilizer statistics used in this report include commercial fertilizers and natural processed and dried organic materials. Purchased natural processed and dried organic materials historically have represented about 1 percent of total nutrient use.

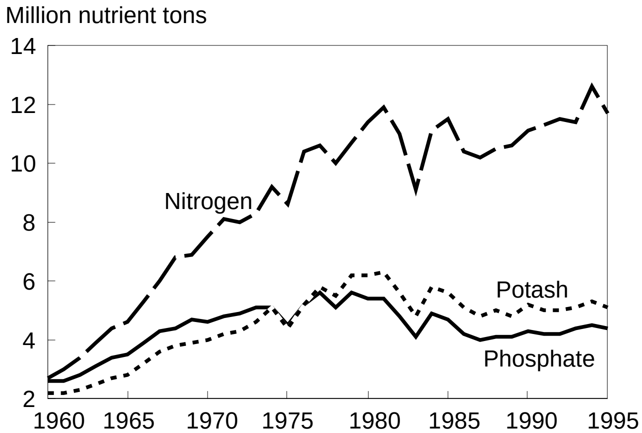
[2] Fertilizer use estimates for 1960-84 are based on USDA data; those for 1985-94 are Tennessee Valley Authority (TVA) estimates; those for 1995 are the Association of American Plant Food Control Officials estimates.

[3] Includes secondary and micronutrients. Most of the difference between primary nutrient tons and total fertilizer materials is filler material.

[4] Totals may not add due to rounding.

Source: USDA, ERS, based on Tennessee Valley Authority, *Commercial Fertilizers*, 1994 and earlier issues; USDA, *Commercial Fertilizers*, 1985 and earlier issues; Association of American Plant Food Control Officials, *Commercial Fertilizers, 1995.*

Figure 3.1.3--U.S. commercial fertilizer use, 1960-95



Source: Compiled by ERS from Tennessee Valley Authority, 1994 and earlier issues; Association of American Plant Food Control Officials, 1995.

increased farmer demand stemming primarily from favorable crop yield responses, especially corn, to nitrogenous fertilizers.

Phosphate's share of total commercial nutrient use declined from 34.5 percent in 1960 to 20.8 percent by 1995 (table 3.1.1). Potash use, historically below that of both nitrogen and phosphate, exceeded phosphate use for the first time in 1977 and will likely hold this position. In 1995, potash accounted for 24.0 percent of total fertilizer use.

Fertilizer products have changed over time. In 1960, mixed fertilizers (containing two or more nutrients) constituted almost 63 percent of total fertilizer consumption (Vroomen and Taylor, 1992). This share declined to 37 percent in 1995. The share of direct application materials (containing primarily one nutrient) increased from 37 percent to 63 percent during this period. The use of major direct-application nitrogen materials increased through the early 1980's (Fertilizer Institute, 1982). High-analysis products such as anhydrous ammonia, nitrogen solutions, and urea benefited from economies in transportation, distribution, and storage, and from the ease and accuracy of applying nitrogen solutions.

Directly applied phosphate fertilizer products have declined since the early 1970's because of the increased use of diammonium phosphate (DAP). The trend throughout the 1960's and 1970's was toward increased use of triple superphosphates (products that contained a higher percentage of phosphate) relative to normal superphosphates because of transportation, distribution, and storage economies. Since 1979, consumption of both normal and triple superphosphate has declined. The use of DAP, a mixed fertilizer containing 18 percent nitrogen and 46 percent phosphate, has dramatically increased since the 1960's (Tennessee Valley Authority, 1994).

The use of potassium chloride, the major directly applied potash fertilizer containing about 60 percent potash, has also greatly increased since the 1960's. Total use of potassium chloride reached 5.4 million tons in 1995, up from 389,000 tons in 1960.

Fertilizer Use by Region and Crop

The Corn Belt (Ohio, Indiana, Illinois, Iowa, and Missouri) uses more commercial fertilizer than any other region (table 3.1.2). Corn, the most fertilizer-using crop, historically has used around 45 percent of all fertilizer. However, from 1985 to 1993 nitrogen use in the Corn Belt decreased from 3.4 to 3.0 million tons, but then increased to 3.5 million tons in 1994 following the 1993 flood. Nitrogen use in the Corn Belt equaled 3.2 million tons in 1995. Phosphate use decreased from 1.5 million tons in 1985 to 1.3 million tons in 1995 and potash use decreased from 2.3 to 2.0 million tons. Fertilizer use is highly dependent on soil type and condition, crop mix, planting methods, and planted acres (Meisinger, 1984: Nelson and Huber, 1987: Mengel, 1986: Pierce and others, 1991: Rhoads, 1991: and Scharf and Alley, 1988). Fewer crop acres have been planted in the Corn Belt since 1981 because of government programs such as the Acreage Reduction Program (ARP) and the Conservation Reserve Program (CRP). Thus, total fertilizer use in the Corn Belt has declined even though application rates per fertilized acre and the proportion of acres treated have increased since the early 1980's. In the areas flooded in 1993, additional nutrients were applied in 1994 in excess of normal application rates to replenish flood-damaged soils. The Northern Plains region (North Dakota, South Dakota, Nebraska, and Kansas) is the second highest user of nitrogen and phosphate; nitrogen use increased from 1.8 million tons in 1985 to 2.1 million tons in 1995 (table 3.1.2).

Fertilizer use among crops differs significantly (Vroomen and Taylor, 1992; USDA, 1995). U.S. farmers use more commercial fertilizer on corn than on any other crop. Nearly all acres in corn, fall potatoes, and rice, and over three-fourths of cotton and wheat acres received some form of commercial fertilizer (table 3.1.3). The most frequently applied nutrient was nitrogen. In contrast, only 27-36 percent

Table 3.1.2—Regional commercial fertilizer use for year ending June 30, 1985-95[1]

Region	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
						1,000 tons					
Nitrogen:											
Northeast	312	278	290	278	313	306	299	328	350	376	349
Lake States	1,211	1,059	1,063	1,053	1,011	1,134	1,128	1,119	1,073	1,186	1,108
Corn Belt	3,443	3,116	2,889	2,991	3,041	3,215	3,280	3,279	3,003	3,562	3,228
Northern Plains	1,837	1,739	1,698	1,737	1,680	1,751	1,978	1,954	2,090	2,319	2,133
Appalachian	687	621	603	592	613	667	662	718	705	720	694
Southeast	720	659	665	614	643	670	627	655	682	701	640
Delta States	548	557	511	523	560	643	609	674	615	663	630
Southern Plains	1,110	965	1,022	1,204	1,217	1,117	1,223	1,192	1,235	1,377	1,208
Mountain	626	557	573	583	626	642	628	666	744	775	765
Pacific	987	860	882	924	916	921	838	849	886	953	953
U.S. total[2]	11,480	10,412	10,196	10,498	10,619	11,065	11,273	11,432	11,382	12,633	11,709
Phosphate:											
Northeast	229	196	203	193	188	197	188	208	211	232	203
Lake States	612	509	493	505	477	508	479	468	474	465	461
Corn Belt	1,478	1,380	1,255	1,303	1,254	1,334	1,262	1,269	1,312	1,317	1,257
Northern Plains	521	498	468	486	522	550	583	577	646	649	617
Appalachian	422	378	378	370	361	381	384	409	410	412	399
Southeast	331	288	300	280	297	308	281	295	314	297	313
Delta States	180	164	132	153	154	177	154	180	172	192	197
Southern Plains	364	298	305	324	342	315	334	288	340	363	341
Mountain	232	213	218	228	253	279	255	270	296	298	300
Pacific	288	250	250	281	270	289	274	248	257	291	326
U.S. total[2]	4,652	4,173	4,003	4,123	4,119	4,339	4,195	4,212	4,431	4,517	4,412
Potash:											
Northeast	288	263	253	249	232	261	262	267	262	299	280
Lake States	1,048	871	912	852	852	941	832	809	779	781	760
Corn Belt	2,264	2,165	2,020	2,126	1,974	2,132	2,044	1,987	2,034	2,133	1,996
Northern Plains	126	115	100	121	129	133	134	123	134	123	124
Appalachian	585	532	508	506	506	538	539	584	575	576	574
Southeast	607	542	524	531	558	559	517	556	581	535	563
Delta States	243	225	184	217	212	240	229	280	288	302	336
Southern Plains	169	142	133	140	149	143	150	146	168	191	168
Mountain	54	49	44	46	53	65	80	55	80	68	79
Pacific	157	137	146	171	155	179	200	220	230	252	231
U.S. total[2]	5,541	5,040	4,824	4,960	4,820	5,192	4,988	5,026	5,131	5,259	5,112

[1] Totals may not add due to rounding. Northeast = ME, NH, VT, MA, RI, CT, NY, NJ, PA, DE, and MD; Lake States = MI, WI, and MN; Corn Belt = OH, IN, IL, IA, and MO; Northern Plains = ND, SD, NE, and KS; Appalachian = VA, WV, NC, KY, and TN; Southeast = SC, GA, FL, and AL; Delta States = MS, AR, and LA; Southern Plains = OK, and TX; Mountain = MT, ID, WY, CO, NM, AZ, UT, and NV; and Pacific = WA, OR, CA, AK, and HA.

[2] Excludes Puerto Rico. Detailed State data shown in USDA, 1995.

Source: USDA, ERS, based on Tennessee Valley Authority, *Commercial Fertilizers*, 1994 and earlier issues; The Association of American Plant Food Control Officials, *Commercial Fertilizers, 1995*.

of the acres in soybeans, a nitrogen-fixing crop, received commercial fertilizer applications in 1995. Nitrogen application rates have been highest for fall potatoes, averaging 221 lbs. per acre in 1995, followed by corn (table 3.1.4). Fall potatoes also have the highest rate of both phosphate and potash applications, two to three times the rates for other major field crops. Nitrogen application rates on corn dropped from 132 lbs. per acre in 1986 to 129 lbs. per acre in 1995. In contrast, the average application rates increased for fall potatoes. The percentage of various crops receiving fertilizer, and fertilizer application rates, vary among the major growing States (USDA, 1995).

Table 3.1.3—Percent of acres receiving various nutrients, selected field crops in major producing States[1]

Crop, year	Manure	Commercial				Sulfur	Lime	Micro-nutrients
		Fertilizer	Nitrogen	Phosphate	Potash			
				Percent				
Corn for grain (10 States):								
1986	NA	96	95	84	76	NA	NA	NA
1987	16	96	96	83	75	3	2	5
1988	18	97	97	87	78	10	6	11
1989	15	97	97	84	75	8	5	11
1990	17	97	97	85	77	9	6	11
1991	19	97	97	82	73	10	4	11
1992	16	97	97	82	72	11	4	12
1993	18	97	97	82	71	10	4	11
1994	16	97	97	83	72	10	5	11
1995	14	98	97	81	72	NA	NA	NA
Cotton (6 States):								
1986	NA	80	80	50	39	NA	NA	NA
1987	3	76	76	47	33	7	1	9
1988	4	80	80	54	32	15	2	18
1989	2	79	79	54	32	21	2	15
1990	4	80	79	49	31	23	2	17
1991	3	81	81	52	34	20	2	18
1992	3	80	80	48	37	22	1	18
1993	4	85	85	54	36	23	3	18
1994	3	87	86	54	37	20	4	20
1995	3	87	87	56	40	NA	NA	NA
Fall potatoes (11 States):								
1989	4	99	98	94	83	48	7	52
1990	5	99	98	98	89	48	7	50
1991	4	99	99	98	88	52	4	56
1992	3	100	100	99	88	57	6	57
1993	4	100	100	98	91	58	6	58
1994	2	100	100	98	91	58	6	59
1995	2	100	99	98	89	NA	NA	NA
Rice (2 States):								
1988	1	99	99	46	36	7	NA	17
1989	*	99	99	46	33	5	NA	13
1990	*	98	97	36	37	13	1	14
1991	2	99	99	30	32	NA	2	11
1992	3	98	98	34	37	10	NA	9
Soybeans, Northern (7 States):								
1990	7	27	14	20	25	1	4	2
1991	6	26	14	19	22	1	4	2
1992	7	27	13	19	23	1	4	2
1993	7	26	12	18	24	1	4	2
1994	8	27	13	19	25	2	4	3
1995	5	27	16	19	23	NA	NA	NA
Soybeans, Southern (7 States):								
1990	2	41	26	38	39	4	6	5
1991	3	37	21	33	35	1	6	3
1992	2	39	22	36	37	2	8	1
1993	2	38	22	34	36	1	6	2
1994 (AR only)	2	37	17	32	34	1	4	2
1995	2	36	21	31	33	NA	NA	NA
All wheat (15 States):								
1986	NA	79	79	48	19	NA	NA	NA
1987	3	80	80	50	15	7	1	1
1988	2	83		83	53	18	6	1
1989	3	81	81	53	18	7	1	2
1990	2	79	79	52	19	7	1	2
1991	4	80	80	54	20	7	1	1
1992	3	84	83	56	18	8	1	2
1993	3	87	86	60	17	9	1	2
1994	3	87	87	59	17	10	1	2
1995	2	87	87	63	18	NA	NA	NA

Table 3.1.4—Average application rates of nutrients on selected field crops in major producing States[1]

Crop, year	Commercial nitrogen	Commercial phosphate	Commercial potash	Sulfur	Lime
	Pounds/acre				*Tons/acre*
Corn for grain (10 States):					
1986	132	61	80	NA	NA
1987	132	61	85	NA	NA
1988	137	63	85	11	1.9
1989	131	59	81	9	1.4
1990	132	60	84	11	1.6
1991	128	60	81	11	1.7
1992	127	57	79	11	1.9
1993	123	56	79	15	1.7
1994	129	57	80	12	1.7
1995	129	56	81	NA	NA
Cotton (6 States):					
1986	77	44	50	NA	NA
1987	82	44	45	NA	NA
1988	78	42	39	10	1.5
1989	84	43	40	23	1.3
1990	86	44	47	10	1.0
1991	91	47	48	12	1.0
1992	88	48	57	13	1.4
1993	89	47	58	13	1.0
1994	110	43	55	13	1.1
1995	95	43	51	NA	NA
Fall potatoes (11 States):					
1989	192	157	155	61	1.0
1990	198	163	143	57	0.9
1991	195	158	143	59	0.9
1992	200	159	147	61	0.9
1993	206	167	156	68	1.0
1994	264	192	184	82	0.9
1995	221	171	170	NA	NA
Rice (2 States):					
1988	127	47	50	19	NA
1989	125	45	45	17	NA
1990	114	45	49	11	1.0
1991	127	46	47	15	NA
1992	134	44	50	18	NA
Soybeans, Northern (7 States):					
1990	22	47	87	9	1.6
1991	24	49	80	12	2.0
1992	20	46	76	10	2.0
1993	18	47	83	15	1.5
1994	24	46	83	13	1.8
1995	27	55	91	NA	NA
Soybeans, Southern (7 States):					
1990	28	47	70	20	1.1
1991	28	45	70	12	1.2
1992	27	49	74	9	1.0
1993	24	44	70	22	0.9
1994 (AR only)	34	48	66	NA	1.3
1995	37	51	68	NA	NA
All wheat (15 States):					
1986	60	36	44	NA	NA
1987	62	35	43	NA	NA
1988	64	37	52	12	2.2
1989	62	37	46	12	1.9
1990	59	36	44	9	1.8
1991	62	36	43	11	1.4
1992	63	34	39	13	1.4
1993	64	34	35	14	1.7
1994	67	35	38	11	1.7
1995	65	33	38	NA	NA

[1] Data not available for manure or micronutrients. Major producing States generally account for 70-90 percent of each crop's acreage. For States included, see "Cropping Practices Survey" in the appendix. NA = Not available. Source: USDA, ERS, based on Cropping Practices Survey data.

Table 3.1.5—Manure and commercial fertilizer use by tillage type on corn for grain, 10 major States, 1990-95[1]

Crop, year	Acres receiving				Average application rates		
	Manure	Commercial nitrogen	Commercial phosphate	Commercial potash	Commercial nitrogen	Commercial phosphate	Commercial potash
	Percent				*Pounds/acre*		
Conventional with plow							
1990	32	94	87	83	109	57	81
1991	35	94	85	79	106	56	77
1992	37	93	84	79	106	51	73
1993	39	95	89	84	95	54	76
1994	39	92	85	80	97	49	70
1995	38	93	83	71	96	50	66
Conventional without plow							
1990	14	97	85	78	138	61	84
1991	16	97	83	75	132	63	83
1992	15	97	84	74	129	58	81
1993	18	97	84	74	127	59	85
1994	16	97	84	74	133	60	84
1995	15	98	81	81	132	59	84
Mulch till							
1990	16	96	81	72	134	64	87
1991	18	97	78	68	130	59	78
1992	12	96	80	69	133	58	81
1993	15	96	81	68	122	57	75
1994	13	98	83	70	129	58	79
1995	14	97	83	70	134	57	75
No till							
1990	7	98	82	65	132	62	90
1991	10	98	81	67	129	59	84
1992	10	98	78	68	127	57	77
1993	10	98	83	73	122	50	71
1994	9	98	79	67	132	56	80
1995	8	98	79	65	134	56	76
Ridge till							
1990	20	100	96	49	145	32	52
1991	7	100	70	36	155	47	52
1992	6	99	96	33	143	41	50
1993	10	97	78	27	149	29	36
1994	2	99	78	38	142	37	57
1995	0	100	72	36	161	29	49

[1] States include IL, IN, IA, MI, MN, MO, NE, OH, SD, and WI.
Source: USDA, ERS, based on Cropping Practices Survey data.

The percentage of and quantity of crop acres receiving lime, sulfur, and micronutrients vary by crop (tables 3.1.3 and 3.1.4). For example, only about 1 percent of wheat acres received lime in 1994, while about 4 percent of northern soybeans and 6 percent of fall potatoes used lime. Lime application rates average between 1 and 2 tons per acre for all crops. Almost 60 percent of potato acres received an average of 82 pounds of sulfur in 1994. Other crops received between 11 and 18 pounds per acre with acres receiving sulfur ranging from 1 to 20 percent. Over 50 percent of potato acres received micronutrients.

Fertilizer use also varies by tillage system (tables 3.1.5-3.1.7). The Cropping Practices Survey data indicate lower nitrogen application rates on land using conventional tillage with plow for corn. These low applications appear to be supplemented with manure. For example, the average nitrogen application rate on

Table 3.1.6—Manure and commercial fertilizer use by tillage type on soybeans, 7 Northern States, 1990-95[1]

Crop, year	Acres receiving				Average application rates		
	Manure	Commercial nitrogen	Commercial phosphate	Commercial potash	Commercial nitrogen	Commercial phosphate	Commercial potash
	Percent				*Pounds/acre*		
Conventional with plow							
1990	8	13	18	25	15	39	87
1991	10	14	18	20	31	53	86
1992	10	14	20	22	13	37	67
1993	9	12	17	22	13	43	82
1994	9	13	18	22	19	38	78
1995	3	16	14	14	11	53	80
Conventional without plow							
1990	7	16	23	28	24	50	83
1991	5	16	21	25	22	48	80
1992	5	13	22	26	18	46	75
1993	7	15	23	29	18	45	81
1994	9	13	20	25	26	44	78
1995	6	16	21	26	31	60	86
Mulch till							
1990	5	11	14	17	19	47	81
1991	6	13	15	17	23	46	76
1992	9	11	14	17	26	49	78
1993	7	9	12	16	15	44	84
1994	9	9	15	18	28	52	89
1995	7	13	14	16	27	57	92
No till							
1990	4	18	27	42	38	53	109
1991	4	11	18	24	28	56	89
1992	9	15	21	30	20	50	85
1993	5	13	22	31	20	52	87
1994	7	15	24	32	20	48	88
1995	3	18	23	29	26	51	97
Ridge till							
1990	20	12	21	30	19	48	109
1991	3	30	36	27	11	39	42
1992	8	26	21	18	26	16	5
1993	0	29	17	21	17	34	54
1994	0	36	31	27	10	20	43
1995	12	21	21	21	16	44	34

[1] Northern States include IL, IN, IA, MN, MO, NE, and OH.
Source: USDA, ERS, based on Cropping Practices Survey data.

corn acreage using conventional tillage with plow was 96 pounds per acre in 1995 compared with, say, 161 pounds for ridge-till land (table 3.1.5). However, 38 percent of conventional-till land using the moldboard plow received manure applications, compared with none for ridge-till.

Factors Affecting Fertilizer Use

Crop Acreage

As indicated, with application rates fairly constant, the total amount of fertilizer used has varied with crop acreage. Acreage of principal crops has varied over the years, ranging from 300 million acres in 1970 to 372 million acres in 1981. Since then, acreage has

Table 3.1.7—Manure and commercial fertilizer use by tillage type on winter wheat, major States, 1991-95[1]

Crop, year	Acres receiving				Average application rates		
	Manure	Commercial nitrogen	Commercial phosphate	Commercial potash	Commercial nitrogen	Commercial phosphate	Commercial potash
	Percent				*Pounds/acre*		
Conventional with plow							
1991	1	97	55	15	65	33	38
1992	2	94	53	13	74	34	37
1993	2	92	48	17	69	41	38
1994	1	95	63	10	63	34	61
1995	4	93	70	10	63	33	52
Conventional without plow							
1991	4	85	49	23	67	40	54
1992	3	87	49	22	67	38	49
1993	2	86	49	17	64	36	46
1994	2	87	49	13	66	37	49
1995	2	87	53	15	69	36	45
Mulch till							
1991	3	73	42	18	55	41	52
1992	1	71	36	16	51	33	39
1993	2	82	32	10	52	36	32
1994	4	67	25	9	55	31	43
1995	4	75	35	7	54	33	54
No till							
1991	6	84	70	48	71	48	75
1992	4	96	83	54	75	49	65
1993	3	95	82	59	80	49	67
1994	2	98	83	58	83	50	65
1995	2	93	76	52	79	56	69
Ridge till							
1991	nr	nr	nr	nr	nr	nr	nr
1992	nr	nr	nr	nr	nr	nr	nr
1993	nr	nr	nr	nr	nr	nr	nr
1994	nr	nr	nr	nr	nr	nr	nr
1995	nr	nr	nr	nr	nr	nr	nr

nr = none reported.
[1] States include AR, CO, ID, IL, IN, KS, MO, MT, NE, OH, OK, OR, SD, TX, and WA in 1991 and 1992. AR and IN not surveyed in 1993-95.
Source: USDA, ERS, based on Cropping Practices Survey data.

