4.5 Nutrient Management

Nutrients are essential for ensuring adequate crop yields and profitability but have long been associated with surface- and ground-water contamination. Many improved practices are available to reduce nutrient losses to the environment, with varying degrees of adoption by farmers. Improving nutrient management to reduce losses to the environment requires (1) a better understanding of the link between agricultural production and water quality; (2) agricultural R&D to develop scientifically and economically sound management practices; and (3) public policies and programs that specifically encourage the adoption of resource-conserving practices.

Contents

Profitable crop production requires significant amounts of nutrients in the form of commercial fertilizers and animal wastes (see chapter 3.1, *Nutrients*), portions of which can subsequently run off into surface waters or leach into groundwater. The two primary agricultural nutrients affecting water quality are nitrogen and phosphorus. Nitrogen, primarily found in the soil as nitrate, is soluble and easily transported by surface runoff, in tile drainage, or by leachate. Phosphorus, primarily in the form of phosphate, is not as soluble as nitrate and is primarily transported by sediment in runoff.

Why Manage Nutrients?

Excessive nitrogen or phosphorus in surface waters can cause algae to grow at an accelerated rate and cloud water, which prevents aquatic plants from receiving sunlight for photosynthesis. When the algae die and are decomposed by bacteria, they deplete the oxygen dissolved in the water and threaten aquatic animal life. This process, eutrophication, can result in clogged pipelines, fish kills, and reduced recreational opportunities or enjoyment. According to EPA, nutrient pollution is the leading cause of water quality impairment in lakes and estuaries and the third leading cause in rivers (1995). Above a certain concentration, nitrate is also a concern for drinking water. Based on the human health effects, EPA has established a maximum contaminant level of 10 mg/liter for nitrate in public drinking systems. Above this level, nitrates can cause methemoglobinemia, which prevents the transport of oxygen in the bloodstream of infants and may be a cancer risk to humans (EPA, 1992). (See chapter 2.2, *Water Quality*, for more information on agriculture's affect on water quality.)

Nutrient pollution of water resources can occur because of unusual wet weather that increases nutrient leaching and runoff. It can also occur when farmers are unaware of the offsite effects of their production decisions, or when they have no assigned cost or penalty for those effects and so choose production systems that may have greater profitability or less economic risk but higher nutrient losses.

Nutrient Balances—An Alternative Measure of Nutrient Use

Total or per-acre nutrient use is of limited value in determining whether nutrients pose an environmental threat. An alternative measure—nutrient mass or residual balance—calculates the residual nitrogen or phosphorus that may remain in the soil or be lost to the environment. Nutrient mass balances indicate how closely nutrient inputs (such as commercial fertilizer, animal manure, other wastes, and nutrients provided by previous legume crops) match nutrient outputs (the amount of nutrient taken up by the harvested crop). A positive net mass balance indicates the amount of residual nutrient that may remain in the soil or be lost to the air, carried by water runoff into surface-water systems, or carried by percolating water into ground water. However, residual nitrogen by itself does not necessarily result in water quality problems. For example, warm, moist soil conditions and dry air may volatilize residual nitrogen to the atmosphere, or vegetative buffers may capture residual nitrogen before it reaches water systems. Therefore, nitrate levels in surface and ground water in some areas of the Southeast tend to be low, even though residual nitrogen may be high.

A negative net balance indicates that the amount of nutrient removed from the field through the harvested crop exceeds the amount of nutrient applied, with the difference coming from nutrients stored in the soil or available through precipitation. Continued negative balances mine or deplete nutrients in soil, disrupt the soil ecosystem, and can damage soil productivity.

Residual balances can be computed on acres or fields to assist farmers in making nutrient management decisions. Calculating balances on a wider geographic area may portray the overall potential for nutrient losses and indicate where nutrient management could be improved. Using USDA's Cropping Practice Surveys, nutrient balances are calculated for major crops (see box, "Computing Nutrient Mass Balances"). Balance estimates are categorized as (1) *high* if the nutrient input exceeded the output in the harvested crop by more than 25 percent, (2) *moderate* if nutrient input exceeded output by less that 25 percent, and (3) *negative* if total nutrient input was less than the output. Declining percentages in the high and negative categories and an increasing percentage in the moderate category indicate improvements in nutrient management. No significant improvement is detected over the 1990-95 period (fig. 4.5.1, 4.5.2).

Computing Nutrient Mass (Residual) Balances

Per-acre, field-level data from the Cropping Practices Survey were used to estimate nutrient balances in pounds per acre for each nutrient on each sample field, using the following procedure:

NB = CF + L + NPK - H - (PR-CR), where

NB = **N**utrient **B**alance

CF = Nutrients from **C**ommerical **F**ertilizer in pounds applied per acre

L = Nitrogen from previous **L**egume crops. If the previous legume crop was soybeans, 1 pound of nitrogen credit was assumed for each bushel of soybeans harvested. If the crop in the previous year was first-year alfalfa, the nitrogen credit per acre was 50 percent of the nitrogen in harvested alfalfa. If the crop was second-year alfalfa, the nitrogen credit was 75 percent of the nitrogen in harvested alfalfa (Meisinger and Randall, 1991).

NPK = **N**itrogen, **P**hosphorus, and potassium (**K**) credits for applied manure for 1990-94 were estimated from two data sources: USDA's Area Study Survey (Alabama, Florida, Georgia, Idaho, Illinois, Indiana, Iowa, Maryland, Nebraska, and Minnesota) and the 1992 Agricultural Census (other States). The estimation procedures used were those developed by Van Dyne and Gilberson (1974) and by Gollehon and Letson (1996). The NPK credits for 1995 were estimated directly from survey data. The estimation procedures were from the *Agricultural Waste Management Field Handbook* (USDA, NRCS, 1992).

H = Nutrients assumed per unit of crop **H**arvested were 0.9 pound of nitrogen and 0.35 pound of phosphorus for each bushel of corn, 1.25 pounds of nitrogen and 0.625 pound of phosphorus for each bushel of wheat, and 0.05 pound of nitrogen and 0.013 pound of phosphorus for each pound of cotton lint and seed (Fertilizer Institute, 1982; Meisinger, 1984).

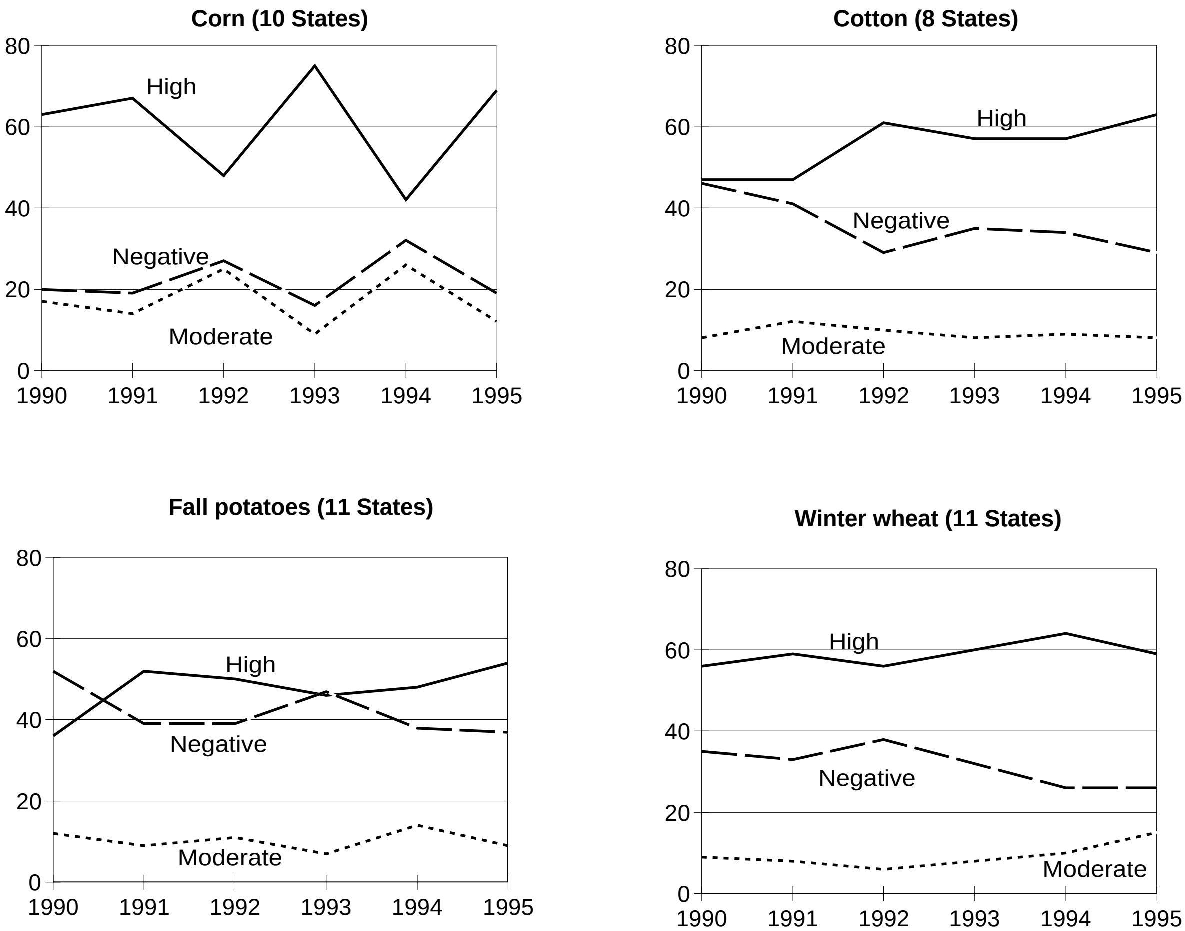
PR = Nutrients from **P**revious crop **R**esidue.