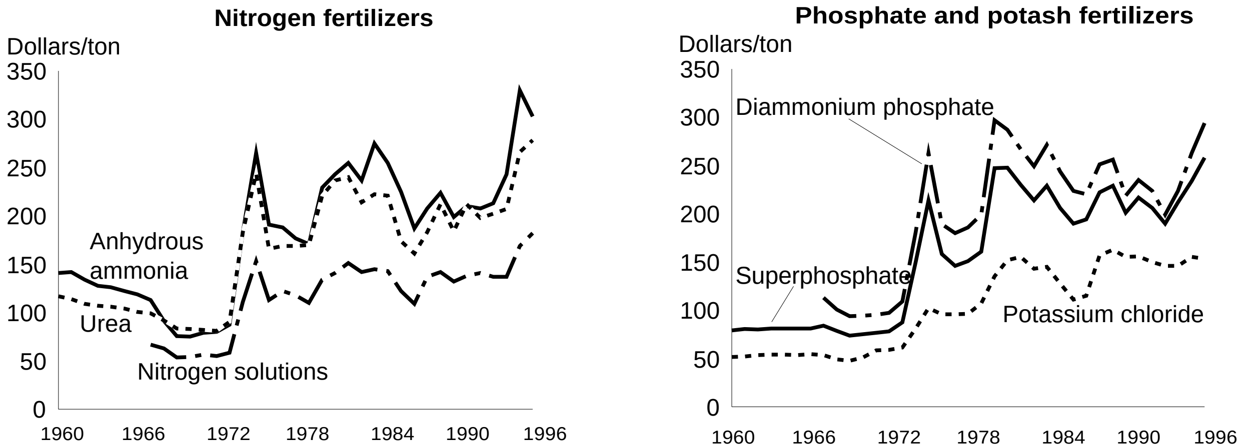
varied between 315 million and 340 million acres. In 1994, acreage of principal crops planted equaled 324 million acres.

Acreage and crop mix planted is dependent on many factors, including government programs, weather, expected commodity prices, input costs, and export market. Acres planted to corn and wheat greatly affect fertilizer use and prices. Corn is the most fertilizer-using crop, accounting for over 45 percent of all use, while wheat is second at 16 percent. Planted corn acreage has ranged from 60 to 85 million acres over the past 30 years and planted wheat acreage has ranged from 53 to 88 million acres. In 1994, approximately 79 and 70 million acres were planted to corn and wheat. To the extent that CRP and ARP acreage comes back into production as a result of contract expiration and higher crop prices, nutrient use could expand.

Fertilizer Prices

Fertilizer use in the United States has historically been inversely related but relatively unresponsive to changes in fertilizer prices, particularly in the short run. Analyses have found elasticities (the percentage change in fertilizer use per percentage change in fertilizer price) to run upwards from -0.19 in the short run and from -0.31 in the long run (after farmers have

Figure 3.1.4--Average farm prices of selected fertilizers, 1960-96



Source: USDA, ERS, based on USDA, NASS 1996 and earlier issues. See also table 3.1.8.

had adequate time to adjust operations) (Griliches, 1958; Denbaly and Vroomen, 1993). In some major Corn Belt States, the elasticities may be even less. One analysis of Indiana and Illinois data—using a model that allowed short- and long-run substitution among agricultural inputs (hired labor, feeds, seeds, fertilizer, pesticides, fuels, and capital) and that included a weather index—found elasticities of about -0.07 for corn both in the short and in the long run (Fernandez-Cornejo, 1993).

Individual fertilizer product prices vary from year to year and substitution among products within nutrient groups does occur. Annual price changes among products can result in different combinations of products used by farmers from year to year.

Fertilizer purchases have historically represented about 6 percent of total farm production costs. Total expenditures on fertilizer by U.S. farmers in 1994 are estimated at $9.1 billion, up 9 percent over 1993. The increase in expenditures is a combination of increased fertilizer prices, increased planted corn acres, and increased application rates over 1993. With current fertilizer prices, 1996 expenditures were likely to have exceeded those of 1994 and 1995.

Throughout the 1960's, prices paid by farmers for most fertilizer products declined as growth in industry capacity exceeded growth in demand (table 3.1.8, fig. 3.1.4). Economic Stabilization Program regulations froze all prices in 1971 to control inflation, including fertilizer prices at the producer level (USDA, 1971-81). Prices were controlled in domestic markets but exported materials were not subject to price regulation. Demand for U.S. fertilizer in strong-currency countries increased as the dollar weakened resulting in a two-price system for U.S. fertilizer, with export prices much higher than domestic prices. With the end of government control in 1973, domestic fertilizer prices increased over 60 percent and equaled world prices.

Decontrol and the oil embargo brought sharp increases in fertilizer prices. By the spring of 1975, farm prices of most fertilizer materials had doubled from 1973. High prices reduced the quantity demanded, causing fertilizer manufacturers' inventories to increase in 1976. Consequently, farm fertilizer prices fell. Prices began to rise again in 1979 following another oil embargo and as a result of strong domestic and export demand and rapidly rising production, transportation, and retailing costs. Rising energy prices in particular were instrumental in increasing production costs, especially for nitrogen products. Prices of most fertilizer products increased in 1980 and 1981 and held steady in 1982.

Fertilizer prices have changed less than other agricultural inputs during the last 10 years. For example, nominal prices farmers paid for fertilizers increased 18 percent from 1984 to 1995 while wage rates went up 51 percent, farm machinery increased 40 percent, agricultural chemicals other than fertilizers increased 28 percent, and seeds went up 16 percent.

Farm fertilizer prices fell during 1983 and again in 1985/86 as a record level of crop acreage was diverted, first by the payment-in-kind program (PIK)

Table 3.1.8—Average U.S. farm prices of selected fertilizers, 1960-96

Year[1]	Anhydrous ammonia (82% nitrogen)	Nitrogen solutions (30% nitrogen)	Urea (45-46% nitrogen)	Ammonium nitrate (33% nitrogen)	Ammonium sulfate (21% nitrogen)	Super-phosphate (20% phosphate)	Super-phosphate (44-46% phosphate)	Diammonium phosphate (18 percent nitrogen, 46 percent phosphate)	Potassium chloride (60% potassium)
	Dollars per ton								
1960	141	NA	117	82	58	38	79	NA	51
1961	142	NA	114	83	58	38	81	NA	52
1962	134	NA	109	82	57	38	80	NA	53
1963	128	NA	107	81	52	41	81	NA	54
1964	126	NA	106	80	53	40	81	NA	54
1965	122	NA	104	79	53	41	81	NA	54
1966	119	NA	101	77	53	41	81	NA	55
1967	113	67	99	74	54	42	84	113	54
1968	91	63	92	68	54	43	78	101	49
1969	76	54	84	62	53	44	74	94	48
1970	75	54	83	60	52	45	75	94	51
1971	79	56	82	63	52	48	77	96	58
1972	80	55	81	65	52	50	78	97	59
1973	88	58	90	71	55	54	88	109	62
1974	183	111	183	139	110	91	150	181	81
1975	265	153	244	186	148	118	214	263	102
1976	191	113	166	135	98	95	158	189	96
1977	188	122	169	141	101	99	146	180	96
1978	177	118	169	140	109	104	151	186	96
1979	171	110	170	138	118	109	161	199	107
1980	229	134	221	165	138	128	247	297	135
1981	243	141	237	185	150	134	248	287	152
1982	255	151	240	195	165	NA	230	267	155
1983	237	142	214	185	149	NA	214	249	143
1984	275	145	222	198	150	NA	229	271	145
1985	255	143	221	192	156	NA	206	244	128
1986	225	122	174	171	149	NA	190	224	111
1987	187	109	161	157	144	NA	194	220	115
1988	208	137	183	166	140	NA	222	251	157
1989	224	142	212	189	154	NA	229	256	163
1990	199	132	184	180	154	NA	201	219	155
1991	210	138	212	184	151	NA	217	235	156
1992	208	141	198	178	151	NA	206	224	150
1993	213	137	202	186	157	NA	190	199	146
1994	243	137	207	196	170	NA	212	224	146
1995	330	169	266	223	182	NA	234	263	155
1996	303	182	278	233	184	NA	258	294	153

NA = Not available.

[1] April prices for 1960-76, 1986-96; all other prices are for March.

Source: USDA, ERS, based on USDA, NASS, *Agricultural Prices*, 1961-96.

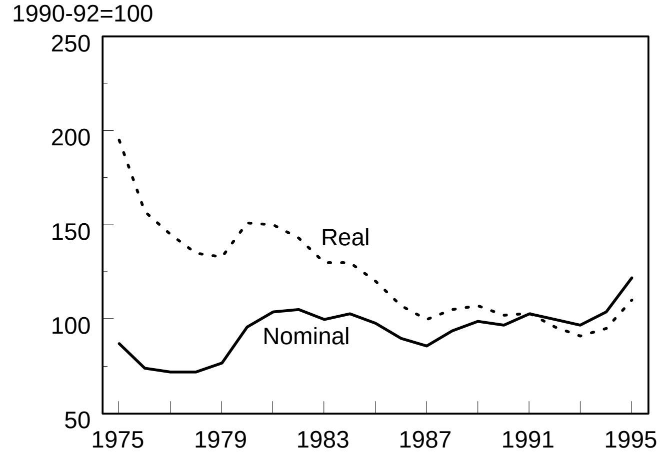
and later by the ARP and CRP programs and excess supplies (Vroomen and Taylor, 1992). Prices rose steadily from 1986 to 1989. Prices of most fertilizer materials have fallen from 1989 levels, but remained relatively stable through 1992 (Taylor, 1994). Prices paid by farmers for fertilizer in 1994-96 increased over 1993 prices due to increased planted acres and other market conditions.

The prices U.S. farmers currently pay for many fertilizer materials have risen significantly since 1993. For example, the price of anhydrous ammonia increased 64 percent from October 1993 to April 1995 to a record high of $330 per ton. Diammonium phosphate's price increased 37 percent over this time period. Other fertilizer products also increased, but not as much. Real fertilizer prices (fertilizer price index adjusted by the implicit price deflator of the United States) have declined from an index of 195 in 1975 to 110 in 1995 using 1990-92 as a base (fig. 3.1.5). In constant dollars, farmers paid 44 percent less for fertilizer in 1995 than they did in 1975.

The increase in fertilizer prices since 1993 is a result of tight world supplies and increased demand. For example, anhydrous ammonia use increased 26 percent from 1993 to 1994, and total nitrogen use increased over 11 percent due to an increase in corn acres (corn uses about 45 percent of all fertilizer). Increases in planted acres of soybeans, cotton, and rice also contributed to an increased demand for fertilizer. Nitrogen application rates on corn increased from 123 to 129 pounds per acre in 1994-95 following the 1993 flood; phosphate and potash application rates also increased. In addition, weather conditions were ideal for the direct application of anhydrous ammonia. There was also an increase in nonagricultural demand for nitrogen in products such as adhesives, plastics, resins, and rubber. During 1995, U.S. fertilizer exports increased over 1994 because of China's increased demand for diammonium phosphate and other fertilizer products.

On the supply side, several factors placed upward pressure on fertilizer prices during 1994 and 1995, including higher priced imports from the former Soviet Union, unscheduled repairs that caused plant closings, low inventories, and an explosion that temporarily closed a large nitrogen production plant. The United States is a net importer of ammonia. Since 1990, U.S. ammonia demand has exceeded U.S. supplies while nitrogen plants have been producing in excess of 100 percent capacity. These factors have occurred during a period in which both agricultural and industrial demands have been growing and ammonium phosphate exports have risen.

Figure 3.1.5--Index of prices paid by farmers for fertilizer



Source: USDA, ERS, based on USDA, NASS 1995 and earlier issues.

Commodity Programs

Commodity programs can directly influence fertilizer use through planted acreage or application rates. The U.S. Government supported crop prices for over half a century by lending farmers money at varying loan rates, using crops as collateral and guaranteeing minimum crop prices (target prices set by law). When market prices of commodity program crops were lower than target prices, participating farmers could receive from the Government deficiency payments for crops planted to base acreage. Deficiency payments were the difference between the target price and the higher of the loan rate or average market price. Participation in commodity programs provided farmers with a more stable farm economy over time; however, participation also required some land to be idled (CRP and ARP programs). Data from the 1991 and 1992 Cropping Practices Survey were analyzed to determine if economic incentives from participation in commodity programs caused program participants to apply fertilizers at greater rates than nonparticipants (Ribaudo and Shoemaker, 1995). Fertilizer and agricultural chemical use between corn grower program participants and nonparticipants were analyzed. The results of that study suggest that economic conditions created by commodity programs increased fertilizer application rates on corn. Future fertilizer use is uncertain. If farm and trade policy continues to provide farmers with more acreage flexibility and freer market

Potential for Agricultural Use of Municipal Wastes

Many urban areas in the United States have an urgent need for a long-term environmentally safe method for recycling and disposal of municipal wastes. Currently the number of landfills is limited and new landfills that meet EPA standards for protecting the environment are costly. Municipal wastes contain nutrients and organic matter and other soil conditioners that can be used for agriculture which could mitigate urban waste disposal problems and their economic costs. The fertilizer-equivalent value to U.S. farmers of municipal solid wastes (MSW) is about $378 million and sewage sludge (SS) is about $72 million. Nutrients from the wastes could reduce dependence on commercial fertilizer from limited supplies of mineral and energy resources. Wastes are being used in the horticultural industry; greater use in agriculture would contribute to the long-term sustainability of agricultural production.

One promising way to use municipal wastes is through composting, a microbiological process that partially decomposes organic wastes through the growth and activity of bacteria, actinomycete, and fungi that are indigenous to the organic wastes. The process reduces the weight and volume of the waste while abating odors, destroying pathogens, and converting nutrients to more plant available forms.

Issues

Technical, economic, and public perception issues hinder agricultural use of municipal wastes. Research is underway to provide better information. Technical issues to be resolved include: (1) uncertainty about the quality of municipal wastes because of heterogeneity and range in chemical and physical characteristics of wastes; (2) concern about the fate and effects of trace elements, synthetic organics and pathogens in wastes on soils, plants, animals and humans; (3) uncertainty about application methods and levels of waste applied to agricultural or horticultural production systems to minimize damage to the environment, such as the accumulation of non-nutrient heavy metals in soils; and (4) inadequate information on blending, mixing, or co-composting different wastes to produce final products with desirable characteristics for agricultural or horticultural use.

Economic issues include: (1) uncertainty about the fertilizer equivalent and soil-conditioning value of municipal wastes; (2) economic application to land; (3) the extent to which municipalities may need to subsidize waste transportation expenses to make its use economically feasible in agricultural production. Public perception issues include the need to show that agricultural use of municipal wastes is environmentally safe and does not pose a human health risk.

Sources: USDA, ERS, based on ARS, 1993; Goldstein and others, 1994; and EPA, 1993.

conditions, fertilizer use could increase as more acres come into production. At the same time, possible declines in commodity prices could reduce the demand for fertilizer.

Increased Nutrient Management

Over 1,400 counties contain areas where groundwater is susceptible to contamination from agricultural pesticides or fertilizers (National Research Council, 1989). States including California, Florida, Iowa, Nebraska, New York, and Wisconsin have developed strategies for dealing with agriculturally induced groundwater contamination. Contamination is prevalent in areas with sandy soils, which are highly porous. In some of these areas, restrictions have been placed on fall applications of nitrogen-based fertilizers. Applications are restricted either under certain weather conditions or during certain time periods. In ammonium form, nitrogen is fairly immobile in soil. Under most conditions, however, ammonium is converted biologically to nitrate, which readily moves with the soil water. Nitrate that is applied in the fall when no crop is planted or when plant uptake is minimal has greater potential of moving with the soil water from the soil to groundwater, streams, and impoundments. Otherwise, it denitrifies and passes to the atmosphere as gas. Effective timing of split fertilizer application during the crop-growing season and the use of nitrification inhibitors can reduce nitrate leaching and denitrification and improve crop nutrient uptake. Efforts to improve nitrogen efficiency will require better synchronization between soil nitrogen availability and crop nitrogen requirements.

A wide variety of nitrogen fertilizer formulations are available to producers to accommodate various times, rates, and methods of application. Additional nitrogen management may be required to minimize contamination of groundwater. Management systems that hold promise include the use of satellite imagery or Global Positioning Systems and grid farming, which allow nitrogen management by soil variation rather than by field. For more discussion of nutrient management, see chapter 4.5.

Author: Harold Taylor, (202) 219-0476 [htaylor@econ.ag.gov].

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Recent ERS Reports on Nutrient Issues

1995 Nutrient Use and Practices on Major Field Crops, AREI Update, May 1996, No. 2 (Harold Taylor). Total nutrient use was 5 percent lower in 1995 than in 1994 with nitrogen use down 7 percent and phosphate and potash use down about 2 percent each. The major factor was decreased corn acreage, which uses 40-45 percent of all fertilizer.

Agricultural Input Trade, AREI Update, 1995, No 10. (Stan Daberkow, Mohinder Gill, Harold Taylor, Marlow Vesterby). The United States is a major exporter of phosphate and nitrogen fertilizer products and a major importer of potash. The value of fertilizer exports has varied from $3.0 billion in 1991 to $1.8 billion in 1993. Data are reported by region and country.

Pesticide and Fertilizer Use and Trends in U.S. Agriculture, AER-717, May 1995 (Biing-Hwan Lin, Merritt Padgitt, Len Bull, Herman Delvo, David Shank, and Harold Taylor). Pesticides and fertilizer contribute to increased productivity in agriculture, but their use is also associated with potential human health, wildlife, and environmental risks. Nitrogen, phosphate, and potash all shared in the dramatic increase in fertilizer use, but the relative use of nitrogen increased much more rapidly from 37 percent of total nutrient use in 1960 to more than 50 percent since 1981.

Chemical Use Practices, RTD Update, July 1994, No. 2 (Harold Taylor, Biing-Hwan Lin, and Herman Delvo). Chemical application timing and methods varied considerably among the major field crops. Fertilizer was more frequently applied before planting to corn, soybeans, and winter wheat, at planting to durum and spring wheat, and after planting to cotton and fall potatoes. Herbicides were most frequently applied after planting to most crops except upland cotton. Area and State-level data are for corn; upland cotton; fall potatoes; soybeans; and winter, spring, and durum wheat.

Fertilizer Use and Price Statistics, SB-893, Sept. 1994 (Harold Taylor). The rapid growth in fertilizer consumption throughout the 1960's and 1970's peaked at 23.7 million nutrient tons in 1981. Use remained relatively stable, ranging from 19.1 to 21.8 million tons during 1984-93. Fertilizer prices vary by product and year, but the fertilizer price index was less during the late 1980's and early 1990's than in 1982. Area and State data are for corn, cotton, soybeans, and wheat from 1964-1993, and total U.S. consumption data are from 1960 to 1993.

(Contact to obtain reports: Harold Taylor, (202) 219-0476 [htaylor@econ.ag.gov])

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Glossary

Ammonium nitrate: A prilled or granulated product containing not less than 33 percent nitrogen, one half of which is in the ammonium form and one half in the nitrate form.

Ammonium sulfate: Soluble in water and contains 21 percent nitrogen and 24 percent sulphur. It is usually made by treating bauxite with sulfuric acid. It is applied to western soils to make them less alkaline.

Anhydrous ammonia: A colorless, pungent gas containing 82.25 percent nitrogen and 17.75 percent hydrogen, which can be liquefied and transported at normal temperatures in high-pressure cylinder tanks, and injected under pressure into the soil or mixed with irrigation water.

Available nutrients: That part of fertilizer supplied to the plant that can be taken up by the plant.

Blended fertilizer: A mechanical mixture of two or more fertilizer materials.

Diammonium phosphate (DAP): A product made from wet process phosphoric acid and ammonia containing 18 percent nitrogen and 46 percent phosphate.

Economically recoverable manure: The excreta of animals (dung and urine) mixed with straw or other materials that can be economically recovered and used as a fertilizer.

Guano: Partially decomposed excrements of birds, bats, seals, or other animals.

Inorganic fertilizers: Fertilizer materials in which carbon is not an essential component of its basic chemical structure.

Lime: A soil conditioner consisting essentially of calcium carbonate, calcium oxide, calcium hydroxide, magnesium carbonate, magnesium oxide, or a combination of these capable of neutralizing soil acidity.

Micronutrients: Boron, chlorine, cobalt, copper, iron, manganese, molybdenum, sodium, and zinc are needed only in small amounts. They contribute to cell division, photosynthesis, fruit formation, carbohydrate and water metabolism, chlorophyll formation, protein synthesis, and seed development.

Mixed fertilizers: Two or more fertilizer materials mixed or granulated together into individual pellets.

Muriate of potash (potassium chloride): A potash salt of hydrochloric acid (muriatic acid) containing 60-62 percent soluble potash.

Natural organic fertilizers: Materials derived from either plant or animal products containing one or more elements (other than carbon, hydrogen, and oxygen) essential for plant growth.

Nitrogen solutions: Solutions of nitrogen fertilizer chemicals in water. Urea ammonium nitrate (UAN) solutions are made from a mixture of urea and ammonium nitrate and contain 28-32 percent nitrogen.

Primary Nutrients:

> **Nitrogen (N)** is an essential element in the production of food protein by the plants and in the conversion of carbon dioxide in the air and water into carbohydrates through photosynthesis. It also is essential for vigorous plant growth and for obtaining high crop yields. Principal forms of nitrogen fertilizer are anhydrous ammonia, urea, ammonium nitrate, and nitrogen solutions.
>
> **Phosphate (P_20_5), the oxide form of phosphorus (P)** is vital to plant growth playing a key role in photosynthesis, respiration, energy storage and transfer, cell division, cell enlargement, genetic coding, and many other plant processes. An adequate level of phosphate provides rapid, extensive growth of young plant roots. Principal forms of phosphate fertilizer are normal and superphosphate, and diammonium phosphate.
>
> **Potash (K_20), the oxide form of potassium (K)** activates many enzyme systems in the plant and helps the plant use water more efficiently with less loss. It is essential for varied process-photosynthesis rates, product formation, winter hardness, and disease resistance. It stops stalks from lodging, preventing a decrease in crop yields. Principal forms of potash fertilizer are potassium chloride, potassium sulfate, and potassium nitrate.