CR = Nutrients in **C**urrent crop **R**esidue remaining on the field.

Nutrients from plant residues are assumed to remain on the field and be equal in nutrient value at beginning and end of season.

State and crop-level estimates were developed by extrapolating and aggregating field-level data.

Figure 4.5.1--Nitrogen mass balances in major producing States, 1990-95: percentage of acres in high, moderate, and negative categories



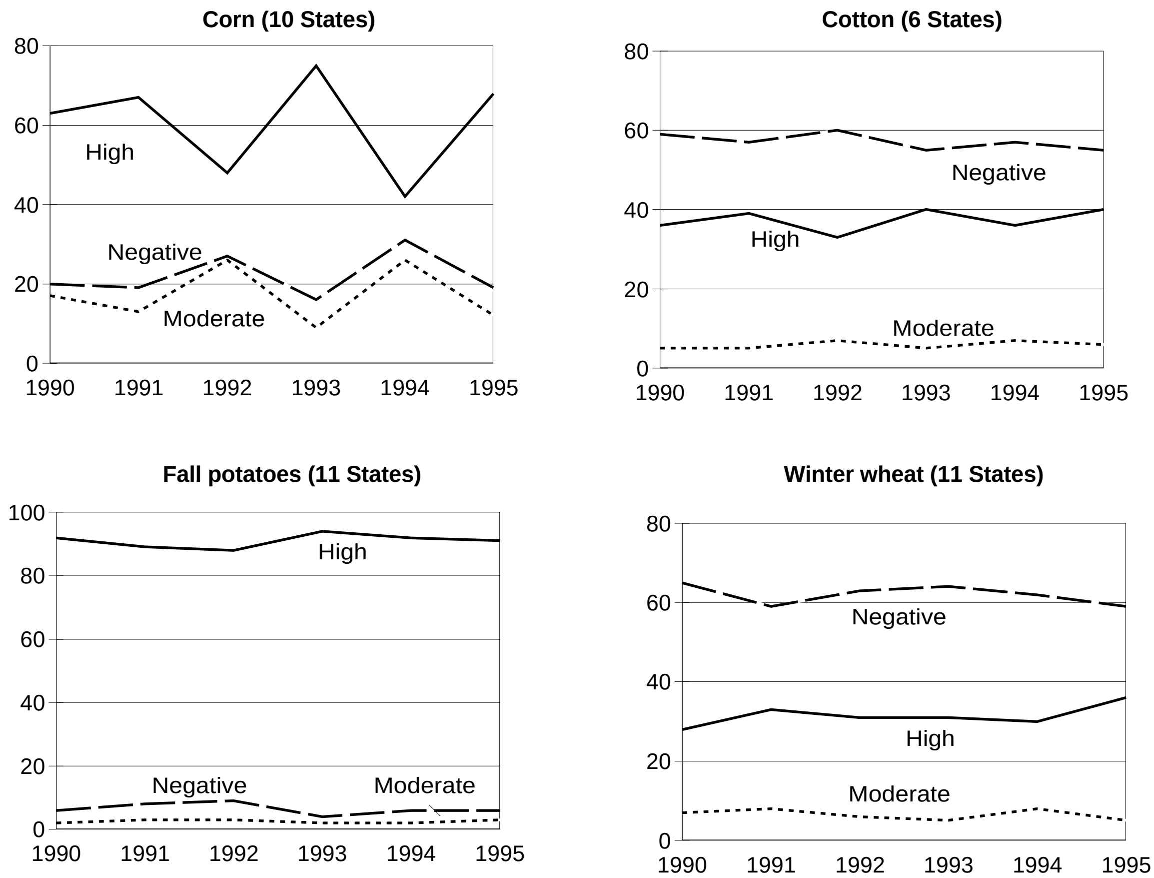
For States included, see "Cropping Practices Survey" in the appendix..