Secondary Nutrients: Calcium, magnesium, and sulfur are essential to plant growth in lesser quantity than nitrogen, phosphate, and potash but in greater quantity than micronutrients.

Sewage sludge: Solids removed from sewage by screening, sedimentation, chemical precipitation, or bacterial digestion.

Sodium nitrate: Sodium salt of nitric acid containing not less than 16 percent nitrate nitrogen and 26 percent sodium.

Superphosphate: Products obtained when rock phosphate is treated with either sulfuric acid or phosphoric acid or a mixture of these acids. Normal superphosphate contains up to 22 percent phosphoric acid. Enriched superphosphate contains more than 22 percent but less than 40 percent phosphoric acid. Concentrated or triple superphosphate contains more than 40 percent phosphoric acid.

Urea: A white crystalline or granular solid synthesized from ammonia and carbon dioxide under high temperature and pressure and containing not less than 45 percent nitrogen.

Sources: *Farm Chemical Handbook 93*, Meister Publishing Company, 1993; Fertilizer Institute, 1982.

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3.2 Pesticides

Pesticides have been the fastest growing agricultural production input in the post-World War II era, and have contributed to the relatively high productivity levels of U.S. agriculture. Agricultural production and storage account for about 75 percent of total U.S. pesticide use. Herbicides and insecticides account for most pesticide use, but the recent increase in pounds of pesticide used is mostly for fungicides and other pesticide products applied to high-valued crops. In recent years, agricultural pesticide expenses have increased about 5.5 percent each year, keeping pace with farm production expenses in general. Pesticides have remained about 4 percent of total production expenses during the 1990's and about one-third of the manufactured inputs (fuels, fertilizers, and pesticides).

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Approximately $7.5 billion per year is spent in the United States on agricultural pesticides (USDA, ERS, Aug. 1996). Herbicides account for about two-thirds of the agricultural expenditures for pesticides while insecticides account for about one-fifth (Aspelin, 1994). (See "Glossary" for definitions of terms.)

Pesticide use has engendered concerns about health risks from residues on food and in drinking water and about the exposure of farmworkers when mixing and applying pesticides or working in treated fields. Pesticide use has also raised concerns about impacts on wildlife and sensitive ecosystems.

Pesticide use has conventionally been measured in pounds of active ingredients applied and acres treated. These measurements are useful for assessing the adoption and intensity of pesticide use, making relative comparisons of use between commodities or production regions, and analyzing the cost of pesticides as a production input. These measurements, however, do not account for changes in the pesticide attributes over time or safety features associated with their use and application. New products and the related changes in intensity of treatment, rather than treatment of additional acres, now account for most pesticide use changes. Product formulation has changed in order to lessen environmental and human health effects, to reduce the development of pesticide-resistant pests, and to provide more cost-effective pest control. Efforts to account for changing risk and productivity in aggregate measures of pesticide use are underway. This chapter reports traditional measures of pesticide use—acres treated and pounds applied—as well as new indicators that attempt to account for some pesticide attributes—toxicity and persistence—that may affect human and environmental health.

Table 3.2.1—Overall pesticide use on selected U.S. crops by pesticide type, 1964-1995[1]

Commodities	1964	1966	1971	1976	1982	1990	1991	1992	1993	1994	1995
					1,000 pounds of active ingredients						
Herbicides	48,158	79,384	175,668	341,390	430,345	344,638	335,177	350,534	323,510	350,449	323,791
Insecticides	123,304	119,240	127,709	131,730	82,651	57,392	52,828	60,047	58,096	67,896	69,599
Fungicides	22,167	23,237	29,308	26,632	25,219	27,762	29,439	34,922	36,583	43,059	44,804
Other pesticide	21,379	18,747	31,710	30,741	34,232	67,900	79,451	90,019	97,810	129,639	127,445
Total on selected crops	215,008	240,608	364,395	530,493	572,448	497,693	496,895	535,522	515,999	591,044	565,639
					1,000 cropland acres						
Area represented	174,552	175,040	190,638	233,221	255,866	228,508	226,021	231,531	226,586	232,804	227,855
Total cropland used for crops	335,000	332,000	340,000	340,800	383,000	341,000	337,000	338,000	330,000	338,500	338,000
					Pounds of active ingredient per planted acre						
Herbicides	0.276	0.454	0.921	1.464	1.682	1.508	1.483	1.514	1.428	1.505	1.421
Insecticides	0.706	0.681	0.670	0.565	0.323	0.251	0.234	0.259	0.256	0.292	0.305
Fungicides	0.127	0.133	0.154	0.114	0.099	0.121	0.130	0.151	0.161	0.185	0.197
Other pesticides	0.122	0.107	0.166	0.127	0.134	0.297	0.352	0.389	0.432	0.557	0.559
Total on selected crops	1.232	1.375	1.911	2.275	2.237	2.178	2.198	2.313	2.277	2.539	2.482
Percent of crop area represented[2]	52	53	56	68	67	67	67	69	69	69	67

[1] Estimates include corn, soybeans, wheat, cotton, potatoes, other vegetables, citrus fruit, apples, and other fruit.
[2] Share of total for the selected crops to total cropland used for crops.
Source: USDA, ERS, AER-717 (prior to 1993); unpublished USDA survey data (following 1993).

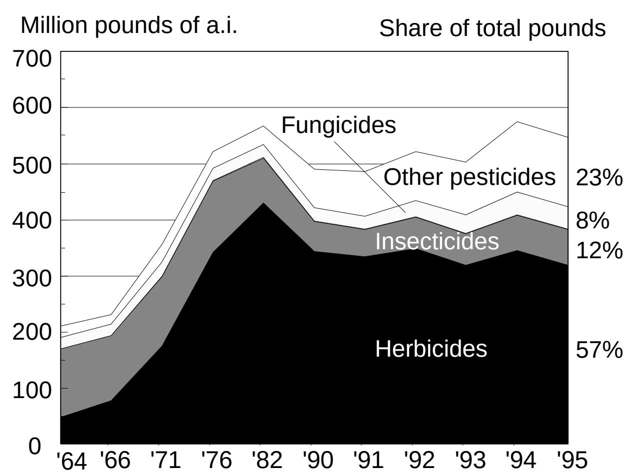
Pesticide Use on Major Crops

Synthetic pesticides were initially developed for commercial agricultural use in the late 1940's and 1950's and were widely adopted by the mid-1970's. USDA's benchmark surveys of pesticide use by farmers show that the quantities applied to major field crops, fruits, and vegetables first peaked in 1982 (fig. 3.2.1 and table 3.2.1). The crops included in the surveys—corn, cotton, soybeans, wheat, fall potatoes, other vegetables, citrus, apples, and other fruit—account for about 67 percent of the current cropland used for crops. Pesticide use on these crops grew from 215 million pounds in 1964 to 572 million pounds in 1982. This increase can be attributed to three factors: increased planted acreage, greater proportion of acres treated with pesticides, and higher application rates per treated acre. (More detail on proportions of acres treated, application rates, and pest management practices can be found in chapter 4.4, *Pest Management*.)

Pesticide use declined between the 1982 and 1990 benchmark surveys as commodity prices fell and large amounts of land were taken out of production by Federal programs.

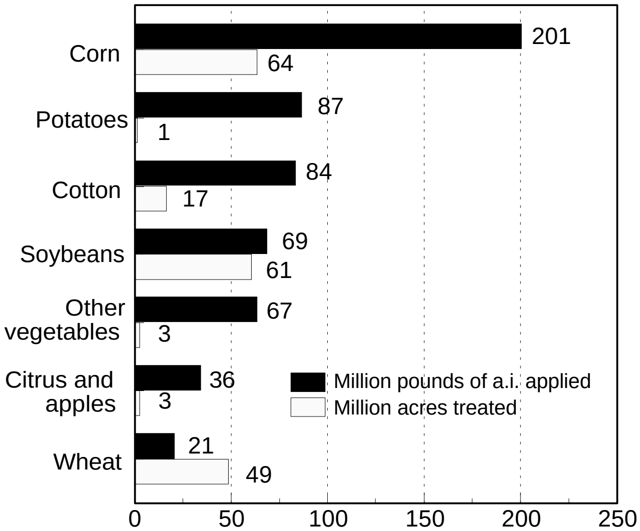
Since 1990, total quantities of pesticides have generally increased, but continue to fluctuate with changes in planted acreage, infestation levels, adoption of new products, and other factors. An estimated 565 million pounds of pesticides were applied to major field crops and most fruits and

Figure 3.2.1--Total pesticide use on major crops, 1964-95



Includes corn, cotton, soybeans, wheat, potatoes, other vegetables, citrus, and apples, and other fruit (about 67 percent of U.S. cropland).
Source: USDA, ERS estimates.

Figure 3.2.2--Amount of pesticide applied and acres treated, 1995



Source: USDA, ERS estimates

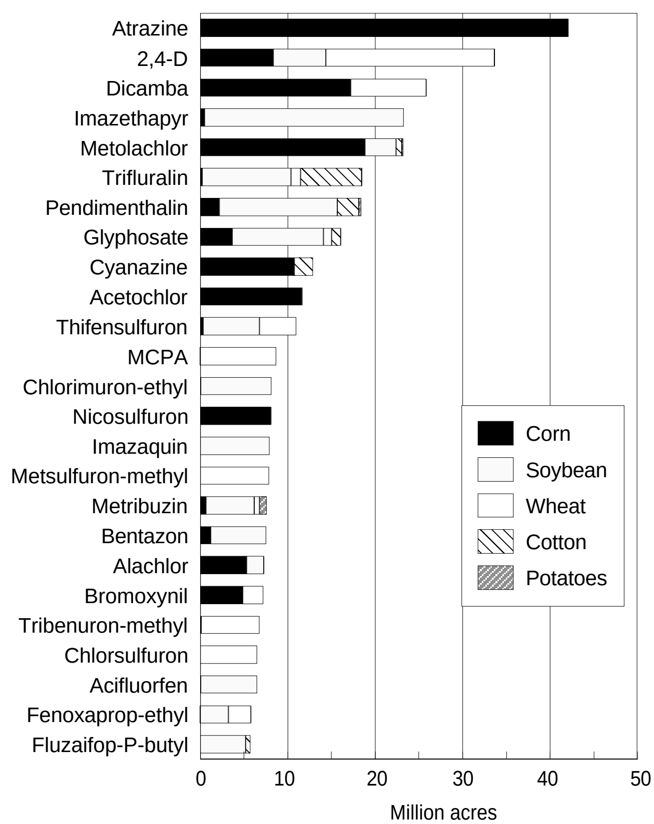
vegetables in 1995, up 13 percent from 1990. Contributing to the increased use was an expanded use of soil fumigants, defoliants, and fungicides on potatoes; expanded cotton acreage; more intensive insecticide treatments of cotton and potatoes; and an increased share of wheat acres treated with herbicides (table 3.2.2). During the same period, the total amount of pesticides applied to corn and soybeans was either unchanged or declined. In 1995, corn received more than double the pesticide amount of any other U.S. crop (fig. 3.2.2). Among the major crops, however, pesticide quantity per acre was by far greatest on fall potatoes.

Herbicides. Herbicides are the largest pesticide class, accounting for 57 percent of pounds of active ingredients in 1995 (table 3.2.1). Weeds compete with crops for water, nutrients, and sunlight, and cause reduced yields. Producers, in managing weeds, must consider infestation levels; weed species resistant to specific ingredients; the effect of treatment on following crops; control of soil weed seed populations; and the labor requirement, cost, and risk of using cultivation or other mechanical methods of weed control. Since 1990, herbicide use has remained relatively unchanged—between 324 million and 350 million pounds (table 3.2.1).

Although many herbicide active ingredients are used in agriculture, a relative few account for most of the use. Atrazine, 2,4-D, and dicamba, all widely used for more than 30 years, still account for the largest treated acreage among major field crops (table 3.2.3, fig. 3.2.3). Atrazine, which remains active in the soil throughout most of the growing season, is used to control many types of weeds in corn and sorghum. The herbicide 2,4-D has been widely used on wheat and corn, and more recently used on soybeans as a preplant application with no-till. Trifluralin, another ingredient available 30 years ago, continues to be the leading herbicide used on cotton and is still widely used on soybeans and many vegetable crops. Since the availability of imazethapyr and some other imidazalinone and sulfonyurea products in the 1980s, trifluralin use, especially on soybeans, has declined.

Insecticides. Insecticides accounted for 12 percent of the total quantity of pesticides applied in 1995 to the surveyed crops (fig. 3.2.1). Damaging insect populations can vary annually depending on weather, pest cycles, cultural practices such as crop rotation and destruction of previous crop residues, and other factors. Insecticide use includes both preventative treatments, which are applied before infestation levels are known, and intervention treatments, which are

Figure 3.2.3--Acres treated with commonly used herbicides, 1995



Source: USDA, ERS 1995 Cropping Practices Survey data.

Table 3.2.2—Estimated quantity of pesticide active ingredient applied to selected U.S. crops, 1964-95[1]

Commodities	1964	1966	1971	1876	1982	1990	1991	1992	1993	1994	1995
					*1,000 pounds of **herbicides***						
Corn	25,476	45,970	101,060	207,061	243,409	217,500	210,200	224,363	201,997	215,636	186,314
Cotton	4,628	6,526	19,610	18,312	20,748	21,114	26,032	25,773	23,567	28,565	32,873
Wheat	9,178	8,247	11,622	21,879	19,524	16,641	13,561	17,387	18,304	20,708	20,054
Sorghum	1,966	4,031	11,538	15,719	15,738	13,485	14,156	na	na	na	na
Rice	2,559	2,819	7,985	8,507	14,089	16,139	16,092	17,665	na	na	na
Soybeans	4,208	10,409	36,519	81,063	133,240	74,400	69,931	67,358	64,092	69,257	68,126
Peanuts	2,894	2,899	4,374	3,366	4,927	4,070	4,510	na	na	na	na
Potatoes	1,297	2,220	2,178	1,764	1,636	2,361	2,547	2,152	2,504	2,866	2,894
Other vegetables	2,194	3,488	3,361	5,419	4,345	4,916	4,712	5,850	5,741	6,137	6,119
Citrus	207	353	546	4,756	6,289	5,652	6,076	5,545	5,086	4,793	4,665
Apples	278	389	156	575	649	396	429	419	445	605	767
Other fruit	692	1,782	615	560	504	1,659	1,690	1,687	1,774	1,882	1,978
					*1,000 pounds of **insecticides***						
Corn	15,668	23,629	25,531	31,979	30,102	23,200	23,036	20,866	18,479	17,349	14,956
Cotton	78,022	64,900	73,357	64,139	19,201	13,583	8,159	15,307	15,429	23,882	30,039
Wheat	891	876	1,712	7,236	2,853	970	208	1,153	152	2,031	910
Sorghum	788	767	5,729	4,604	2,559	1,085	1,140	na	na	na	na
Rice	284	312	946	508	565	161	309	178	na	na	na
Soybeans	4,997	3,217	5,621	7,866	11,621	0	445	359	346	203	515
Peanuts	5,518	5,529	5,993	2,439	1,035	1,726	1,913	na	na	na	na
Potatoes	1,456	2,972	2,770	3,261	3,776	3,591	3,597	3,514	3,943	4,459	3,109
Other vegetables	8,290	8,163	8,269	5,671	4,465	4,709	4,466	5,482	5,305	5,591	5,573
Citrus	1,425	2,858	3,049	4,604	5,306	2,811	3,977	4,538	5,271	5,110	5,143
Apples	10,828	8,494	4,831	3,613	3,312	3,691	4,013	3,909	4,150	3,846	3,564
Other fruit	1,727	4,131	2,569	3,361	2,016	4,837	4,928	4,919	5,023	5,424	5,789
					*1,000 pounds of **fungicides***						
Corn	0	0	0	20	69	0	0	0	0	0	19
Cotton	171	376	220	49	200	988	701	785	684	1,065	1,045
Wheat	0	0	0	862	1,088	172	73	1,154	688	1,012	500
Sorghum	0	0	0	0	0	0	0	na	na	na	na
Rice	0	0	0	0	80	194	426	388	na	na	na
Soybeans	0	0	0	176	71	0	0	85	0	45	13
Peanuts	1,106	1,108	4,431	6,834	4,739	7,321	8,114	6,725	na	na	na
Potatoes	3,229	3,531	4,124	4,168	4,031	2,808	3,172	3,616	4,369	6,358	7,973
Other vegetables	4,530	4,093	5,667	5,051	6,692	12,917	13,126	17,260	18,715	21,880	21,810
Citrus	4,929	4,056	9,257	5,897	4,881	2,555	3,598	3,429	3,322	3,582	4,019
Apples	7,750	8,496	7,207	6,489	5,667	4,177	4,544	4,377	4,599	4,627	4,680
Other fruit	1,558	2,685	2,833	3,921	2,520	4,146	4,224	4,216	4,206	4,491	4,745
					*1,000 pounds of **other pesticides***						
Corn	76	546	443	483	130	0	0	0	0	0	0
Cotton	12,431	14,207	18,696	12,682	9,347	15,188	15,457	15,781	12,658	15,616	19,733
Wheat	0	47	245	0	0	0	0	0	0	0	0
Sorghum	0	40	0	266	44	0	0	na	na	na	na
Rice	0	0	0	0	17	0	0	109	na	na	na
Soybeans	0	49	52	2,030	2,430	0	0	0	0	0	0
Peanuts	6,990	7,005	471	1,188	1,627	2,364	2,620	na	na	na	na
Potatoes	91	9	6,397	8,576	15,188	35,069	45,626	49,671	157,494	79,809	72,928
Other vegetables	5,819	569	3,435	5,061	6,206	17,283	17,998	24,189	27,516	33,400	33,293
Citrus	1,539	681	1,280	214	7	10	15	31	49	108	179
Apples	1,037	1,079	548	574	421	73	73	66	65	79	93
Other fruit	386	1,560	614	1,120	504	276	282	281	27	627	1,221
					*1,000 pounds of **all pesticide types***						
Corn	41,220	70,145	127,034	239,543	273,710	240,700	233,235	245,229	220,476	232,985	201,289
Cotton	95,252	86,009	111,883	95,182	49,497	50,873	50,349	57,646	52,338	69,128	83,689
Wheat	10,069	9,170	13,579	29,977	23,465	17,782	13,842	19,694	19,144	23,751	21,464
Sorghum	2,754	4,838	17,267	20,589	18,341	14,570	15,296	na	na	na	na
Rice	2,843	3,131	8,931	9,015	14,751	16,494	16,827	18,340	na	na	na
Soybeans	9,205	13,675	42,192	91,135	147,362	74,400	70,376	67,802	64,438	69,505	68,655
Peanuts	16,509	16,541	15,268	13,827	12,327	15,482	17,157	na	na	na	na
Potatoes	6,073	8,732	15,470	17,769	24,631	43,830	54,942	58,953	68,309	93,492	86,904
Other vegetables	20,833	16,313	20,732	21,202	21,707	39,824	40,302	52,781	57,277	67,008	66,795
Citrus	8,100	7,948	14,132	15,471	16,483	11,028	13,666	13,544	13,729	13,594	14,006
Apples	19,893	18,458	12,742	11,251	10,049	8,337	9,059	8,771	9,260	9,157	9,104
Other fruit	4,364	10,158	6,631	8,963	5,544	10,919	11,123	11,103	11,030	12,424	13,734

[1] Estimates are constructed for the total U.S. acreage of the selected commodities. In years when the surveys did not include all states producing the crop, the estimates assume similar use rates for those States. Petroleum distillates are excluded. Source: USDA, ERS, AER-717 (prior to 1993), and unpublished USDA survey data following 1993.

Table 3.2.3—Herbicide active ingredients used on field crops, major producing States, 1990-95[1]

Active ingredient	1990	1991	1992	1993	1994	1995
			1,000 pounds			
Atrazine	45,144	44,439	46,203	41,878	45,586	38,611
Metolachlor	36,834	42,473	42,188	41,411	46,787	37,142
Cyanazine	22,024	24,118	27,238	27,367	29,519	24,066
Acetochlor	0	0	0	0	7,314	22,586
Trifluralin	17,892	18,426	16,585	13,975	13,722	13,392
Pendimethalin	8,779	10,595	11,303	12,685	13,702	16,024
2,4-D	9,055	6,800	7,753	10,962	12,207	12,266
Alachlor	41,476	45,992	45,146	36,561	27,270	11,144
EPTC	28,671	15,222	11,269	11,881	7,473	8,238
Glyphosate	1,963	3,048	2,606	5,809	6,491	8,117
Dicamba	4,488	3,803	5,307	5,051	7,098	6,139
Bentazon	4,910	3,889	4,414	3,969	4,959	4,364
MCPA	2,496	2,286	2,608	2,447	2,971	3,030
Butylate	10,510	5,975	5,979	3,850	2,117	1,609
Metribuzin	2,959	2,537	1,975	2,003	1,773	1,498
Imazethapyr	290	649	764	918	1,083	1,329
Sethoxydim	397	483	546	468	588	625
Imazaquin	607	541	589	617	758	564
Chlorimuron-ethyl	199	173	139	143	129	118
Other herbicides[2]	40,173	35,297	33,682	33,336	27,207	27,105
All herbicides	264,050	254,154	253,742	244,070	257,754	237,967
			1,000 acres treated			
Atrazine	37,513	39,485	43,509	39,037	42,909	36,130
2,4-D	23,831	18,929	22,353	29,866	32,340	31,549
Dicamba	17,735	15,886	22,197	22,367	28,487	24,875
Imazethapyr	5,328	11,679	14,321	16,214	19,425	22,837
Metolachlor	19,539	22,307	22,617	22,078	24,328	19,452
Trifluralin	23,556	23,089	21,425	18,367	18,146	17,064
Pendimethalin	9,123	11,437	13,216	13,788	14,450	16,412
Glyphosate	3,626	5,962	6,043	11,848	12,911	14,971
Cyanazine	13,206	14,164	15,724	14,531	15,150	12,414
Acetochlor	0	0	0	0	4,103	11,284
MCPA	7,220	6,852	7,884	7,670	8,547	8,038
Bentazon	8,146	6,629	7,656	6,246	8,038	7,070
Chlorimuron-ethyl	8,339	7,509	7,461	7,232	6,787	6,633
Imazaquin	5,262	5,771	6,623	6,322	7,794	6,353
Alachlor	21,044	22,535	22,307	17,744	13,766	6,348
Metribuzin	8,924	7,706	6,705	6,437	5,811	5,892
Sethoxydim	2,255	2,643	3,079	2,591	3,228	3,532
EPTC	6,504	3,684	2,634	2,988	1,855	2,137
Butylate	2,715	1,564	1,439	1,021	630	465

[1] Represents planted area of corn (10 States), soybeans (8 States), cotton (6 States), winter wheat (11 States), spring and durum wheat (4 States), and fall potatoes (11 States). For States included, see "Cropping Practices Survey" in the appendix. For these crops, the area represented in 1995 was about 165 million acres, 75 percent of total planted acres of these crops.