Source: USDA, ERS, estimates based on Cropping Practices Survey data.

Positive residual balances can occur if farmers underestimate available nutrients or overapply nitrogen—the most critical nutrient—in order to support high crop yields. Other factors are the relatively low marginal cost of applying extra nutrients at the time of initial application in the fall and spring before planting and the extra cost and uncertainty (due to weather delays) of making a timely, second application if needed after planting. High nutrient balances also occur when poor weather or excessive pest damage result in crop yields lower than farmers anticipate and less nutrients are taken up by the harvested crop. Consequently, balances may vary significantly from year to year. Persistent high balances on land vulnerable to leaching can be of particular concern for groundwater quality (see chapter 2.2, *Water Quality*, for areas vulnerable to groundwater contamination).

Nitrogen balances. Over half of the corn, cotton, potato, and wheat acres in major producing States had high nitrogen mass balances during 1990-95, suggesting potential nitrogen losses to the environment (fig. 4.5.1, table 4.5.1). Also, in most years, one-fifth or more of these acres had negative nitrogen balances, indicating the mining of nitrogen in the soil to supply crop needs. The percentage of corn acres with high nitrogen balance varies considerably from year to year mainly due to annual variation in yield and crop nutrient uptake. The percentages of cotton and wheat acres with a high nitrogen balance have been increasing, as farmers appear to be applying more nitrogen fertilizer in anticipation of higher crop prices in recent years (NASS, 1996).

Figure 4.5.2--Phosphate mass balances in major producing States, 1990-95: percentage of acres in high, moderate, and negative categories



For States included, see "Cropping Practices Survey" in the appendix.
Source: USDA, ERS, estimates based on Cropping Practices Survey data.

Phosphorus balances. High phosphate balances occurred on 36 percent (winter wheat) to 94 percent (potatoes) of major field crops during 1990-95 (fig. 4.5.2, table 4.5.2). In areas with high soil erosion and runoff, the high residual balance of phosphorus could contribute to water quality problems and require improved management. Phosphorus is more stable than nitrogen and more likely to remain in the soil with less loss to the environment unless the soil itself erodes away. Because of this greater stability, and to reduce costs, many farmers apply extra phosphorus one year then skip a year or more (USDA, NRCS 1995a). The large percentage of acres with negative mass balances is also evidence of this practice.

Nutrient Management Practices

Effective nutrient management, which includes assessing nutrient need, timing nutrient application, and placing nutrients close to crop roots, can help reduce nutrient losses to the environment while sustaining long-term productivity and profitability. The efficacy of each practice is strongly influenced by the conditions in each field, the farmer’s management knowledge and skill, economic factors, and weather (table 4.5.3).

Assessing nutrient needs. Farmers following conventional practices may apply fertilizer at rates based on optimistic yields and may not account for all sources of nutrients. Improved management requires more information about the nutrients available for crop needs and the use of balances to better assess nutrient need. In addition to computing acre- or field-

Table 4.5.1—Nitrogen mass balances for selected crops in major producing states, 1990-95[1]