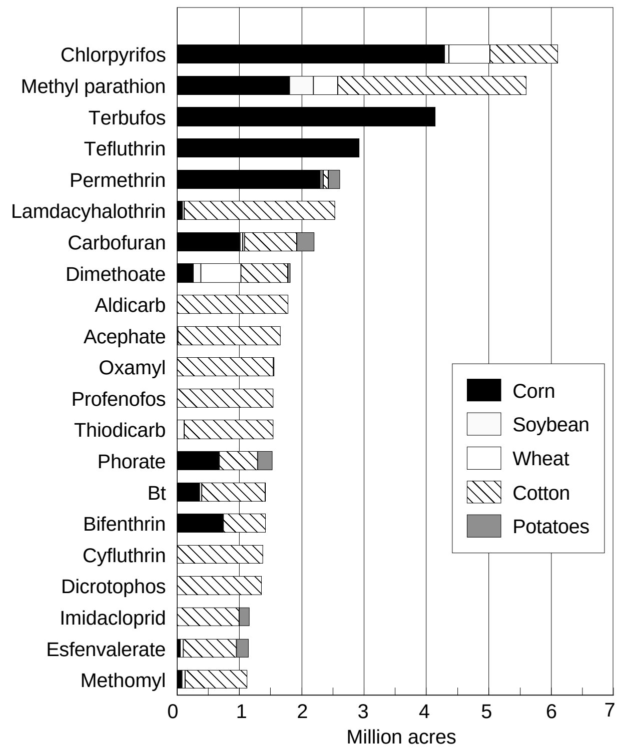
[2] Total pounds of all other herbicides used. No single ingredient in any year exceeded 5 million pounds.

Source: USDA, ERS, Cropping Practices Surveys, 1990 to 1995.

based on monitored infestation levels and expected crop damages. While the quantity of insecticides applied has increased in recent years, the amount is down significantly from the 1960's and early 1970's (table 3.2.1). The drop from earlier years is primarily due to the replacement of organochlorine insecticides, used prior the 1970's, with other insecticides that can be applied at much lower rates. The 69.4 million pounds of insecticide applied in 1995 was about half the quantity used in 1976 and earlier years. Since 1990, insecticide use has declined on corn (with fewer acres treated) but increased on cotton (with expanded area and more intensive treatments per acre) (table 3.2.2).

Three insecticide active ingredients (chlorpyrifos, methyl parathion, and terbufos) account for 43 percent of insecticides used on the five major field crops (fig. 3.2.4, table 3.2.4). Chlorpyrifos was the most used insecticide on corn, second most used on wheat, and applied to 9 percent of the cotton acreage. It is used to treat corn rootworm larvae, cutworms, Russian wheat aphid, and bollworms. Methyl parathion is used mostly on cotton to treat boll weevil and other cotton insects while terbufos is used for corn insects.

Figure 3.2.4--Acres treated with commonly used insecticides, 1995



Source: USDA, ERS 1995 Cropping Practices Survey data.

Fungicides. Fungicides are applied to fewer acres than are herbicides and insecticides and account for the smallest share of total pesticide use (table 3.2.1). Fungicides are mostly used on fruits and vegetables to control diseases that affect the health of the plant or quality and appearance of fruit. The 44.6 million pounds estimated for 1995 is up 21 percent from 1993 and 61 percent from 1990. A large share of this increase is attributed to diseases on potatoes and other vegetables. Several common fungicides used to treat potatoes for early and late blight (chlorothalonil, mancozeb, metalaxyl, and copper hydroxide) had a 40 to 400 percent increase in use over this period. Some cotton and wheat acres are treated for diseases, but these treatments account for only a small share of total fungicide use.

Other pesticides. Pesticides designated as "other," which include soil fumigants, growth regulators, desiccants, and harvest aids, had the largest increase in use of any of the pesticide classes (table 3.2.1, fig. 3.2.1). The use of these pesticides, whose function is not necessarily to destroy a pest organism, increased about 17 percent each year since 1990 and accounts for about 23 percent of the total pounds of all active ingredients applied to the surveyed crops. Growth regulators, desiccants, and harvest aids, normally applied at low rates, are used to affect the branching structure of plants, to control the time of maturity or ripening, to aid mechanical harvesting, to defoliate plants before harvest, and to alter other plant functions to improve quality or yield. Fumigants, normally applied at very high application rates, are used mostly on vegetable root crops susceptible to damage from soil nematodes and other soil organisms. Fumigants and some desiccants, with application rates that often exceed 200-300 pounds per acre, account for most of the quantity of pesticides in this class but only a small share of the area treated. Small changes in the use of such products, when averaged with other products applied at only a few pounds or less per acre, can grossly affect the significance of the overall change in pesticide use. USDA reports (NASS, 1991-96) show that the increase of 3 fumigants (methyl bromide, metam sodium, and dichloropropene) account for most of the increase in pesticide quantity between 1990 and 1995 but were applied to a relatively small share of the acres.

Table 3.2.4—Insecticide active ingredients used on field crops, major producing States, 1990-1994[1]

Active ingredient	1990[2]	1991	1992	1993	1994	1995
			1,000 pounds			
Chlorpyrifos	5,511	7,141	6,382	6,242	6,370	5,933
Methyl parathion	531	2,421	3,837	4,794	7,429	5,996
Terbufos	8,831	5,331	5,528	4,571	4,290	3,268
Phorate	2,787	2,531	2,005	2,549	2,127	1,830
Profenofos	.	322	1,276	1,326	1,875	1,742
Carbofuran	1,773	1,803	1,207	720	748	1,290
Aldicarb	44	559	564	637	938	1,140
Fonofos	2,652	2,888	2,121	1,837	1,628	844
Methomyl	0	183	269	382	240	580
Dimethoate	165	307	483	639	619	484
Esfenvalerate	18	73	81	47	56	302
Permethrin	104	318	185	146	274	247
Carbaryl	255	164	131	56	186	218
Other insecticides[3]	4,620	7,999	8,910	8,922	12,045	11,313
All insecticides	26,705	30,567	31,271	31,107	36,341	35,187
			1,000 acres treated			
Chlorpyrifos	4,467	6,468	6,340	5,835	6,457	5,753
Methyl parathion	1,255	3,104	3,834	3,964	5,078	4,881
Terbufos	7,847	4,855	5,083	4,293	4,050	3,139
Permethrin	812	2,826	1,598	1,190	2,459	2,226
Carbofuran	1,751	2,030	1,371	863	1,082	1,825
Aldicarb	17	1,033	1,030	1,164	1,532	1,784
Profenofos	363	993	1,227	1,532	2,400	1,543
Phorate	1,918	1,638	1,550	1,981	1,810	1,513
Dimethoate	576	989	1,674	1,276	2,016	1,504
Esfenvalerate	345	1,560	1,228	703	773	1,011
Methomyl	0	636	723	778	613	1,077
Fonofos	2,569	2,646	1,789	1,813	1,504	895
Carbaryl	370	370	176	73	167	137

[1] Represents planted area of corn (10 States), soybeans (8 States), cotton (6 States), winter wheat (11 States), spring and durum wheat (4 States), and fall potatoes (11 States). For States included, see "Cropping Practices Survey" in the appendix. For these crops, the area represented in 1995 was about 165 million acres, 75 percent of total planted acres of these crops.

[2] Does not include insecticides applied to cotton.

[3] Total pounds of all other herbicides used. No single ingredient in any year exceeded 1 million pounds.

Source: USDA, ERS, Cropping Practices Surveys, 1990 to 1995.

Indicators of Potential Pesticide Impact or Risk

Pesticide use in the United States, as traditionally reported in pounds of active ingredient applied, reached a record level in 1994 (table 3.2.1). However, pesticide weight, as a measure of use, has two particularly notable drawbacks when evaluating the potential for harm to human health and the environment. First, the more than 350 pesticide active ingredients used in U.S. agricultural production in the last 40 years vary widely in terms of toxicity per unit of weight, irrespective of the scale used to measure toxicity.[1] Second, weight does not account for the persistence of the pesticide in the environment. The longer a pesticide ingredient remains active in the environment, the more potential there is for it to come in contact with non-target species. Persistence varies widely between active ingredients, but many modern pesticides have half-lives (the typical measure of persistence) of 10-100 days in the fields where they are applied. This is significantly less than some organochlorine products banned from use in the 1970's, which had half-lives as high as 30 years.

Many new pesticide ingredients are applied at lower rates (in ounces rather than pounds per acre) and are

[1] There are numerous measures of toxicity for individual pesticide active ingredients, including those designed to measure chronic and acute toxicity to humans, and toxicities to various avian, aquatic, and beneficial insect species. The relative toxicity of each pesticide ingredient varies depending upon which measure is used; for a given measure, there is wide variation in toxicity among pesticide ingredients.

less persistent in the environment. In addition, many (formerly) widely used, but highly toxic and persistent, ingredients have been restricted or banned by the Environmental Protection Agency. In order to account for these differences in exposure and toxicity, adjustment factors were used to convert historic pesticide-use data (published in terms of pounds applied) into indicators of risk that are more meaningful with respect to potential environmental or health impacts. The adjustment creates a common denominator that accounts for variation in toxicity and persistence among individual pesticide ingredients. Thus, the amount of each pesticide active ingredient applied is aggregated in common units that are consistent across time, regions, pesticide types, toxicity, and persistence. Other researchers have created indexes using related methodology to make assessments of aggregate changes in pesticide toxicity (Kovach and others, 1992; Levitan and others, 1995).

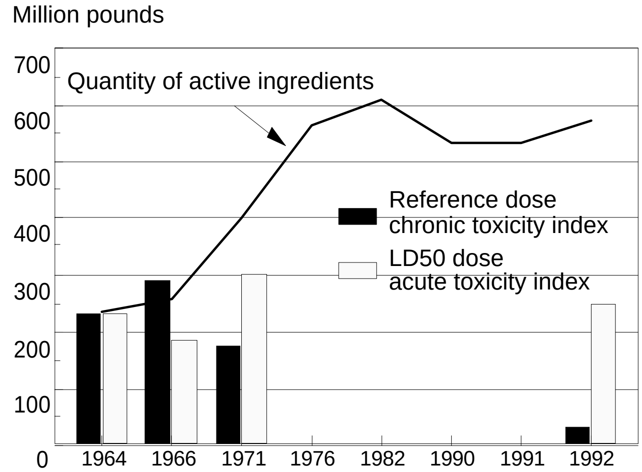
The potential risk indicators are based on indexes of the combined toxicity and persistence of each individual ingredient. (See box, "Estimating Pesticide Impact or Risk.") The indexes are created by calculating the number of units (Reference Dose or LD50) contained in 1 pound of each pesticide active ingredient and multiplying that value by the estimated number of days (as measured by half-life) that an application of the ingredient remains active in the environment. The calculated index value for each ingredient can be multiplied by the pounds applied and then summed over all ingredients to obtain an aggregate indicator of potential risk.

The analysis first compares pounds of active ingredient applied, then compares two potential risk indicators (table 3.2.5). Both of the risk indicators adjust for persistence, but each employs an alternative measure of toxicity. An indicator of potential chronic risk is based on Reference Dose, which is a measure of long-term (chronic) toxicity. An indicator of potential acute risk is based on the Oral LD50, and measures acute toxicity associated with ingestion of the pesticide.

For most consumers, chronic intake through food and water is the principal health concern stemming from pesticide use in agriculture. A health-risk measure, based on Reference Dose, was chosen to represent this long-term risk to health. The acute measure, based on LD50, is of more interest to farmers, farmworkers, and pesticide applicators who are more prone to acute exposure.

While the total pounds of active ingredients applied in 1992 was up 247 percent from 1964, the total potential chronic risk from the 1992 pesticides was actually less than the risk from the pesticides applied in 1964 (fig 3.2.5). Much of the reduction in the potential chronic risk indicator reflects the removal of many organochlorine insecticides, such as aldrin, DDT, chlordane, and toxaphene.

Figure 3.2.5--Comparison of indicators of pesticide use and risk



Source: USDA, ERS, based on USDA, 1960; USDA, 1968; USDA, 1974; Gianessi, 1995.

Even with the ban on highly toxic and persistent organochlorine insecticides and other reductions in use, insecticides continue to account for most of the potential risk (table 3.2.5). Insecticides accounted for about 92 percent of the total potential acute risk and more than half of the total potential chronic risk in 1992. While the total potential risk associated with herbicides and fungicides increased 7 to 8 times over the 28-year time period, these pesticide classes still accounted for under 20 percent of the total potential chronic risk and 5 percent of the total potential acute risk in 1992. The potential chronic risk from all other classified pesticides—mostly soil fumigants—increased about 75 percent in this period and accounted for over 30 percent of the total potential chronic risks in 1992.

The results also suggest that when toxicity is defined in acute terms, potential risk from pesticide application may be slightly greater in 1992 than it was in 1964. The acute measure may be most meaningful to farmers, pesticide applicators, and farmworkers, all of whom have higher probabilities of acute exposure. However, the Environmental Protection Agency and State agencies have instituted a number of farmworker safety regulations (protective clothing, enclosed application systems, field re-entry

Estimating Pesticide Impact or Risk

Impact or risk from pesticides can be estimated from some combination of toxicity and exposure factors. Ideally, procedures and estimated measurements used to account for the potential environmental and human-health impacts of pesticide applications would include factors related to mobility of pesticides, persistence in the environment, exposure route (proportion of pesticide likely to enter the air, run off in surface water, adhere to sediment, percolate into ground water, and remain as residue on food), toxicity to each of many species, and size of the populations potentially subject to exposure. Toxicity varies by species, and varies depending upon whether the exposure is chronic or acute. Likewise, persistence is not an inherent characteristic of a pesticide active ingredient, but varies with temperature, moisture, and exposure to sunlight and to microbial degradation. Further, the data generally available on persistence are for the first soil half-life, which itself is but one indicator of persistence, and are not necessarily equal to subsequent half-lives. The amount of pesticide in runoff, leachate, and soil particles depends not only on the amount of rainfall, but its intensity and the interval between pesticide application and the occurrence of the rain. Each of these factors is occurrence-specific.

A system capable of accounting for all of these factors cannot be realistically constructed, especially for large areas. Data requirements would be prohibitive, and the relevance of the measure would be site-specific, unsuitable for analysis of trends on a national scale. Even if the volume of data could be modeled and managed, measures of relevant attributes do not exist for many of the more than 350 pesticide active ingredients that have been used as inputs to agricultural production over the past several decades.

The risk indicators reported here are a simplified calculation of pesticide risk, developed to be workable for analysis of historical trends at the national level. Other researchers have created indexes using related methods to conduct pesticide impact assessments for other purposes, relying on less aggregate analysis (Kovach and others, 1992; Levitan and others, 1995). By necessity, many relevant environmental and safety factors are not taken into account in the estimates reported here making these indicators less than ideal. Nevertheless, these risk indicators are superior to the information contained in data on pounds applied or acres treated. To emphasize the abstraction of this indicator from variation that exists in the real world, we view the indicators as a measure of the “potential” impact from pesticide use.

The Chronic risk index was created by combining Reference Dose as the indicator of chronic toxicity and soil half-life as an indicator of potential exposure. Use of Reference Dose implies that the units relate to human health, and may not necessarily be useful indicators of potential impact on other species. For active ingredients for which it was available, the EPA’s Reference Dose measure was used. If that measure was not available, a Reference Dose estimate from the Office of Pesticide Programs (EPA), characterized by less rigorous review, was substituted. Lacking either of those indicators of toxicity for some active ingredients, estimates reported by the World Health Organization were used. Averages for the active ingredient’s chemical family were used in other cases. Using Reference Dose does not take into account carcinogenic potential that is built into other health measures from the EPA, such as health advisory levels and maximum contaminate levels. These latter measures are available only for a very limited number of active ingredients, however.

The soil half-life measures are taken from databases constructed by the Agricultural Research Service. As such, the indicators for each active ingredient are midpoints of the range of soil half-lives reported in the literature, which in turn are based on estimates derived under a variety of soil, moisture, and temperature conditions.

The acute risk index was created by combining an Oral LD50 measure of toxicity and the same soil half-life measure of potential exposure. Where available, the Oral LD50 for rats was used. For some active ingredients, this measure was not available, and an Oral LD50 for a related mammal, usually mice, was substituted. This procedure is less than ideal in that acute toxicity varies widely among species. No adjustment was made to translate the rat LD50 into human terms. The Oral LD50 is a severe threshold, implying the ingestion of an amount of active ingredient sufficient to kill 50 percent of the treated animals. Such a severe level of exposure is unlikely in reality. Despite its limitation, Oral LD50 for rats or related mammals should provide a relative indicator of risk to humans and other species from acute exposure. EPA has developed less severe indicators in the form of 1- and 10-day health advisory levels, but they are available only for a limited number of active ingredients.

Table 3.2.5—Indicators of pesticide use and risk on major crops, selected years 1964-92[1]

Pesticide type	Measures[2]	1964	1966	1971	1992
		Percent of total pesticides			
Herbicides	pounds a.i.	23.58	34.26	49.83	67.30
	chronic risk indicator	0.21	0.27	0.93	15.26
	acute risk indicator	0.77	1.40	1.85	4.93
Insecticides	pounds a.i.	55.07	47.74	34.52	10.13
	chronic risk indicator	97.72	97.97	95.45	54.04
	acute risk indicator	91.32	94.82	88.84	91.76
Fungicides	pounds a.i.	9.33	8.49	7.74	6.57
	chronic risk indicator	0.05	0.06	0.08	2.95
	acute risk indicator	0.01	0.03	0.02	0.09
Other pesticides	pounds a.i.	12.02	9.50	7.91	16.00
	chronic risk indicator	2.02	1.70	3.53	30.75
	acute risk indicator	7.89	3.75	9.29	3.22
		Index: 1964 = 100			
Herbicides:	pounds a.i.	100	159	362	706
	chronic risk indicator	100	163	344	838
	acute risk indicator	100	145	283	705
Insecticides:	pounds a.i.	100	95	107	45
	chronic risk indicator	100	125	75	5
	acute risk indicator	100	382	115	111
Fungicides:	pounds a.i.	100	100	142	174
	chronic risk indicator	100	133	120	648
	acute risk indicator	100	179	160	744
Other pesticides:	pounds a.i.	100	87	113	329
	chronic risk indicator	100	105	134	173
	acute risk indicator	100	38	139	45
Total pesticides:	pounds a.i.	100	109	171	247
	chronic risk indicator	100	125	76	11
	acute risk indicator	100	80	118	110

[1] Estimates include corn, soybeans, wheat, cotton, sorghum, rice, peanuts, potatoes, other vegetables, citrus, and apples. See table 3.2.2 for pesticide quantities. [2] See glossary for definitions. Source: USDA, ERS, preliminary estimates.

intervals, and training) to reduce farmworkers' exposure to pesticides.

Factors Affecting Pesticide Use

Prior to the development of synthetic pesticides following World War II, a farmer's solution to weed, insect, and disease problems was primarily the use of physical and cultural practices. Weeds were controlled by tillage, mowing, site selection, crop rotation, use of seeds free of weedseeds, and hoeing or pulling by hand. Insect pests and diseases were controlled through seed selection, crop rotations, adjustment of planting dates, and other cultural practices, but the risk of severe infestations, yield losses, and even abandoned production was still ever-present.

Between 1950 and 1980, chemical pest control was widely adopted on most crops (table 3.2.2). Public and private research introduced new pesticides (and other innovations) that could increase yields and substitute for some farm labor, machinery, and fuel. Higher prices for energy and other manufactured inputs along with rising wage rates promoted this trend. By 1980, herbicide use climbed toward 100 percent of the acreage of corn, soybeans, cotton, and many other crops. Insecticides and other pesticides were also widely used.

Although the adoption of pesticides as a crop production technology was nearly complete by the mid 1970's, many factors continue to affect the use of pesticides. Changes in planted acres or shifts in production between commodities and regions can affect the number of acres treated and applied quantities. Pest cycles and annual fluctuations caused by weather and other environmental conditions often determine whether infestation levels reach treatment thresholds. Changes in pesticide regulations, prices, new products, and pest resistance to pesticides also affect the producer's selection of active ingredients, application rates, and methods of treatment. (See chapter 4.4, *Pest Management* for more information.)

Federal Agricultural Programs

Federal commodity and conservation programs provide mixed incentives to both increase and decrease pesticide use. Acreage restrictions and set-aside provisions in past commodity programs and the Conservation Reserve Program reduced planted acreage and, hence, pesticide use on those acres that otherwise would have been in production. Pesticide use dropped in 1983 with the large feedgrain acreage idled under the payment-in-kind program (PIK) and has subsequently paralleled other major changes in planted acreage (Aspelin, 1994). On the other hand, Federal programs can provide incentives to increase pesticide use on the land that is not set aside. When planted acreage was constrained and price expectations included program payments, producers tended to substitute nonland inputs, including fertilizer and pesticide, to boost yields and capture higher returns on their eligible planted acreage. Participants in Federal commodity programs used higher nitrogen fertilizer and herbicide application rates than producers who did not participate (Ribaudo and Shoemaker, 1995).

The Federal Agriculture Improvement and Reform Act of 1996 removes the link between income support payments and current farm production and will likely remove most incentives for producers to substitute yield increasing inputs per acre of planted land. However, producers' greater planting flexibility could lead to increased pesticide use as idled land returns to production. Producers are now permitted to plant 100 percent of their total base acreage plus additional acreage to any crop (with some exceptions for fruits and vegetables) without loss of Federal subsidy.

Pesticide Prices

Aggregate pesticide use is negatively related, but relatively unresponsive, to changes in pesticide prices (Fernandez-Cornejo, 1992; McIntosh and Williams, 1992; and Oskam and others, 1992). That is, the percentage change in quantity of pesticide use is relatively less than the percentage change in the price of pesticides. Given the evidence that pesticide demand is relatively unresponsive to pesticide price changes, along with relatively small annual pesticide price changes over the last several years, we would expect that pesticide use, in general, has been largely unaffected by prices.

While overall pesticide use may not be very responsive to small price changes, individual product use can vary from year to year. When different pesticide products are perfect or near-perfect substitutes, small price changes can result in significant changes in the mix of products used as farmers attempt to maximize profits. Pesticide prices, as measured by the agricultural chemicals price index, increased 2-5 percent annually from 1991 to 1995 (table 3.2.6). In total over the 1991-95 period, herbicide prices increased about 12 percent while fungicide prices rose nearly 16 percent, and insecticide prices showed a 19-percent increase. Fungicide prices, which ranged from a 2-percent annual decline (1993-94) to a 7-percent annual increase (1994-95), were the most variable.

Reflecting the price changes and increased use, pesticide expenditures for all farm uses increased about 2 to 7 percent annually over 1991-95 (USDA, Aug. 1996). Pesticide costs per acre for cotton, soybeans, and wheat remained relatively unchanged between 1991 and 1995, but the pesticide costs for corn increased about 4 percent each year. Pesticide costs for corn edged over $25 per acre in 1994, accounting for 13 percent of total fixed and variable cash production expenses. Pesticide expenditures on cotton, with the largest cost for insecticides, were about $50 per acre and accounted for 15 percent of cash production expenses. Pesticide costs on soybeans ($24 per acre) accounted for 13 percent of cash production expenses while costs on wheat ($6 per acre) accounted for 8 percent.

Index numbers are useful aggregate measures for monitoring price changes, but indexes can mask movements in individual components of the index. Common pesticide active ingredients showed different price trends between 1991 and 1995 (table 3.2.6). These price changes typically reflect shifts in factors such as cost of manufacturing and distribution, price of competing products, patent protection, and planted acreage of the treated crop.

Among insecticides, carbaryl, methyl parathion, and phorate had price increases of 25 percent or more.

Table 3.2.6—Selected April pesticide prices, 1991-1995

Active ingredient	1991	1992	1993	1994	1995	1991-92	1992-93	1993-94	1994-95	1991-95
	Dollars per pound of active ingredient					*Annual percent change*				
Insecticides:										
Aldicarb	22.20	na	22.07	24.67	24.33	na	na	11.8	-1.4	9.6
Carbaryl	4.44	4.95	5.36	5.41	5.74	11.5	8.3	0.9	6.0	29.3
Carbofuran	10.40	10.87	12.20	12.80	12.73	4.5	12.3	4.9	-0.5	22.4
Chlorpyrifos	10.65	11.30	12.03	12.10	12.33	6.1	6.4	0.6	1.9	15.7
Dimethoate	na	11.12	11.05	9.70	10.11	na	-0.7	-12.2	4.2	
Esfenvalerate	187.88	192.42	200.00	210.61	219.70	2.4	3.9	5.3	4.3	16.9
Methomyl	21.44	21.60	22.43	24.14	24.36	0.8	3.8	7.6	0.9	13.7
Methyl parathion	5.10	5.35	5.83	5.98	6.83	4.9	8.9	2.6	14.2	33.8
Permethrin	45.94	46.88	48.13	47.81	48.13	2.0	2.7	-0.6	0.7	4.8
Phorate	7.80	8.05	8.80	9.15	9.90	3.2	9.3	4.0	8.2	26.9
Fungicides:										
Benomyl	31.60	32.60	34.00	35.80	36.00	3.2	4.3	5.3	0.6	13.9
Captan	5.12	5.74	5.96	6.16	6.62	12.1	3.8	3.4	7.5	29.3
Chlorothalonil	7.30	8.04	8.63	8.67	8.75	10.2	7.4	0.4	1.0	19.9
Iprodione	40.40	43.60	45.60	46.60	46.00	7.9	4.6	2.2	-1.3	13.9
Mancozeb	3.54	3.79	3.94	3.87	4.01	7.3	3.7	-1.6	3.7	13.5
Maneb	3.13	na	3.24	3.16	3.38	na	na	-2.3	6.7	8.0
Metalaxyl	74.50	74.00	76.50	81.00	85.00	-0.7	3.4	5.9	4.9	14.1
Sulfur	0.73	0.69	0.53	0.39	0.37	-4.3	-24.2	-26.0	-5.4	-49.3
Triadimefon	108.40	100.00	112.40	115.60	120.20	-7.7	12.4	2.8	4.0	10.9
Ziram	3.24	na	3.61	3.70	3.66	na	na	2.6	-1.1	13.0
Herbicides:										
2,4-D	2.83	2.93	3.20	3.38	3.55	3.5	9.4	5.5	5.2	25.7
Alachlor	6.15	6.35	6.45	6.48	7.03	3.3	1.6	0.4	8.5	14.2
Atrazine	na	2.88	3.15	3.45	3.60	na	9.6	9.5	4.3	
Bentazon	15.38	15.75	16.40	16.98	18.28	2.4	4.1	3.5	7.7	18.9
Chlorimuron	1139.20	1145.60	1152.00	1171.20	1184.00	0.6	0.6	1.7	1.1	3.9
Cyanazine	5.65	5.83	5.95	6.55	7.08	3.1	2.1	10.1	8.0	25.2
Dicamba	17.45	18.18	19.48	19.40	21.88	4.2	7.2	-0.4	12.8	25.4
Glyphosate	13.85	na	13.03	13.40	13.53	na	na	2.9	0.9	-2.3
Imazaquin	134.67	135.33	137.33	140.67	142.67	0.5	1.5	2.4	1.4	5.9
MCPA	3.25	3.25	3.65	3.68	3.98	0.0	12.3	0.7	8.2	22.3
Metolachlor	7.49	7.69	7.79	7.85	8.46	2.7	1.3	0.8	7.8	13.0
Metribuzin	31.73	32.67	34.27	36.27	36.67	2.9	4.9	5.8	1.1	15.5
Pendimethalin	8.85	9.27	9.24	9.12	8.76	4.8	-0.3	-1.3	-4.0	-1.0
Sethoxydim	82.00	76.67	75.33	76.00	74.67	-6.5	-1.7	0.9	-1.8	-8.9
Trifluralin	7.50	8.00	8.08	8.13	8.20	6.7	0.9	0.6	0.9	9.3
Agricultural chemicals price index (1990-92 = 100)	101	103	107	112	115	2.0	3.9	4.7	2.7	13.9
Herbicides	101	102	106	110	113	1.0	3.9	3.8	2.7	11.9
Insecticides	101	104	110	117	120	3.0	5.8	6.4	2.6	18.8
Fungicides & others	101	105	111	109	117	4.0	5.7	-1.8	7.3	15.8

na = not available.
Source: USDA, ERS, based on NASS farm supply dealers annual survey.

These latter three insecticides are widely used on corn as well as several minor fruit and vegetable crops. Most fungicide prices rose over 10 percent, while captan and chlorothalonil increased more than 20 percent. Both captan and chlorothalonil are used extensively on fruit, vegetable, and nut crops such as apples (captan) and peanuts (chlorothalonil) while sulfur (which dropped in price) is heavily applied to grapes.

Among herbicides, the price of sethoxydim dropped while those for 2,4-D, atrazine, cyanazine, dicamba, and MCPA rose. With the exception of MCPA, which is used primarily on wheat and barley, the herbicides with the greatest price increases were extensively used in corn production. However, 2,4-D and dicamba are also used on pasture and wheat land; atrazine is heavily used on corn and sorghum; and cyanazine is a major cotton herbicide.

Pesticide Legislation

The U.S. Environmental Protection Agency (EPA) registers pesticides and ensures they are safe. The Food Quality Protection Act of 1996 defines safe for dietary consumption products as "a reasonable certainty that no harm will result from aggregate exposure" including food, drinking water, and nonoccupational exposures. Under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and its amendments, the EPA decides which pesticides are registered and prescribes labeling and other regulatory requirements on their use to prevent unreasonable adverse effects on health and the environment. EPA also regulates pesticides under the Federal Food, Drug, and Cosmetic Act (FFDCA), which requires that tolerances for residues on food and drinking water be established. These tolerances are enforced through monitoring and inspections conducted by the Food and Drug Administration and USDA. (See box, “Pesticide Tolerance and Dietary Risks.")

The Clean Air Act (1970), Clean Water Act (1972), Resource Conservation and Recovery Act (1976), and the Comprehensive Environmental Response, Compensation, and Liability Act (1980) (or Superfund) also contain provisions that apply to pesticide manufacturers that affect their cost of production. The Clean Air Act mandates discharge limits on pollutants, RCRA specifies how to dispose of toxic substances, and the Superfund stipulates who pays for the cleanup of toxic dump sites. All of these regulatory requirements affect the development time and cost of pesticide production. Recent estimates suggest that the research and development of a new

Pesticide Tolerance and Dietary Risks

The Food Quality Protection Act of 1996 sets a consistent safety standard for pesticide use on all foods, and for all health risks. Under the new law, both fresh and processed foods may contain chemical residues at tolerance levels that have been determined to be safe by the EPA. Previously, the largely unenforced "Delaney Clause" of the Federal Food, Drug, and Cosmetic Act prohibited processed foods, but not fresh foods, from containing even trace amounts of carcinogenic chemical residues. The new law contains provisions that "ensure that there is reasonable certainty that no harm will result to infants and children from aggregate exposure." The EPA is required to reassess existing tolerances of all pesticides within 10 years, with priority given to pesticides that may pose the greatest risk to public health.

USDA’s pesticide monitoring by the Agricultural Marketing Service (AMS) measures residues on both domestic and imported samples of fresh fruits and vegetables common in the diets of the U.S. population. The AMS monitoring is used not only to respond to food safety concerns but also to provide the EPA with data to assess the actual dietary risk posed by pesticides. Without actual exposure data, the pesticide registration process assumes all producers apply maximum allowable amounts. This assumed maximum risk may significantly exceed actual risk and jeopardize the registration process for products important to agricultural production. Some pesticide residues were found on 71 percent of the samples in 1993 and 46 percent of the samples in 1994; however, few exceeded established tolerance levels (USDA, AMS, 1996). Of 7,589 samples analyzed in 1994, 4 residue samples exceeded established tolerance and 88 samples had residues where no tolerance was established. Even though the use of DDT has been banned since 1972, 5.5 percent of the 1994 detections were for DDT or its metabolites. Once applied, DDT is slow to degrade in the soil and can continue to occur on crops grown in that soil. The DDT residues were found primarily in root crops and none exceeded tolerance levels. On samples where any pesticide residue was detected, 38 percent were from postharvest pesticide products normally applied to produce to prevent spoilage during storage and transportation.

pesticide takes 11 years and can cost manufacturers between $50 and $70 million (Ollinger and Fernandez-Cornejo, 1995). Results of a study of the impact of pesticide product regulation on innovation and the market structure in the U.S. pesticide industry indicate that regulation encourages the development of less toxic pesticide materials but discourages new chemical registrations, encourages firms to abandon pesticide registrations for minor crops, and favors large firms over smaller ones. Pesticide regulation also encourages firms to develop biological pesticides as an alternative to chemical pesticides (Ollinger and Fernandez-Cornejo, 1995).

States are also active in regulating pesticide use. In 1996, most States had some regulations related to pesticide use in agriculture and/or lawn care, and over half have groundwater laws, posting requirements, and pesticide reporting regulations (Meister Publishing, 1996). Over a third of the States had health advisory levels, containment regulations, and bulk chemical regulations, and 13 States had requirements for reporting pesticide illnesses.

The majority of States also have pesticide registration fees, many of which have increased in the last several years. Nine States tax pesticide products or have other special taxes (Meister Publishing, 1996) that have been used to fund research on pesticide alternatives. For example, the Leopold Center for Sustainable Agriculture, which conducts research on environmentally friendly alternatives, is partially supported from a tax on pesticide and fertilizer sales.

Pesticide Registrations

The EPA registration process requires manufacturers to provide scientific data to substantiate that a proposed product is safe and poses no unreasonable adverse effects to human health or the environment. Tests pertaining to toxicology, reproduction disorders and abnormalities, and potential for tumors from exposure to the pesticide are required. Other required tests evaluate the effect of pesticides on aquatic systems and wildlife, farm worker health, and the environment. The registration process can require up to 70 different types of tests to substantiate the safety of the product. Since 1989, the number of pesticide active ingredients for sale in the United States has decreased by 50 percent and further declines are expected due to reregistration requirements and costs (Pease and others, 1996).

The recently enacted Food Quality Protection Act of 1996 requires periodic re-evaluation of pesticide registrations to ensure that the scientific data supporting registrations remain current. The new law mandates a screening program for estrogenic and other endocrine or synergistic effects and sets a goal for all pesticides to be reviewed and updated on a 15-year cycle. The registration and re-registration process also prescribes those commodities on which the pesticides can be used, at what concentration they can be applied, when and how they are to be applied, and what safety precautions are to be used during and after application. Table 3.2.7 identifies some of the key regulatory action taken against agricultural pesticides and gives the status of special reviews being conducted for reregistration.

The EPA is currently conducting a special review of triazine herbicides (atrazine, cyanazine, and simazine). In 1995, the manufacturers of cyanazine voluntarily withdrew its registration rather than proceed with the special review. Cyanazine, which is identified as a carcinogenic material, is the third most used herbicide on corn and cotton and is also commonly used on sorghum and other crops to control grasses and broadleaf weeds. The manufacturer has agreed to stop selling products containing cyanazine by 1999.

Mevinphos and propargite are insecticides that have been voluntarily canceled by their manufacturers. Mevinphos was canceled for all uses in 1994 due to concerns about acute toxicity and farmworker safety. Because this pesticide degrades quickly after application, it requires only a short interval before harvesting. It was used for aphid control on many fresh fruits and vegetables late in the growing season when other agents could not be applied. Propargite was withdrawn in early 1996 due to concern about residues on fresh market produce and possible exposure to infants and children. It was canceled for use on apples, apricots, cranberries, figs, green beans, lima beans, peaches, pears, plums, and strawberries.

In 1993, regulatory action was taken for methyl bromide under the Clean Air Act because of its adverse affect on the ozone layer in the upper atmosphere. Production and use will be terminated in 2001 and annual production until that date is limited to the 1991 level.

Pesticide Resistance

Pesticide resistance is most likely to develop when a pesticide with a single mode of action is used over and over in the absence of any other management measures to control a specific pest. If a weed, insect, or fungi species contains an extremely low number of biotypes resistant to the killing mode of the pesticide,

Table 3.2.7—EPA regulatory actions and special review status on selected pesticides used in field crops production, 1972 - June 1995

Pesticide	Regulatory action and date
Alachlor	Uses restricted and label warning, 1987; under EPA review for groundwater contamination
Aldicarb	Use canceled on bananas, posing dietary risk, 1992
Aldrin	All uses canceled except for termite control, 1972
Captafol	All uses canceled, 1987
Chlordimeform	All uses canceled, 1988. Use of existing inventory until 1989
Cyanazine	Manufacturers voluntarily phasing out production by 2000 but stock can be used until 2003
DDT	All uses canceled except control of vector diseases, health quarantine, and body lice, 1972
Diazinon	All use on golf course and sod farms canceled, 1990
Dimethoate	Dust formulation denied and label changed, 1981
Dinoseb	All uses canceled, 1989
EBDC (Mancozeb, Maneb,Metiram, Nabam, Zineb)	Protective clothing and wildlife hazard warning, 1982
Endrin	All uses canceled, 1985
EPN	All uses canceled, 1987
Ethalfluralin	Benefits exceeded risks, additional data required, 1985
Heptachlor	All uses canceled except homeowner termite product, 1988
Linuron	No regulatory action needed, 1989
Methyl Bromide	Annual production and use limited to 1991 levels with use to be terminated in 2001, 1993
Mevinphos	Voluntary cancellation of all uses, 1994
Monocrotophos	All uses canceled, 1988
Parathion	Use on field crops only, 1991; under EPA review with toxicological data requested
Propargite	Registered use for 10 crops canceled, 1996. Use for other crops remains legal
Toxaphene	Most uses canceled except emergency use for corn, cotton, and small grains for specific insect infestation, 1982
Trifluralin	Restrictions on product formulation, 1982
2,4-D (2,4-DB, 2,4-DP)	Industry agreed to reduce exposure through label change and user education, 1992

Source: USDA, ERS, based on information in EPA, 1995.

then those species that survive the pesticide treatment reproduce future generations containing the pesticide resistant trait. As this process repeats, the resistance trait multiplies and begins to account for a significant share of the species' population.

Although herbicide-resistant weeds have been documented since the early 1950's, their prominence in the last two decades has increased, resulting in management strategies that seek to minimize development of pesticide-resistant species. Rotating pesticides with different modes of action, applying mixtures of herbicides, reducing application rates, and combining mechanical or nonchemical control practices are some management strategies to reduce pesticide resistance (Meister Publishing, 1966). Resistance to triazine herbicides (atrazine, cyanazine, and simazine) is one of the more common weed-resistant problems in corn and sorghum. Farmers responding to USDA's Cropping Practices Survey in 1994 reported that 16 percent of the corn acreage had triazine-resistant weeds. To deter these and other weed resistance problems, producers reported that they alternated herbicides on the majority of corn, soybean, and cotton acreage. In recent years, producers also have reported using different active ingredients on each treated acre and lowering the application rates, both practices prescribed to deter herbicide resistance.

Similar to the development of weeds resistant to herbicides, the incidence of insects, mites, and disease-causing fungi species resistant to pesticides also causes producers to switch to different chemicals or pest controls (NRC, 1986). Once insect or fungi species develop resistance to one ingredient, the time required to develop resistance to other ingredients of the same chemical family is often much less. Over a short period of time, species resistant to an entire family of ingredients can develop and require a different mode of treatment. At least partially due to development of insecticide resistance, cotton insecticide families shifted from mostly organochlorines prior to the 1970's to organophosphates and carbamates and more recently to synthetic pyrethroids (Benbrook, 1996). Scouting to determine economic thresholds for treatments, alternating the use of pesticide families, and several other management strategies to combat resistance are now in use (see chapter 4.4, *Pest Management*).

New Pest Control Products and Technology

Each year, the EPA registers several new pesticides which producers may adopt if they offer improved pest control and are profitable. Acetachlor was granted conditional registration in 1994 as an herbicide for use on corn that would help reduce overall herbicide usage. The registration allows automatic cancellation if the use of other herbicide products is not reduced or if acetachlor is found in ground water. In 1995, about 23 million pounds of the new product were applied to 20 percent of U.S. corn acreage (table 3.2.3). The reduced pounds of alternative herbicides (alachlor, metolachlor, atrazine, EPTC, butylate, and 2,4-D) more than offset the pounds of acetachlor.

Other pesticide products have significantly affected the quantity of total use. For example, Imazethapyr, first registered for use on soybeans in 1989, has become the most widely used soybean herbicide in the United States. This herbicide, applied at less than 1 ounce per acre, often replaced trifluralin and other older products, applied at rates many times higher than imazethapyr.

Transgenic corn and cotton seeds have been marketed recently in the hope of reducing the need to apply insecticides. These seeds were bioengineered to produce Bt, a bacterial insecticide that can control cotton bollworms, European corn borer, and other insects when they eat plant tissues containing the Bt bacteria. Some scientists are concerned that the plants do not produce sufficient levels of pesticides and that the pest survival rates will speed up the evolution of pest resistance to Bt, including Bt sprays. Resistance management plans are often prescribed when these products are adopted (*Science*, 1996). About 13 percent of the U.S. cotton acreage was reported planted with this transgenic cotton seed in 1996. Bt, as a spray insecticide, was applied to 9 percent of the 1995 cotton acres, but only 1 percent of the corn acres.

Author: Merritt Padgitt, (202) 219-0433 [mpadgitt@econ.ag.gov]. Contributors: Charles Barnard, Stan Daberkow, Craig Osteen, and Renata Penn.

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Glossary

Acute Risk Indicator—An indicator of the potential human and environmental health risk from an acute exposure to pesticides. An indicator value equal to 1 is the presence of 1 LD50 dose in the environment for 1 day. (See box, "Estimating Pesticide Impact or Risk," p. 124)

Amount of pesticide applied is the total pounds of all pesticide active ingredient (excluding carrier materials) applied. Because this sum can include materials applied at very different rates, differences in the amount applied do not necessarily represent differences in the intensity of the treatment or potential health and environmental risks.

Chronic Risk Indicator—An indicator of the potential human health risk from a chronic exposure to pesticides. An indicator value equal to 1 is the presence of 1 Reference Dose in the environment for 1 day.

LD50 dose—The constructed measure reflects the pesticide dose level (mg/kg of body weight) which results in 50 percent mortality of laboratory test animals. The LD50 values used in constructing the acute risk indicator relate to ingestion of the active ingredient (Oral LD50).

Land receiving pesticides represents an area treated one or more times with a pesticide material. Pesticide materials include products used to kill weed, plant, and fungi pests, as well as products used as growth regulators, soil fumigants, desiccants, and harvest aids.

Number of acre-treatments applied represents total number of ingredients applications made throughout the growing season. A single treatment containing two ingredients is counted as 2 acre-treatments as is 2 treatments containing a single ingredient.

Number of ingredients applied represents the total number of different active ingredients applied throughout the growing season on a field. It does not reflect repeat applications of the same ingredient during the production year.

Number of treatments applied represents the number of application passes made over a field to apply pesticides. One or more pesticide materials may be applied with each treatment. This measurement reflects labor and pesticide application equipment usage.

Pesticide, according to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), is "... any substance or mixture of substances intended for preventing, destroying, repelling or mitigating any insects, rodents, nematodes, fungi, or weeds, or any other forms of life declared to be pests; and any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant." Types or classes of pesticides are:

- **Fungicides—**Control plant diseases and molds that either kill plants by invading plant tissues or cause rotting and other damage to the fruit before and after it can be harvested.