Crop and year	Acres	Nutrient inputs				Nutrient output in harvested cropland	Nutrient mass balance			
		Commer-cial fertilizer	Previous legumes	Manure	Total		Average	Above 25 percent	0-25 percent	Negative
	1,000	*Average pounds per acre*						*Percent of acres*		
Corn										
1990	58,700	130	21	6	157	113	44	63	17	20
1991	60,350	128	22	7	157	102	55	67	14	19
1992	62,700	128	22	6	156	128	28	48	25	27
1993	57,300	123	24	6	153	92	61	75	9	16
1994	62,500	127	21	6	154	131	23	42	26	32
1995	52,200	130	28	2	160	105	55	69	12	19
Cotton										
1990	8,444	68	3	3	74	54	20	47	8	46
1991	10,850	79	3	4	86	62	24	47	12	41
1992	10,115	86	1	4	91	60	31	61	10	29
1993	10,126	80	2	3	85	57	28	57	8	35
1994	10,023	95	2	4	101	61	40	57	9	34
1995	10,480	82	2	3	87	47	40	63	8	29
Potatoes										
1990	624	191	7	5	203	149	54	56	9	35
1991	655	176	4	1	181	141	40	59	8	33
1992	607	183	3	1	187	161	26	56	6	38
1993	647	177	3	1	181	139	42	60	8	32
1994	652	246	3	--	249	142	107	64	10	26
1995	669	206	1	1	208	138	70	59	15	26
Wheat, Winter										
1990	38,650	51	0	1	52	49	3	36	12	52
1991	30,980	53	5	1	59	41	18	52	9	39
1992	33,465	54	4	1	59	44	15	50	11	39
1993	35,210	53	4	1	58	48	10	46	7	47
1994	32,930	56	4	1	61	45	16	48	14	38
1995	32,670	57	6	1	64	43	21	54	9	1

-- = Less than 0.5

[1] See "Cropping Practices Survey" in the appendix for major producing States included.

Source: USDA, ERS, estimates based on Cropping Practices Survey data (see box, "Computing Nutrient Mass Balances").

level mass balances, analyzing plant tissue during the growing season can detect any emerging nitrogen deficiency. Soil nitrogen tests can be administered both when a majority of fertilizer is applied before planting and when a majority is applied as a side-dress application.

Soil tests for nitrogen, phosphorus, potassium, PH levels, and micronutrients, though essential for improving nutrient management, are an additional expense that many farmers forgo. Nevertheless, soil nitrogen tests and plant analysis can help farmers improve their net farm income (Babcock and Blackmer, 1994; Shortle et al., 1993; Bosch et al., 1994). In particular, soil tests help those farmers who underestimate the nutrient carryover from the previous season to avoid overapplying, thus reducing nitrogen loss and improving their net farm income (Huang et al., 1996). The economic benefit of soil nitrogen testing is greatest in fields where manure was applied and where the previous season was dry (Bosch et al., 1994; Bock et al., 1992; Fuglie and Bosch, 1995). The ideal time to conduct soil nitrogen testing and application is just before plants require nutrients, because nitrogen (as nitrate in the soil) quickly dissipates. However, benefits to the farmer from soil nitrogen tests may disappear if weather conditions prevent farmers from entering fields soon after testing. Because phosphorus is relatively stable in the soil, testing for this nutrient can be conducted any time before fertilization.

Table 4.5.2—Phosphate mass balances for selected crops in major producing States, 1990-95[1]

Crop and year	Acres	Nutrient inputs				Nutrient output in harvested cropland	Nutrient mass balance			
		Commer-cial fertilizer	Previous legumes	Manure	Total		Average	Above 25 percent	0-25 percent	Negative
	1,000	*Average pounds per acre*						*Percent of acres*		
Corn										
1990	58,700	52	0	6	58	44	14	50	12	38
1991	60,350	52	0	7	59	40	19	54	11	36
1992	62,700	47	0	5	52	50	2	36	14	50
1993	57,300	47	0	6	53	36	17	57	10	33
1994	62,500	48	0	6	54	51	3	37	13	50
1995	52,200	47	0	2	49	41	8	43	11	46
Cotton										
1990	8,444	23	0	2	25	26	-1	36	5	59
1991	10,850	26	0	3	29	30	-1	39	5	57
1992	10,115	27	0	4	31	29	2	33	7	60
1993	10,126	26	0	3	29	28	1	40	5	55
1994	10,023	24	0	4	28	30	-2	36	7	57
1995	10,480	23	0	2	25	23	2	40	6	55
Potatoes										
1990	624	159	0	6	165	28	137	92	2	6
1991	655	43	0	1	144	27	117	89	3	8
1992	607	146	0	1	147	30	117	88	3	9
1993	647	148	0	1	149	26	123	94	2	4
1994	652	171	0	--	171	27	144	92	2	6
1995	669	157	0	1	158	26	132	91	3	6
Soybeans										
1990	39,600	10	0	3	13	34	-21	13	4	83
1991	41,850	9	0	3	12	33	-21	13	3	84
1992	41,600	10	0	3	13	37	-24	11	7	82
1993	42,300	9	0	3	12	32	-20	13	5	82
1994	43,750	10	0	3	13	40	-27	9	5	86
1995	41,700	11	0	1	12	35	-22	13	3	84
Wheat, Winter										
1990	38,650	19	0	1	20	25	-5	28	7	65
1991	30,980	20	0	1	21	21	0	33	8	59
1992	33,465	18	0	1	19	22	-3	31	6	63
1993	35,210	19	0	1	20	24	-4	31	5	64
1994	32,930	19	0	1	20	23	-3	30	8	62
1995	32,670	20	0	1	21	22	-1	36	5	59