- **Herbicides**—Control weeds which compete for water, nutrients, and sunlight and reduce crop yields. Herbicides that are applied before weeds emerge are referred to *preemergence herbicides*. Preemergence herbicides have been the foundation of row crop weed control for the past 30 years. Herbicides applied after weeds emerge are referred to as *postemergence herbicides*. Postemergence herbicides are sometimes considered more environmentally sound than preemergence herbicides because they normally have little or no soil residual activity. Treatments applied prior to any tillage or planting to kill existing vegetation are referred to as *burndown applications*. Burndown applications are often a part of no-till systems.

- **Insecticides—**Control insects that damage crops. Also include materials used to control mites and nematodes.

- **Other Pesticides—**Include soil fumigants, growth regulators, desiccants, and other pesticide materials not otherwise classified.

Reference Dose—The constructed measure reflects the long-term safety/toxicity of pesticides to humans. It is measured as the no-observable-effect level of a pesticide ingredient multiplied by an uncertainty factor, which adds an additional safety factor in translating animal no-observable-effect levels to human no-observable-effect levels. The constructed value represents the "dose" (mg./lb. of body weight) which could be consumed daily over a 70-year life span by a person weighing 70 kg. without having adverse health effects.

Recent ERS Research on Pesticide Issues

"Phasing Out Registered Pesticide Uses as an Alternative to Total Bans: A Case Study of Methyl Bromide," *Journal of Agribusiness*, Vol. 15, No. 1, 1997. (Walt Ferguson, Jet Yee) This article examines how a phase-out strategy, in place of an immediate ban on all crops, would affect consumers and producers and still achieve much of the human health and environmental benefits of an immediate and total ban.

Agricultural Chemical Usage, 1995 Fruits Summary (Ag CH1 96), July 1996. This report continues a series of biennial reports of chemical use on most fruit commodities produced in the United States. This summary contains state estimates of primary nutrients and pesticide active ingredients use in the on-farm production of these commodities.

Agricultural Chemical Usage, 1995 Field Crop Summary. (Ag CH 1 96), March 1996. This report continues a series of annual field crop summaries since 1990 that estimate on farm fertilizer and pesticide use on U.S.-produced corn, cotton, potatoes, soybeans, and wheat. This summary contains State estimates of the primary nutrients and pesticide active ingredients used in the production of these commodities.

Pesticide Residues, Reducing Dietary Risks. AER-728, Jan. 1996. (Fred Kuchler, Katherine Ralston, Laurian Unnevehr, Ram Chandran) New data on pesticide residues, food consumption, and pesticide use are used to analyze the sources of consumers' dietary intake of pesticide residues and the benefits of research to develop safer alternatives to pesticide use. This study reports that canceled but persistent chemicals appear among the highest risk indicators; postharvest uses account for the largest share of dietary intake of residues; residue levels vary among domestic and imported commodities; and consumption patterns, especially those of children, influence risks from pesticide residues.

Regulation, Innovation, and Market Structure in the U.S. Pesticide Industry. AER-719, 1995. (Michael Ollinger, Jorge Fernandez-Cornejo) This report examines how EPA regulation affects new chemical pesticide registrations, new chemical pesticide safety and use, industry composition, and technology choice.

"The Effect of Feedgrain Program Participation on Chemical Use." *Agricultural and Resource Economics Review*, Oct. 1995. (Marc Ribaudo, Robbin Shoemaker) This journal article addresses whether commodity programs create economic incentives and conditions that result in higher per-acre use of chemicals than would occur under free-market conditions. The feedgrain program appears to provide incentives for participants to apply more fertilizer and herbicides than nonparticipants.

Agricultural Chemical Usage, 1994 Vegetable Summary. (Ag CH1 95), July 1995. This report continues a series of biennial reports of chemical use on most vegetable commodities produced in the United States. This summary contains State estimates of primary nutrients and pesticide active ingredients used in the on farm production of these commodities.

Pesticide and Fertilizer Use and Trends in U.S. Agriculture. AER-717, May 1995. (Biing-Hwan Lin, Merritt Padgitt, Len Bull, Herman Delvo, David Shank, Harold Taylor) Trends in fertilizer and pesticide use since 1964 along with economic analysis of factors influencing agricultural chemical use are contained in this report.

Adoption of Integrated Pest Management in U.S. Agriculture. AIB-707, Sept 1994. (Marc Ribaudo, Robbin Shoemaker) This report summarizes information on the extent of adoption of integrated pest management (IPM) techniques in the production of fruits, vegetables, and major field crops. Levels of IPM vary widely among crops and regions, but about half of all fruit, vegetable, and major field crop acreage uses some IPM techniques.

Atrazine: Environmental Characteristics and Economics of Management. AER-699, 1994. (Marc Ribaudo, A. Bauzaher) This report presents the costs and benefits of an atrazine ban, a ban on pre-plant and pre-emergent applications, and a targeted ban to achieve a surface water standard. A complete atrazine ban is hypothesized to be the costliest strategy, while the targeted strategy is the least costly.

Economic Effects of Banning Methyl Bromide for Soil Fumigation. AER-677, 1994. (Walt Ferguson, A. Padula) This report estimates the consequences for producers and consumers of banning the use of methyl bromide for agricultural uses.

(Contact to obtain reports: Merritt Padgitt, (202) 219-0433 [mpadgitt@econ.ag.gov])

3.3 Energy

Agriculture uses energy directly for operating machinery and equipment on the farm and indirectly in fertilizers and pesticides produced off the farm. Since a 1978 peak, total energy use in agriculture (excluding electricity) fell by 25 percent to 1.6 quadrillion British thermal units (Btu) in 1993, due to improved energy efficiency. An additional 1 quadrillion Btu of energy is used by the food processing industry. Agriculture also supplies renewable energy in the form of biomass for electricity generation and as feedstocks, mostly corn, for production of alternative fuels such as ethanol.

Contents

Different types of energy are often required for different activities in food production. Energy used to produce food is classified as either direct or indirect. Direct energy, mostly refined petroleum products, is used on farms for planting and harvesting, fertilizer and pesticide application, and transportation, while electricity is used for irrigation and other purposes. Dairies require a major input of electricity for cooling milk, operating milking systems, and supplying hot water for sanitation. Indirect energy, on the other hand, is consumed off the farm for manufacturing fertilizers and pesticides. In addition, substantial amounts of energy, including natural gas, oil, electricity, and coal, are used in manufacturing or processing of food after it leaves the farm. Most food processing firms use energy to provide steam, hot water, and process heating.

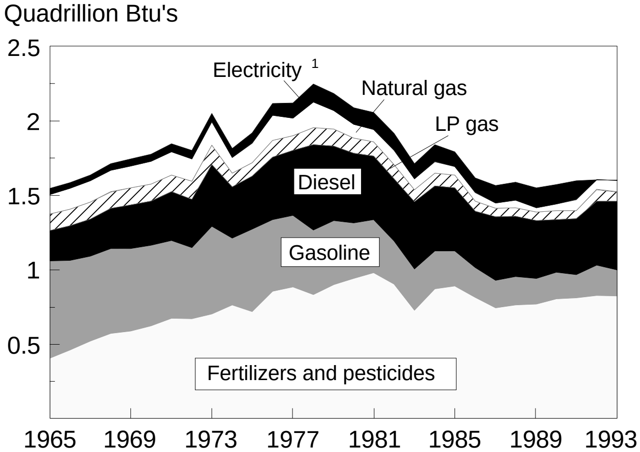
The agricultural sector also supplies energy. The Clean Air Act Amendment of 1990 (CAA) has increased the demand for ethanol—already used as a fuel extender and octane enhancer—by requiring oxygenates in about 35 percent of the Nation's gasoline. Ethanol primarily uses corn as a feedstock, but can use other biomass as well. On a larger scale, biomass from agricultural and forestry sources is used directly as fuel for electricity generation.

Energy Use in Agricultural Production

Agricultural energy use peaked at 2.2 quadrillion Btu in 1978. However, oil price shocks during the late 1970's and early 1980's forced farmers to become more energy-efficient. Many farmers have switched from gasoline-powered to fuel-efficient diesel-powered engines, adopted energy-conserving tillage practices, shifted to larger multifunction machines, and adopted energy-saving methods of crop drying and irrigation. Between 1978 and 1993, energy (excluding electricity) used by agriculture declined 25 percent, primarily due to a reduction in the direct use of energy (gasoline, diesel, liquefied petroleum or LP gas, and natural gas); energy used to produce fertilizers and pesticides declined only slightly. (Separate electricity expenditures in agriculture have not been available since 1991.)

In addition, the composition of energy use has changed significantly. Gasoline use has dropped from 42 percent of total energy use in 1965 to only 11 percent in 1993, while diesel's share of diesel fuel has risen from 13 percent to 29 percent (fig 3.3.1). This

Figure 3.3.1--Composition of energy use in agriculture, 1965-93



[1] No data on electricity use since 1991.

Source: USDA, ERS.

change reflects the shift away from gasoline-powered machinery toward more efficient, diesel-powered machinery.

While farm energy use declined by 25 percent between 1978 and 1993, agricultural output increased by almost 47 percent (in 1987 dollars, Economic Report of the President, 1995). As a result, the ratio of energy use to agricultural output fell by 50 percent between 1978 and 1993.

Demand for refined petroleum products such as diesel fuel, gasoline, and LP gas in agricultural production is determined mainly by the number of acres planted and harvested, price of energy, and weather. Farm fuel use in 1994 was greater than in 1993. Diesel fuel use, at 3.5 billion gallons, was up 6 percent from 1993 while LP gas, at 0.9 billion gallons, increased 3 percent (table 3.3.1). This increase was due principally to lower fuel prices and a slight increase in the number of acres planted and harvested. Gasoline consumption, at 1.4 billion gallons, was unchanged from the 1993 level.

Farm fuel prices in the United States are heavily influenced by international market conditions, particularly crude oil supplies by the Organization of Petroleum Exporting Countries (OPEC). Historically, each 1-percent increase in the U.S. price of imported crude oil has translated into a 0.7-percent rise in the farm price of gasoline and diesel fuel. Following the Arab Oil Embargo of 1973-74, world oil prices rose rapidly. They escalated again due to the Iranian crisis in 1979, peaked in 1981, then fell

Table 3.3.1—Fuel purchased for farm use, 1974-94[1]

Year	Gasoline	Diesel	LP gas
		Billion gallons	
1974	3.7	2.6	1.4
1975	4.5	2.4	1.0
1976	3.9	2.8	1.2
1977	3.8	2.9	1.1
1978	3.6	3.2	1.3
1979	3.4	3.2	1.1
1980	3.0	3.2	1.1
1981	2.7	3.1	1.0
1982	2.4	2.9	1.1
1983	2.3	3.0	0.9
1984	2.1	3.0	0.9
1985	1.9	2.9	0.9
1986	1.7	2.9	0.7
1987	1.5	3.0	0.6
1988	1.6	2.8	0.6
1989	1.3	2.5	0.7
1990	1.5	2.7	0.6
1991	1.4	2.8	0.6
1992	1.6	3.1	0.9
1993	1.4	3.3	0.7
1994	1.4	3.5	0.9

[1] Excludes Alaska, Hawaii, and fuels used for household and personal business.

Source: USDA, ERS, based on NASS, Farm Production Expenditures Summaries, and unpublished data.

steadily until 1985, and fell sharply in 1986 due to a glut of oil in the world market. Oil prices rose sharply again in 1990 and 1991 following the Persian Gulf war and have since been falling gradually. Farm gasoline prices mirrored world oil prices, rising, for example, from 47 cents per gallon in 1974 to $1.29 in 1981. Between 1992 and 1994, gasoline prices fell steadily, then rose slightly in 1995 (table 3.3.2). During the first half of 1996, gasoline prices were on the rise due to increased seasonal demand.

Farm fuel expenditures represented 3.5 percent of total farm production expenses in 1994, down from 3.6 percent in 1993 (table 3.3.3). In 1994, farm fuel expenditures totaled $5.55 billion, an increase of less than 1 percent from 1993. An increase in the number of acres planted and harvested in 1994, even with lower energy prices, accounted for this slight increase in total expenditures. The Corn Belt, at $1.02 billion, was the farm production region with the highest total energy expenditures, followed by the Northern Plains at $704 million (fig. 3.3.2). Farm expenditures for

Table 3.3.2—Average U.S. farm fuel prices, 1974-95[1]

Year	Gasoline[2,3]	Diesel[3,4]	LP gas[3]
		$/gallon[5]	
1974	0.47	0.37	0.30
1975	0.50	0.39	0.30
1976	0.53	0.41	0.33
1977	0.57	0.45	0.39
1978	0.60	0.46	0.40
1979	0.80	0.68	0.44
1980	1.15	0.99	0.62
1981	1.29	1.16	0.70
1982	1.23	1.11	0.71
1983	1.18	1.00	0.77
1984	1.16	1.00	0.76
1985	1.15	0.97	0.73
1986	0.74	0.58	0.55
1987	0.92	0.71	0.59
1988	0.93	0.73	0.59
1989	1.05	0.76	0.58
1990	1.17	0.95	0.83
1991	1.19	0.87	0.75
1992	1.15	0.82	0.72
1993	1.14	0.82	0.78
1994	1.08	0.77	0.72
1995[6]	1.11	0.77	0.73

[1] Based on surveys of farm supply dealers conducted by the National Agricultural Statistics Service (NASS), USDA.

[2] Leaded regular gasoline survey item discontinued after 1992, and unleaded gasoline survey item added January, 1993.

[3] Includes Federal, State, and local per gallon taxes.

[4] Excludes Federal excise tax.

[5] Bulk delivery.

[6] Prices based on April 1995 survey of farm supply dealers conducted by NASS, USDA.

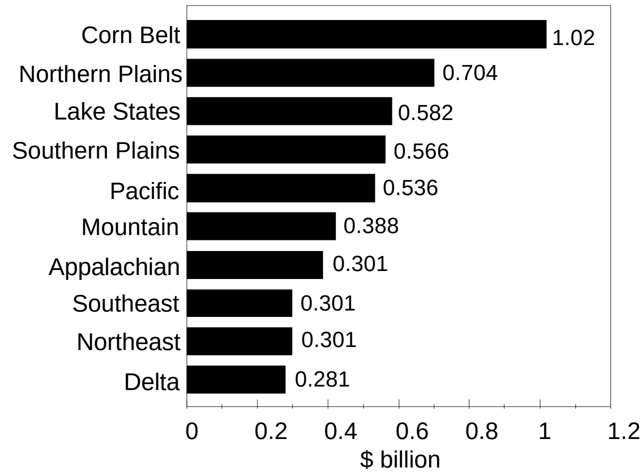
Source: USDA, ERS.

electricity were an additional $2.33 billion in 1991, the last year separate data were gathered. If a similar expenditure for electricity occurred in 1994, total farm energy expenditures would be $7.9 billion or 4.9 percent of total farm production expenses.

Energy Use in Food Processing

Energy is an important input to manufacturing and processing food after it leaves the farmgate. Food and kindred products, SIC (Standard Industrial Classification) 20, is the Nation's largest manufacturing sector with the value of its shipment as high as $404 billion in 1993. The sector's firms process foods and beverages largely for human consumption, as well as related products such as animal feed. Food manufacturing and processing

Figure 3.3.2--Farm sector fuel expenditures, by region, 1994



Source: USDA, ERS, based on NASS, Farm Production Expenditures, 1994 Summary.

firms use power-driven machines and material-handling equipment and, in 1991, consumed 4.7 percent (1 quadrillion Btu) of total energy.

Industries within the food and kindred products sector use different types of energy and at various intensities. Eight industries of the sector's 49 accounted for nearly half of the total energy consumed (table 3.3.4). The most common energy sources are natural gas, electricity, coal, LP gas, and residual and distillate fuel oil. Beet sugar is the most energy-intensive industry at 28,300 Btu per dollar of shipments, compared with meat packing at 1,000 Btu.

The sector's output rose 25 percent between 1977 and 1991, while its energy use fell 2 percent, mainly due to improvements in efficiency such as waste heat recovery and the substitution of membrane separation for thermal separation.

Energy from Agricultural Biomass

Biomass (plant and animal matter) includes a broad range of biological materials—such as agricultural and forestry products and wastes including animal manure—that can be used to produce energy. These feedstocks may be used for direct combustion, gasified, and/or processed into biofuels such as ethanol, methanol, ethyl or methyl esters, methane, and biocrude. Biomass could provide clean energy and thereby reduce the emissions of greenhouse gases and other pollutants.

Table 3.3.3—Farm energy expenditures, 1980-94

Year	Gasoline	Diesel	LP gas	Other	Total fuel	Fuel share of farm production expense	Electricity: Non-irrigation	Electricity: Irrigation	Total energy
			$billion			*Percent*		*$billion*	
1980	3.31	3.12	0.67	0.82	7.92	5.9	1.22	0.54	9.68
1981	3.36	3.35	0.70	0.81	8.22	6.2	1.32	0.66	10.20
1982	2.87	3.25	0.76	0.85	7.73	5.9	1.42	0.69	9.83
1983	2.64	3.15	0.66	0.89	7.34	5.6	1.62	0.59	9.55
1984	2.40	3.06	0.72	0.82	7.00	5.4	1.64	0.59	9.23
1985	2.16	2.92	0.69	0.68	6.45	5.1	1.56	0.65	8.68
1986	1.51	2.04	0.49	0.65	4.33	4.1	1.42	0.58	6.69
1987	1.37	2.13	0.38	0.47	4.35	3.9	2.03	0.43	6.81
1988	1.42	2.12	0.38	0.53	4.45	3.8	2.17	0.48	7.10
1989	1.44	2.12	0.38	0.51	4.45	3.6	1.69	0.64	6.78
1990	1.65	2.42	0.53	0.57	5.14	3.9	1.65	0.65	7.47
1991	1.50	2.34	0.44	0.65	4.93	3.8	1.57	0.76	7.25
1992	1.72	2.65	0.65	0.63	5.65	3.9	na	na	na
1993	1.58	2.69	0.58	0.67	5.52	3.6	na	na	na
1994	1.50	2.70	0.62	0.73	5.55	3.5	na	na	na

na = not available.

Source: USDA, ERS, based on NASS, Farm Production Expenditures, 1980-1994 Summaries. Data for 1992-94 are from the NASS, unpublished data.

Table 3.3.4—Consumption of energy by industry group, 1991

Standard Industrial Classification	Industry group[1]	Total	Net electricity[2]	Residual fuel oil	Distillate fuel oil[3]	Natural gas [4]	LP gas	Coal
					Trillion Btu			
20	Food and kindred products	956	169	27	17	W	5	154
2011	Meatpacking plant	49	12	1	1	32	1	1
2033	Canning fruits & vegetables	44	5	2	1	36	*	Q
2037	Frozen fruits & vegetables	40	10	2	*	26	*	0
2046	Wet-corn milling	140	14	*	*	52	*	68
2051	Bread, cake, & related prod.	32	8	*	1	23	*	0
2063	Beet sugar	67	1	W	*	19	*	43
2075	Soybean oil	51	6	*	*	25	*	13
2082	Malt beverage	50	8	3	*	23	*	16

[1] Only the eight largest subcategories of food and kindred products are shown.
[2] "Net electricity" is the sum of purchases in and generation from noncombustible renewable resources, minus quantities sold and transferred out.
[3] Includes Nos. 1, 2, and 4 fuel oils and Nos. 1, 2, and 4 diesel fuels.
[4] Includes natural gas obtained from utilities, transmission pipe lines, and any other supplier(s) such as brokers and producers.
* Estimate less than 0.5.
Q = Withheld because of relative standard error greater than 50 percent.
W = Withheld to avoid disclosing data for individual establishments.
Source: USDA, ERS, based on U.S. Department of Energy/Energy Information Administration, 1994.

With the improvement in technologies, many agricultural products are now used for producing electricity and liquid fuel for transportation. In 1993, over three quadrillion Btu of biomass energy were consumed in the United States, representing about 3.7 percent of total U.S. energy consumption. Energy from wood accounted for 87 percent of total biomass energy consumption, while energy from solid waste and corn-ethanol made up 10 and 3 percent. Wood was consumed in the United States for industrial and utility (two-thirds) as well as residential use (one-third). Wood energy use in the commercial sector was estimated to be over 20 billion Btu in 1986, the last year of available data.

Consumption of wood in the residential sector has been declining, due to people moving from rural to urban areas; the scarcity of inexpensive fuel wood; environmental restrictions on the burning of wood, especially in populated areas; and the emergence of clean-burning and more efficient gas fireplaces.

Biomass Electricity

During the 1980's national interest grew in wood-burning electric-generating plants as a result of the National Energy Policy Act and state utility regulatory actions. More than 5,800 megawatts of power from wood-fueled electricity were added to the 200 existing in 1979. Of nearly a thousand wood-fired plants ranging from 1 to over 100 megawatts, only a third offer electricity for sale. The rest are owned and operated by paper and wood production industries for their own use.

Biomass-based electricity is most economical in those regions where electricity is relatively expensive and wood is cheap.

Despite rapid growth in the 1980s, the biomass power industry is now in a low-growth phase because of low fossil fuel prices, excess capacity, competitive bidding for power sales, and costly permitting procedures. Competition from efficient natural gas-turbine generators has also dampened the market for biomass projects. Natural gas has benefited from its low investment cost per kilowatt hour (Kwh), affordability and abundance due to new drilling technology, and ability to burn cleaner than coal, wood, and oil.

Energy crops (wood and grass) could become important feedstocks for the production of liquid fuels, electricity, chemicals, and other industrial products. With increases in yield and competitive conversion technologies, biomass crops such as herbaceous plants and wood might compete with fossil fuels for a broad range of uses. A biomass industry could also provide new income for farmers, jobs in rural areas, and markets for agricultural residues. Key to this scenario are increases in fossil fuel prices; more rapid advances in biomass gasification, gas clean-up, and gas-turbine power generation; and market development for biomass coproducts such as pulp wood chemicals. Policies that restrict greenhouse gas emissions or promote biomass production on idled land could also help.

Fuel Ethanol Production Processes

Ethanol is produced from corn by two standard production processes: wet- and dry-milling. With the exception of the initial separation process, the two processes are very similar. In dry-milling, the first step consists of grinding the corn, which is then slurried with water to form the mash and cooked. Enzymes convert the starch in the mash to sugar and, in the next stage, yeast ferment the sugars to produce beer. In the dry-mill process, the beer, containing alcohol, water, and dissolved solids, is separated from solids. It is then distilled and dehydrated to create anhydrous ethanol. The solids are dried and sold as distillers' dried grain with solubles (DDGS), commonly used as an animal protein feed. Using current technology, a bushel of corn when processed will yield 2.6 gallons of fuel-grade ethanol and 16.5-17.5 lbs. of DDGS. Carbon dioxide may also be collected from a fermentation tank.

In wet-milling, the first step involves soaking the corn kernels in water and sulfur dioxide and separating the corn into its major components: the germ, fiber, gluten, and starch. All other components of the corn kernel are removed prior to fermentation of starch. These components are used to produce three coproducts: corn oil, corn gluten feed (CGF), and corn gluten meal (CGM). A bushel of corn, when processed by wet-milling, can produce 1.6 lbs. of corn oil, 12.5 lbs. of CGF, and 2.5 lbs. of CGM. The remaining starch is saccharified, fermented, and distilled as in the dry-milling production process.

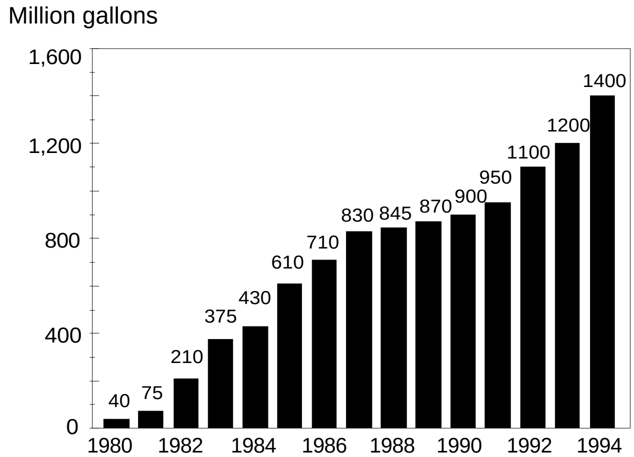
The Federal Government offers incentives for commercially competitive biomass energy, including unconventional fuel credits (99.3 cents per million Btu); power production tax credits (1.6 cents per kwh); alcohol fuel credits (60 cents per gallon of ethanol or methanol from biomass, in addition to 10 cents per gallon for “small” ethanol producers); accelerated depreciation (5 years versus 15-20 years) for certain biomass energy facilities; tax-exempt financing; cash subsidies (1.5 cents per kwh); and investment tax credits (6.5 percent) for growing energy crops exclusively for conversion of biomass to electricity (direct combustion and gasification) and liquid fuels. Given its uncertain competitiveness, biomass depends on projects that successfully demonstrate its utility for energy production in the United States. The U.S. Department of Energy (DOE) and the U.S. Department of Agriculture (USDA) are collaborating to develop technologies and to foster business arrangements that integrate electricity generation and rural development through biomass-based renewable energy (see chapter 5.1, *Agricultural Technology Development*). USDA will participate in these projects using existing authorities and programs, and DOE will share costs under authority of the Energy Policy Act of 1992 and the President’s Climate Change Action Plan.

Fuel Ethanol

The oil embargoes of 1973 and 1979 renewed interest in alcohol fuels, primarily fuel ethanol from grain. Energy security, new Federal gasoline standards, and government incentives have driven the grain-based fuel ethanol industry. When the energy crisis first exposed U.S. vulnerability to energy supply interruptions, fuel ethanol from agricultural resources was viewed only as a potential gasoline extender. In 1990, ethanol emerged as an octane enhancer after the Environmental Protection Agency (EPA) began to phase out lead in gasoline. More recently, ethanol production received a major boost with the passage of EPA’s Clean Air Act Amendments (CAA) of 1990 establishing the Oxygenated Fuels Program and Reformulated Gasoline (RFG) Program to control carbon monoxide (CO) and to mitigate ground-level ozone problems. Both programs require oxygen levels in gasoline of 2.7 percent (by weight) for oxygenated fuel and 2.0 percent for reformulated gasoline. The three leading oxygen additives are ethanol; ethyl tertiary butyl ether (ETBE), made from ethanol; and methyl tertiary butyl ether (MTBE) made from methanol, which is derived from natural gas.

Adding ethanol, ETBE, or MTBE to gasoline to create "oxygenated" blends reduces the amount of CO

Figure 3.3.3--U.S. ethanol production, 1980-94



Source: USDA, ERS, based on Renewable Fuels Association, 1994.

released into the atmosphere. These three additives compete closely for markets. Methanol had been a cheaper oxygen additive than ethanol, but RFG programs and other chemical applications increased the demand for methanol, pushing methanol prices to $1.40 per gallon in 1994 from 35 cents in 1993. A temporary shutdown of a large methanol producing plant due to an explosion also caused methanol prices to rise. That gave ethanol, a substitute for methanol, a temporary boost. The methanol situation is expected to ease in 1997 as additional capacity comes on line. In addition, the Treasury Department announced in 1994 that the ethanol portion of ETBE was eligible for an exemption from the Federal excise tax of 18.4 cents per gallon, now available to ethanol. As gasoline blended with ETBE contains 5.6 percent ethanol, the tax break per gallon of ETBE amounts to 3 cents. For gasohol (gasoline containing 10 percent ethanol), the exemption is 4.5 cents. This ruling increased ETBE’s competitiveness with other qualifying alcohols in the RFG market. Ethanol’s competitiveness will also improve as producers adopt energy-efficient technologies and other cost-saving innovations.

Fuel ethanol production in the United States has grown from just a few thousand gallons in the mid-1970’s to 1.4 billion gallons in 1994 (fig. 3.3.3). As of July 1995, U.S. fuel ethanol industry was comprised of 41 operational facilities in 15 States. Several large producers dominate the industry. Archer Daniels Midland alone had 59 percent of U.S. annual operational production capacity (1.7 billion gallons) in 1995. About 71 percent of fuel ethanol’s production capacity is in the Corn Belt region, followed by the Northern Plains with 14 percent. U.S. ethanol production capacity is nearly 2.2 billion gallons per year, including capacity under construction or in the engineering/financing stage and capacity which is shut down at present. The two main processes for producing ethanol from corn are wet-milling and dry-milling (see box, "Fuel Ethanol Production Processes," p. 139). Wet-milling accounts for about 60 percent of total ethanol production.

Ethanol production costs vary greatly, depending largely on net feedstock cost (grain cost minus value of byproducts). For 1981-91, net feedstock cost ranged from 10 to 67 cents per gallon of ethanol, due mainly to large swings in the price of corn ($1.58 to $3.16 per bushel). Changes in coproduct prices also contributed to this variation. Together, capital and operating costs for wet milling ranged from 78 cents to $1.07 per gallon, bringing the cost of ethanol to $0.88-1.74 per gallon. With an expected price of corn of about $3 per bushel in the 1995/96 marketing year, total cost of producing ethanol could rise 20 to 23 cents per gallon due to higher net corn cost, lowering its competitiveness with other fuels. Higher corn prices have reduced profits for fuel ethanol producers and, consequently, production has been cut. In May 1996, the market price of corn reached a record $4.98 per bushel and some large ethanol producers further cut back production.

Author: Mohinder Gill, (202) 219-0447 [mgill@econ.ag.gov]. Contributor: Hosein Shapouri.

Recent ERS Reports on Energy Issues

Farm Energy, AREI Update, 1995 No. 16 (Mohinder Gill). Farm fuel prices are influenced by crude oil prices especially imported crude oil. In 1994, compared with 1993, farm fuel prices fell by 5 - 8 percent as the imported crude oil price fell by 4 percent. Farm energy expenditures, at $5.56 billion in 1994, were 1 percent less, compared with 1993 an estimated 5.8 billion gallons of fuel was consumed in 1994, 7 percent higher than 1993, because of increased planted acreage.

"The Agricultural Demand for Electricity in the United States," *International Journal of Energy Research*, 1995 Vol. 19 (Noel D. Uri and Mohinder Gill). The price of electricity is a factor impacting the quantity of electricity demanded by farmers for irrigation and nonirrigation uses, but there is no indication that other types of energy are substitutes for electricity. Number of acres irrigated and number of acres planted are important factors driving the demand for electricity for irrigation and nonirrigation uses.

(Contact to obtain reports: Mohinder Gill, (202) 219-0447 [mgill@econ.ag.gov].

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3.4 Farm Machinery

Increasingly complex farm machinery is an essential contributor to the productivity gains of U.S. agriculture. Expenditures on farm machinery in 1995 made up 13 percent of total production expenditures. Farm machinery sales in 1995 and 1996 leveled off somewhat after showing significant increases in 1993 and 1994. The increased value of farm assets and higher farm cash receipts have helped maintain farm machinery sales.

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Farm machinery and equipment are increasing in complexity, price, and, in many cases, size. Expenditures on farm machinery make up 13 percent of total production expenditures and farm machinery assets are 9 percent of total farm assets (USDA, ERS, 1996b; USDA, NASS, 1996b). Trends toward conservation tillage and no-till have prompted inventions such as the air drill and the coulter chisel plow. Precision farming is the impetus for new inventions, including continuous yield monitoring equipment and variable-input gaging devices, and will likely inspire more inventions in the near future.

Operation of farm machinery can cause soil compaction and contribute to engine emissions. These environmental effects can be lessened by using specific farming practices and special exhaust systems and fuels. Engine exhaust emissions will be reduced as new tractors meet EPA requirements by the year 2000 (USDA, ERS, 1994b). The risks in operating farm machinery make agriculture one of the Nation's most hazardous occupations, but improved safety measures are reducing accidents and injuries (see box, "Farm Machinery Safety").

Farm Machinery Sales

After showing a significant increase in 1994, purchases of farm machinery continued to increase through 1996, but at a slower rate. Farm tractor purchases increased 9 percent from 1993 (57,800 units) to 1994 (63,200). From 1994 to 1995, the increase in purchases was 2 percent (to 64,600 units) (table 3.4.1, fig. 3.4.1). Purchases increased 4 percent in 1996. Combine sales were also up in 1995, increasing by 8 percent, but slowed in 1996. Tractor and combine sales are indicators of the general farm machinery economy; retail sales data on other machinery are not available.

Several demand factors were favorable for increased purchases of tractors and farm machinery in 1996, and purchases increased in most horsepower classes. Tractor sales in the 40-99 horsepower category increased 4 percent in 1996. Tractor sales in the 100-and-over horsepower category also increased 4 percent. Purchases of four-wheel-drive tractors stayed the same.

Farm Machinery Safety

Agriculture is one of the Nation's most hazardous occupations. Estimates of annual agricultural deaths vary between 26 and 50 workers per 100,000, compared with an annual rate of 11 for all industries combined (USDHHS, 1992; MMS, 1995).

Little data are available on farm accidents, injuries, and illnesses. The census of agriculture included questions on the number of injuries and deaths on farms for the first time in 1992. Runyan, in 1993, published a review and synopsis of data sources on farm accidents. Nationally, some data are available from several sources: the Department of Labor, Department of Commerce, Product Safety Commission, Department of Health and Human Services, National Safety Council, Department of Agriculture, and the State Workers' Compensation Systems. Also, some data are available from State and local sources, including newspapers, coroners, hospitals, and medical personnel.

Farm-related injuries totaled 64,813 in 1992 according to the census of agriculture (USDC, 1994a). There were 673 farm-related deaths. The census does not report the cause of injuries and deaths, but many were likely related to machinery use. A recent study of farm accidents in Kentucky found that 82 percent of tractor-related fatalities were due to rollovers. Most of these occurred while mowing (32 percent). All the victims were male. The median age of the tractors was 23 years, ranging from 2 to 41 years. Most of the fatalities could have been prevented had the tractor been equipped with rollover protection (ROPS) and seatbelts. ROPS and seatbelts were not required on new tractors until 1976 (MMS, 1995).

The farm machinery industry has done much to improve farm safety. Rollover protection is provided on new tractors. Fully enclosed cabs offer protection on most larger tractors, combines, and other self-propelled equipment. Power take-off shields have been standard equipment for many years. Warning decals are placed near hazardous locations. More effort to educate farmers, their families, and farmworkers about the dangers in operating farm machinery and equipment could help reduce injuries and fatalities.

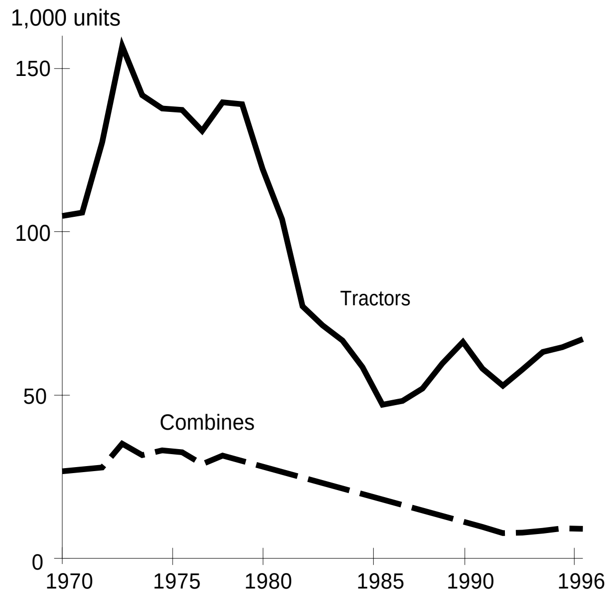
There are economic costs associated with deaths, injuries, and illnesses from farm-related causes. A New York study of people killed in farm accidents estimated that from $218,001 to $362,047 (adjusted to 1987 dollars) of lifetime expected income and opportunity costs (per person) were foregone due to farm accidents (Kelsey, 1991). Costs include health care, discounted future earnings, and special devices such as wheelchairs and lifts. In some cases, the farm has to be sold to help pay for medical expenses. Society also bears many of the costs of farm accidents when the family is unable to pay medical costs and expenses.

Table 3.4.1—Domestic farm machinery unit sales, 1986-96

Machinery category	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
						Units					
Tractors:											
Two-wheel-drive--											
40-99 hp	30,800	30,700	33,100	35,000	38,400	33,900	34,500	35,500	39,100	39,700	41,200
100 hp and over	14,300	15,900	16,100	20,600	22,800	20,100	15,600	19,000	20,400	20,500	21,400
Four-wheel-drive	2,000	1,700	2,700	4,100	5,100	4,100	2,700	3,300	3,700	4,400	4,400
All farm wheel tractors	47,100	48,400	51,700	59,700	66,300	58,100	52,800	57,800	63,200	64,600	67,000
Self-propelled combines	7,700	7,200	6,000	9,100	10,400	9,700	7,700	7,850	8,500	9,200	9,000

Source: USDA, ERS, based on Equipment Manufacturers Institute, various years.

Figure 3.4.1--Farm tractor and combine unit sales, 1970-96



Tractors-40 HP & up and self-propelled combines.

Source: USDA, ERS, based on Equipment Manufacturers Institute, various years.

Table 3.4.2—Plant capacity utilization in the farm machinery and equipment industry (fourth quarter)

Year	Capacity utilization rates[1]
	Percent
1980	62
1981	48
1982	31
1983	38
1984	41
1985	37
1986	24
1987	43
1988	54
1989	66
1990	66
1991	64
1992	56
1993	59
1994	66

[1]For 1989 and later, percent of full production; for 1988 and earlier, percent of "practical capacity."

1993 and 1994 estimated.

Source: USDA, ERS, based on USDC, 1994b and Federal Reserve, 1995.

Farm machinery plant capacity being utilized was estimated at 66 percent for 1994, compared with 24 percent in 1986 (table 3.4.2). Plant capacity utilization increased every year since 1992. The low rate in 1986 followed several years of low demand for farm machinery and large dealer inventories. Total or full production capacity was low throughout most of the 1980's as farm machinery manufacturers cut back, consolidated, and merged in response to low sales and economic pressures. The same capacity utilization rate in the 1970's produced more farm machinery since full production for the industry was higher. Also, capacity utilization was higher, 83-85 percent throughout the 1970's, as the farm machinery industry responded to high demand caused by high farm incomes, large exports, and high real estate asset values (USDC, 1994b).

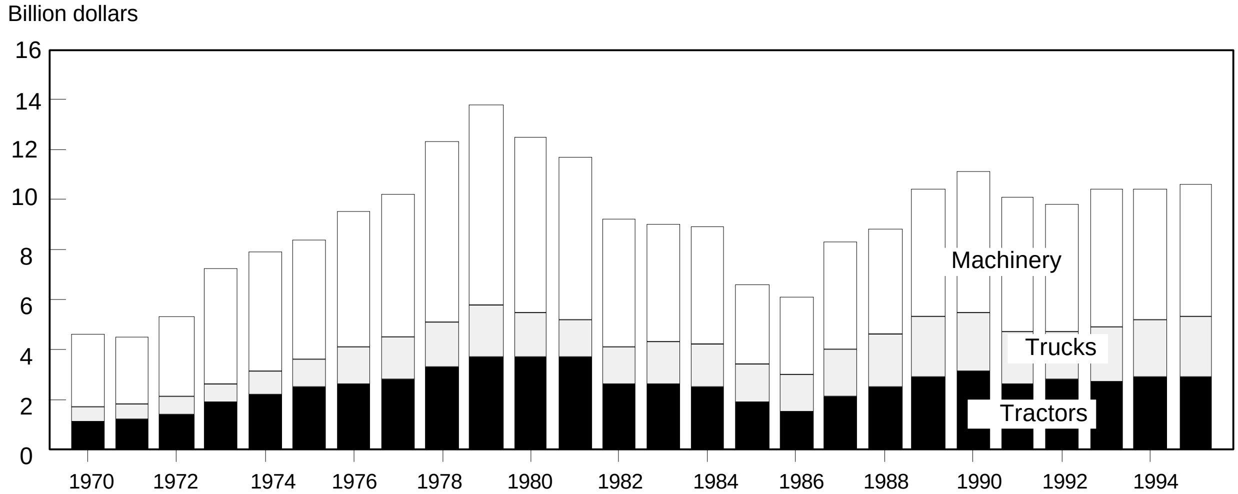
Capital Expenditures and Depreciation

Another indicator of the economic health of the farming sector is the difference between capital expenditures and depreciation, which represents the amount of capital accumulation or depletion. Capital expenditures are the dollar value investment in tractors, trucks, farm autos, and farm machinery as opposed to *units* of tractors and combines sold. Capital expenditures are the purchases of new and used durable machinery and equipment (less trade-ins) that will be used (and depreciated) over a number of years (USDA, ERS, 1988). Depreciation, also referred to as economic depreciation or capital consumption (as opposed to depreciation for income tax purposes), measures the amount of capital stock used up in the production process (McGath and Strickland, 1995).

Capital expenditures on tractors, trucks, and farm machinery, in nominal dollars, reached a peak in 1979 and, despite recent gains, are still $3 billion below that peak (fig. 3.4.2, table 3.4.3). In real terms (adjusted for inflation), depreciation of farm machinery has exceeded capital expenditures every year since 1980 (fig. 3.4.3). In 1985, real depreciation reached $8.5 billion and real capital expenditures were $4.2 billion, a gap of $4.3 billion. In 1995, capital depletion was $1.1 billion, about the same as in 1994.

Capital depletion in the farming sector may be due to several reasons. The mechanization of agriculture is changing. Tractors, combines, and other powered machinery have been getting larger and more efficient. Tillage practices have been changing from conventional tillage, which involved working the soil many times prior to planting, to reduced and no-till

Figure 3.4.2--Farm machinery capital expenditures, 1970-95

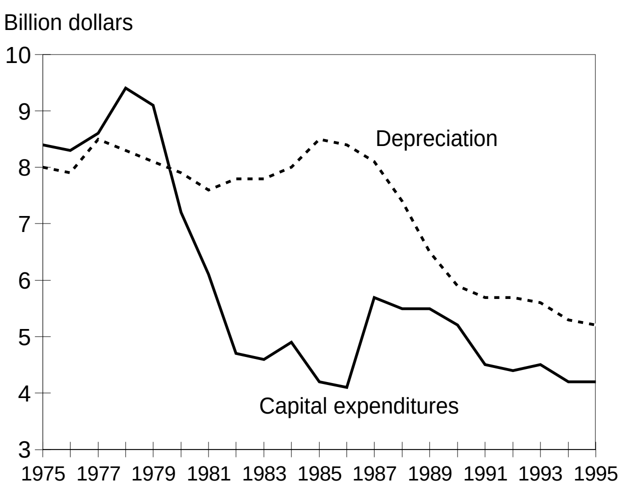


1995 forecast.
Nominal dollars.

Source: USDA, ERS, 1994a and other ERS sources.

practices, which require fewer times over the soil, help conserve soil, and prolong the useful life of tractors and equipment. Also, farming was very profitable in the late 1970's, which encouraged farmers to buy more and larger tractors and machinery than needed for efficient operations. More than 157,000 farm tractors were sold in 1973, compared with only 47,000 in 1986. In the early 1980's, farm income declined, farmers bought less machinery, and the farming sector remained productive by keeping old machinery in repair and using the extra machinery capacity built up during the late 1970's. Delaying expenditures on farm machinery can result in higher repair costs, but there is usually a period of time when the difference in cost between keeping an old machine and buying a new one is small.

Figure 3.4.3--Machinery capital expenditures and depreciation, 1975-95



Adjusted to 1975 dollars; 1995 estimated.

Source: USDA, ERS, 1994a and other ERS sources.

At some point in the future, capital investment should equal and surpass depreciation. The gap between capital expenditures and depreciation narrowed in the late 1980's, but increased again in 1991. Capital depletion has been a little over $1 billion each year since 1993. However, this was only about 3 percent of the total capital inventory stock of machinery on farms and likely represents adjustments due to efficiencies in technology and changes in farming practices. More farmers are buying the specialized machinery needed to comply with conservation plans. Also, capital expenditures likely increased in 1996. These factors should soon bring back capital accumulation in the farming sector.

Factors Affecting Machinery Demand

Farm machinery demand is affected by various factors, including machinery prices, interest rates, farm equity, farm income, and cropland used for crops (see box, "Factors Affecting Demand for Farm Machinery," p. 148). Machinery prices and interest rates determine the cost of purchasing farm equipment. Farm equity is the result of assets minus debt and is a measure of the collateral available to

Table 3.4.3—Trends in U.S. farm investment expenditures and factors affecting farm investment demand, 1988-96

Item	1988	1989	1990	1991	1992	1993	1994	1995	1996F
Capital expenditures:					*$ billion*				
Tractors	2.54	2.90	3.12	2.59	2.83	2.69	2.89	2.91	2.90-2.98
Other farm machinery	4.22	5.09	5.59	5.41	5.13	5.49	5.18	5.05	5.15-5.30
Total	6.76	7.99	8.71	8.00	7.96	8.18	8.07	7.96	8.05-8.28
Repairs	4.16	4.71	4.50	4.55	4.18	4.46	4.35	4.56	4.49-4.60
Trucks and autos	2.37	2.58	2.63	2.40	2.30	2.50	2.56	2.80	2.62-2.82
Farm buildings[1]	2.39	2.53	2.80	2.75	2.37	3.39	3.25	3.01	3.10-3.23
Factors affecting demand:									
Interest expenses	14.3	13.9	13.4	12.1	11.2	10.8	11.8	12.8	13.0
Production expenses	137.8	144.9	153.7	153.4	152.5	160.5	167.4	175.6	183.1
Farm business assets:									
Real estate assets[2]	595.5	615.7	618.4	624.4	642.8	673.4	706.9	755.7	808.6
Other assets[2]	205.6	214.1	220.3	219.4	226.1	231.1	231.2	222.3	226.5
Farm business debt[2,3]	139.4	137.2	138.0	139.2	139.0	141.9	146.8	150.8	155.4
Equity[2]	661.7	692.4	700.7	704.6	729.9	762.6	791.3	827.2	879.7
Agricultural exports[4]	35.3	39.6	39.4	39.2	42.9	42.6	45.7	55.8	60.4
Cash receipts	151.2	161.1	169.4	167.8	171.3	177.6	180.8	185.8	200.4
Net farm income	38.0	47.9	44.8	38.4	48.0	43.6	48.4	34.8	51.7
Net cash income	54.5	54.2	52.9	50.4	55.5	58.9	50.5	48.8	57.4
Government payments	14.5	10.9	9.3	8.2	9.2	13.4	7.9	7.3	7.8
					Million acres				
Idled acres[5]	77.7	60.8	61.6	64.5	54.9	59.8	49.2	54.8	34.4
Interest rates:					*Percent*				
Real prime rate[6,7]	5.4	6.5	5.7	4.5	3.5	3.4	4.8	6.3	6.2
Nominal farm machinery loan rate[7]	11.7	12.8	12.3	11.3	9.3	8.7	8.6	10.3	9.7
Real farm machinery loan rate[6,7]	8.4	8.4	8.0	7.5	6.5	5.3	6.3	7.8	7.6
Debt-asset ratio[8]	17.4	16.5	16.4	16.5	16.0	15.7	15.6	15.4	15.0

F-forecast.

[1] Includes service buildings, structures, and land improvements.

[2] Calculated using nominal dollar balance sheet data, excluding farm households, for December 31 of each year.

[3] Excludes Commodity Credit Corporation loans.

[4] Fiscal year.

[5] Includes acres idled through commodity programs and acres enrolled in the Conservation Reserve Program.

[6] Deflated by the Gross Domestic Product deflator.

[7] Average annual interest rate. From the quarterly sample survey of commercial banks: Agricultural Financial Databook, Board of Governors of the Federal Reserve System.

[8] Outstanding farm debt divided by the sum of farm real and nonreal estate asset values.

Sources: USDA, ERS, 1997, 1996b, 1994a; FRS, 1995.

Table 3.4.4—Prices paid indexes for selected production items and interest, annual averages[1]

Year	Farm machinery	Trucks and autos	Fuels	Feed	Livestock and poultry	Interest	Production items, interest, taxes and wage rates	GDP price deflator
				1990-92 = 100				*1992=100*
1984	85	78	93	112	73	124	91	76
1985	85	83	93	95	74	106	87	78
1986	83	86	76	88	73	98	85	81
1987	85	88	76	83	85	96	87	83
1988	89	90	77	104	91	100	92	86
1989	94	93	83	110	93	106	97	90
1990	96	97	100	103	102	107	99	94
1991	100	100	104	98	102	100	100	97
1992	104	102	96	99	96	93	101	100
1993	107	105	93	101	104	87	102	103
1994	113	107	95	105	94	94	105	105
1995	121	107	94	105	82	101	109	108
1996	125	108	105	130	75	105	114	110
1997, Jan.-Apr., avg.	127	110	109	125	89	106	116	111

[1] Indexes are current, actual (undeflated) prices, weighted by the relative importance of component items that make up each individual category and converted to the base year 1990-92=100 (USDA, 1990). First quarter, for 1997 GDP.

Source: USDA, ERS, based on NASS, 1996a, 1997; Council of Economic Advisers, 1997.

back farm machinery loans. Farm income is determined from cash receipts, less production expenses, and is an indication of cash flow available to purchase farm machinery.

Farm machinery prices rose 4 percentage points from 1995 to 1996 (table 3.4.4). Increased machinery prices depress farm machinery demand (Conley, 1992; Cromarty, 1959). The April 1997 prices-paid index (1990-92=100) for farm machinery was 127, 2 points above 1996; prices for trucks and autos also rose 2 points. The price index for all production items rose only 2 points.

The farm machinery nominal interest rate decreased to 8.6 percent in 1994, the lowest in 9 years. However, the real prime rate (adjusted for inflation) reached a low in 1993 and steadily rose to 6.3 percent in 1995 (table 3.4.3). Both the nominal and real farm machinery interest rates lag behind the prime rate and fell in 1996—to 9.7 percent and 7.6 percent. Higher interest rates have a negative effect on farm machinery investments (Kolajo and Adrian, 1986). As interest rates rise, the total cost of machinery bought on credit increases, dampening purchases. While the real rate reflects the actual cost of borrowing, the nominal rate likely has more effect on machinery purchases because it is more obvious to farmers. The importance of real versus nominal interest rates depends on the extent that farmers take into account expectations about inflation rates.

One of the more favorable farm machinery demand indicators has been sizable increases every year since 1991 in the value of farm equity (assets minus debt). Equity increased from $705 billion in 1991 to $880 billion in 1996. The increase in equity is due to large jumps in asset values, primarily real estate. The value of farm real estate assets has also increased every year since 1991 (table 3.4.3). Total assets include both real estate and nonreal estate items, and, when increasing, have a positive effect on farm machinery demand (Cromarty, 1959). Farm business assets were $1,035 billion in 1996, an increase of $57 billion (6 percent) from 1995. Farm business debt, which has a dampening effect on farm machinery demand, was up $4.6 billion in 1996, an increase of 3 percent. When farm equity increases, more collateral is available to finance farm machinery capital expenditures. Farm equity increased again in 1996. The ratio of debts to assets decreased to 15 percent

Factors Affecting Demand for Farm Machinery

Agricultural exports—Exports of U.S. agricultural products (fiscal year October 1 through September 30).

Cash receipts—Sales of all crop and livestock commodities. Cash receipts are like "money in the pocket" and correlate closely with purchases of farm machinery.

Debt-asset ratio—Farm business debt divided by farm business assets. Lower debt/asset ratios mean more favorable borrowing positions and more investment in tractors, combines, and other farm machinery.

Equity—Total assets minus debt. Farm equity represents a farmer's net worth; the greater the equity, the more collateral the farmer has available to back loans for capital investment.

Farm business debt—Real estate and nonreal estate debt.

Farm machinery loan rate—Average annual interest rate as reported in the quarterly survey of commercial banks by the Federal Reserve System (FRS, 1995). An inverse relationship exists between interest rates and the purchase of farm machinery. Lower interest rates imply greater purchases of farm machinery.

Idled acres—Cropland idled through commodity programs or enrolled in the Conservation Reserve Program. More land idled means less cropland to be cultivated, seeded, and harvested. Machinery is used less, prolonging useful life.

Interest expenses—Interest on both real estate and nonreal estate debt.

Net cash income—Gross cash income (cash receipts, direct government payments, and farm-related income) minus cash expenses.

Net farm income—Gross cash income, nonmoney income, and inventory adjustments minus total production expenses. Net farm income has a high correlation with machinery purchases when purchases are lagged several months behind income.

Nonreal estate assets—Includes livestock, crops, machinery, motor vehicles, and financial assets.

Real estate assets—Land and service structures. Increasing assets place a farmer in a more favorable position for obtaining capital investment loans.

Real prime rate—Bank prime rate, adjusted for inflation by the gross domestic product deflator.

Total production expenses—Total of cash expenses (inputs purchased, such as feed, seed, fertilizer, pesticides, fuel, repairs, custom work, and labor; interest; rent; and property taxes) plus noncash expenses, which include capital replacement and accidental damage.

from 1995 to 1996, the lowest ratio since the early 1960's, indicating a favorable borrowing position.

Farm income has a lagged effect on machinery sales, with higher purchases a year or more from the year of increased income (Rayner and Cowling, 1968). Increases in income have a positive effect on farmers' expectations about future income, which spurs machinery demand. Net farm income is cash income plus or minus the value of inventory changes, nonmoney income, noncash expenses, and operator dwelling expenses. Net farm income was up 7 percent in 1996 to $51.7 billion, from the previous high of $48.4 billion in 1994 (table 3.4.3). Cash receipts were up every year, 1992-96.

Commodity prices, a major determinant of cash receipts, rose significantly in 1996, especially for wheat, corn, and soybeans. Increased commodity prices, alone, with no changes in other input factors, would normally brighten the outlook for the farm economy and increase the demand for farm machinery. Higher crop prices, coupled with large inventory adjustments, resulted in high net farm income in 1996. Higher commodity prices are the result of low world carryover stocks, primarily caused by drought and adverse weather conditions in major grain growing countries. High prices also reflect the high export demand for several major commodities. Commodity exports were $60.4 billion in 1996, up $4.6 billion from 1995, an 8-percent increase (table 3.4.3). This is the highest level of commodity exports in at least 10 years. Wheat, feedgrains, and oilseeds compose the largest share of commodity exports. The upward trend in commodity exports favors increased investment in farm machinery.

In 1996, idled land decreased to 34 million acres from a high of 77.7 million in 1988. As Conservation Reserve Program (CRP) contracts expire, some of that land will come into production, possibly spurring demand for farm machinery. Some farmers will still have the same complement of machinery that existed before they signed up for the CRP. Others who may have put the entire farm in the CRP and reduced their machinery inventories will need to obtain more equipment. The overall effect of reductions in CRP acreage should be some increase in demand for farm machinery.

Changes in Farming Practices and Machinery

Two major change factors influencing the farm machinery industry are the emerging interest in precision farming and the continuing adoption of conservation tillage and crop residue management practices.

Precision Agriculture

The newest innovation in agriculture is the trend toward computerized equipment that allows precise quantity and placement of inputs such as fertilizer, seed, and pesticides (Christensen and Krause, 1995). This new technology is known variously as precision farming, site-specific farming, soil-specific crop management, prescription farming, focused fertilizing, spatially variable controlled crop production, and site-specific nutrient management systems. Ideally, precision farming will improve input efficiency and reduce the use of chemicals and fertilizers.

However, unresolved questions need further research. For example, what size of farming operation will benefit most from precision farming? The complexity and expense of the machinery and operations may make precision farming more plausible by large-scale operations, perhaps further concentrating U.S. agriculture. On the other hand, the costs of yield monitors, global positioning computers, and other precision farming equipment is decreasing. And expensive variable-rate fertilizer, pesticide, and seeding equipment is being increasingly supplied by dealers on a custom or rental basis, forestalling large investments at the farm level for equipment that will quickly become obsolete as newer technology is developed. The issue then becomes one of managerial time required to learn and apply the technology. Large-scale farmers may not be able to spend as much time on this technology as medium-scale farmers. Also, small-scale farmers who spend a lot of time working off the farm may not be able to devote much time to precision farming.

Precision farming generally employs satellite technology, which tracks equipment location within a few meters in a field. Site-specific information is important because crop yields can differ significantly throughout a field. Computers record crop yields, soil characteristics, and other data continuously within each field. Fertilizers and pesticides can then be specified from information in the computer data base. This information is used to vary seed, fertilizer, and pesticide quantities to site-specific field locations (Robert and others, 1992).

Precision farming is still in its infancy. Equipment is expensive; variable-rate fertilizer applicators cost as much as $250,000. However, prices are declining as manufacturers develop more efficient ways of producing the specialized computers, receivers, metering devices, and variable-rate seeders, sprayers, and fertilizing equipment. Farmers also face time constraints in learning precision farming. Few courses or training sessions are available and most of the subject matter is highly technical, involving computers and space-age locating, monitoring, and metering equipment.

Researchers at ARS (Agricultural Research Service, USDA) and several universities are investigating the relationships between soil conditions, moisture, nutrient balances, and crop yields, and how these relationships bear on input applications (USDA, NAL, 1994). The farm equipment industry also researches precision farming and has outpaced public research in many areas. Preliminary research indicates improved efficiencies in the use of fertilizers and pesticides. Instead of broadcasting nutrients and chemicals across the field, precision farming prescribes appropriate amounts by soil, moisture, nutrient balance, and other site-specific factors. In addition to improving input inefficiency, precision farming has the potential to lessen adverse environmental effects of current farming practices. By improving input efficiency, precision farming can reduce residual quantities that may otherwise enter streams and groundwater.

While precision farming more commonly refers to site-specific field tracking technology and computerized metering equipment, it may also apply to other innovations. Among the newest is a cultivator that tills between plants within a row (Paulson, 1995). It incorporates video cameras and computer technology with robotics to eliminate weeds to within one-third inch of the plant. It can operate at speeds of up to 10 miles per hour, can be used at night, and can distinguish between weeds and crops. While still in the testing stage, it has promise for the cultivation of row crops such as corn, cotton, lettuce and tomatoes. This technology could reduce the need for herbicides used to eliminate weeds.

Crop Residue Management

The other major change occurring in the farm machinery industry is the continuing development of conservation tillage machinery and equipment used for crop residue management. Tillage equipment used to practice conservation tillage involves several designs aimed at leaving at least 30 percent of the soil surface covered with crop residue. This new and innovative machinery goes by various names, including air drill, mulchmaster, mulch tiller, and conservation disk chisel. Machinery is designed to leave residue on the surface by tilling the ground under the past crop residue instead of turning the ground over and burying residue as was done with moldboard plows and large offset disks.

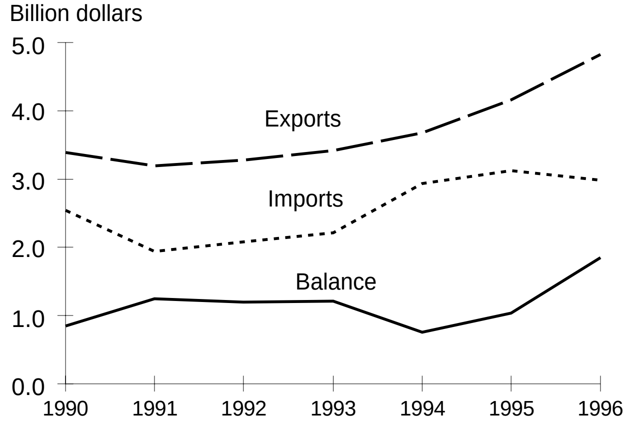
With conservation tillage, the ground is worked fewer times during a crop cycle than with conventional tillage, leaving more residue on the surface. Increased residue helps prevent soil erosion. No-till engages the ground just once, when planting the seed.

Other benefits of crop residue management (and fewer times over the field) are less machinery and equipment wear and lower maintenance. Capital expenditures are reduced as are fuel and labor costs. (See chapter 4.2, *Crop Residue Management*, for a discussion of trends in conservation tillage. See also USDA, ERS, 1994b, page 114, for a discussion of the effects of these trends on farm machinery purchases.)

Farm Machinery Trade

The United States had a trade surplus in farm machinery of $1.85 billion in 1996, up from $1.04 billion in 1995. Exports of farm machinery have exceeded imports for the last 7 years (fig. 3.4.4). Major export and import countries were Canada, the United Kingdom, Germany, and Japan.

Figure 3.4.4--Farm machinery exports, imports, and trade balance (exports minus imports), 1990-96



Source: USDA, ERS, based on unpublished U.S. Department of Commerce data.

Total imports and exports, and consequently the farm machinery trade balance, can be volatile from year to year. A single large sale of combines or irrigation equipment can significantly affect total exports. Changes in factors that affect U.S. demand for farm machinery will affect import totals. Both imports and exports can increase and the trade balance decrease, as happened in 1994 (fig. 3.4.4).

Exports of farm machinery totaled $4.8 billion in 1996, up 16 percent from 1995 (table 3.4.5). Imports for 1996, $3.0 billion, decreased 4 percent from 1995 (table 3.4.6).

The largest export category—tractor gear boxes, axles, chassis, engines, brakes, differentials, wheels, mufflers, exhausts, steering assembles, and parts and accessories not elsewhere classified—accounted for 22 percent of farm machinery exports ($1.0 billion) in 1996. Farm tractors over 100 horsepower made up 14 percent of 1996 exports. Other big export items included combines and harvesters, horticultural equipment, irrigation equipment, and agricultural engines.

Canada was the major export market in 1996, accounting for 32 percent of U.S. farm machinery exports. Canada was also the major supplier of farm machinery imports into the United States, accounting for 22 percent of all 1996 imports (USDA, ERS, 1996b).

Table 3.4.5—U.S. farm machinery exports, 1990-96[1]

Item	1990	1991	1992	1993	1994	1995	1996
				Million dollars			
Total	3,392	3,196	3,280	3,419	3,684	4,158	4,830
Tractors							
Wheel tractors, 40-100 HP	16	12	18	31	45	98	109
Wheel tractors, over 100 HP	331	335	356	445	417	525	691
Wheel tractors, used & misc.	91	84	76	88	87	86	103
Crawlers, less than 160 HP[2]	13	14	13	16	15	16	12
Crawlers, over 160 HP[2]	296	356	327	232	312	310	325
Crawlers, used[2]	17	25	21	16	21	18	16
Self-propelled combines	182	163	205	310	275	288	496
Other combines and harvesters	196	171	141	162	200	218	257
Balers	74	60	66	77	78	68	71
Mowers	42	46	47	55	65	51	42
Other haying equipment	49	34	34	52	52	46	43
Moldboard plows	2	1	1	1	1	0	0
Disc and other plows	9	10	11	15	15	12	17
Harrows and cultivators	28	27	29	43	45	40	50
Seeders and planters	36	29	34	46	52	39	82
Fertilizing equipment	18	22	22	23	27	22	26
Spraying equipment	10	22	24	22	23	25	26
Other seeding, fert., & spray equipment	61	80	84	94	119	116	124
Irrigation equipment	183	174	185	200	157	154	197
Horticultural equipment	179	95	154	176	180	185	229
Crop market preparation equipment	57	65	69	78	61	91	75
Cleaning and grading equipment	21	18	21	17	20	23	27
Dairy equipment	53	54	58	64	72	82	79
Poultry equipment	65	95	101	88	113	132	142
Other livestock equipment	43	49	48	56	60	54	70
Agricultural tools	24	27	41	21	22	20	24
Agricultural engines[2]	315	269	312	253	197	316	427
Gear boxes, axles, and assemblies[2]	969	846	758	711	925	1,096	1,046
Trailers, wagons and parts	13	13	20	27	26	25	24

[1] Some items may not be comparable to previous ERS trade data due to reclassification. Total exports may differ from those derived by other agencies due to inclusion or exclusion of specific categories.
[2] Includes industrial and other non-agricultural uses.
Source: USDA, ERS, based on unpublished U.S. Department of Commerce data.

Author: Marlow Vesterby, (202) 219-0422 [vesterby@econ.ag.gov]

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Table 3.4.6—U.S. farm machinery imports and trade balance, 1990-96[1]

Item	1990	1991	1992	1993	1994	1995	1996
				Million dollars			
Total	2,545	1,945	2,083	2,210	2,932	3,120	2,981
Tractors							
Wheel tractors, 40-100 HP	718	547	569	565	699	722	623
Wheel tractors, over 100 HP	183	172	188	137	202	220	232
Wheel tractors, used & misc.	97	46	38	59	129	133	115
Crawlers, less than 160 HP	129	82	93	149	204	187	184
Crawlers, over 160 HP	9	2	47	15	36	140	82
Crawlers, used	4	1	1	5	8	4	4
Self-propelled combines	22	18	15	16	25	25	17
Other combines and harvesters	124	95	93	121	113	130	136
Balers	79	71	62	55	67	77	55
Mowers	77	60	60	64	72	73	65
Other haying equipment	33	26	21	33	45	50	35
Moldboard plows	6	6	3	3	1	1	1
Disc and other plows	44	32	27	22	22	21	24
Harrows and cultivators	190	128	118	122	143	138	155
Seeders and planters	40	19	26	56	53	47	66
Fertilizing equipment	17	14	15	16	16	14	14
Spraying equipment	20	12	13	14	14	15	19
Other seeding, fert., & spray equipment	22	21	22	25	29	26	33
Irrigation equipment	7	13	19	17	11	12	16
Horticultural equipment	37	27	27	36	43	44	41
Crop market preparation equipment	20	16	19	20	23	24	29
Cleaning and grading equipment	8	9	9	15	17	12	10
Dairy equipment	18	11	19	18	18	21	20
Poultry equipment	21	27	25	22	25	25	31
Other livestock equipment	25	18	21	23	28	31	29
Agricultural tools	55	35	39	40	43	44	45
Agricultural engines	87	58	71	69	104	127	80
Gear boxes, axles, and assemblies	446	376	419	468	734	746	804
Trailers, wagons and parts	7	4	4	6	8	9	12
Balance: exports minus imports	847	1,251	1,197	1,209	753	1,039	1,849

[1] Some items may not be comparable to previous ERS trade data due to reclassification. Total imports may differ from those derived by other agencies due to inclusion or exclusion of specific categories.

Source: USDA, ERS, based on unpublished U.S. Department of Commerce data.

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