-- = Less than 0.5

[1] See "Cropping Practices Survey" in the appendix for major producing States included.

Source: USDA, ERS, estimates based on Cropping Practices Survey data (see box, "Computing Nutrient Mass Balances").

In 1995, soil testing ranged from 22 percent of winter wheat acres to 83 percent of potato acres (tables 4.5.4-4.5.9). The extent of soil testing varies from year to year, but during 1990-95, most soil testing included nitrogen testing, and soil testing for nitrogen increased on potatoes and soybeans.

Testing of plant tissues during the growing season indicates any emerging nutrient deficiency, which can then be corrected by an additional nutrient application. With tissue testing, farmers can apply fertilizers at lower rates based on realistic or average yield expectations, then detect and correct (if economical to do so and if conditions permit) any deficiency that might result from above-average growing conditions. In 1994, the only year data were collected, farmers used tissue testing (primarily for nitrogen) on 61 percent of potato acres (table 4.5.7)and 12 percent of cotton acres (table 4.5.6).

Table 4.5.3—Nutrient management operations and improved versus conventional practices

Nutrient management operation	Conventional practices	Improved practices
Assessing nutrient need	Limited testing for residual nutrient levels, or plant tissue tests to detect nutrient deficiency in plant before applying nutrients.	Annual or regular soil and plant tissue testing before applying nutrients.
	Limited use of the nutrient mass balance accounting method to determine appropriate application rate. Amount applied based on recommended rates for yield maximization, with no crediting for nutrients from other sources.	Nutrient mass balance accounting method used to determine appropriate application rate based on recommended rate for realistic yield goal, with crediting given for nutrients in previous legume, irrigation water, and manure. Manure analyzed for nutrients.
	Same application rate on all parts of field.	Nutrient application rates varied according to the yield potential of soil in various parts of the field.
	The importance of soil factors overlooked.	Optimal levels of soil factors—such as soil PH, organic matter, and micro-nutrients—maintained.
Timing nutrient application	Fall and early spring applications of nitrogen before planting.	Split application of nitrogen fertilizer at planting and after planting.
	Application sometimes made before expected heavy rain.	No application before expected heavy rain.
Nutrient placement	Ground and air broadcast, and application in furrow.	Banded and injected (knifed-in) applications, and chemigation.
Nutrient product selection	Nitrate-based fertilizer sometimes used on high leaching field, and ammonia-based fertilizer on high volatilization field.	Ammonia-based fertilizer used on high leaching field, and nitrate-based fertilizer for low leaching field. Nitrogen stabilizers used in ammonia-based nitrogen fertilizer.
	No application of manure to increase organic matter in soil.	Manure applied to increase organic matter in soil.
Crop selection and management	Continuous planting of same nitrogen-using crop. No planting of cover crops between crop seasons.	Nitrogen-using crops rotated with nitrogen fixing crops. Cover crops planted between crop seasons to tie up and preserve nutrients.
Irrigation management	Conventional gravity irrigation with an excessive application of water.	Improved gravity irrigation practices or sprinkler irrigation used to apply water more timely and uniformly according to crop needs.
Manure and organic waste management	Crop residues removed. No manure or organic waste applied. No manure testing. Inadequate manure storage for properly timing manure applications.	Manure and organic waste application based on manure and waste test results and nutrient management plan. Adequate manure storage for timing manure application, with manure injected or incorporated into soil.

Source: USDA, ERS.

Table 4.5.4—Nutrient management practices on corn, 10 major producing States, 1990-95[1]

Activities and practices	1990	1991	1992	1993	1994	1995
Nutrient sources:			*Percent of planted acres*			
Commercial fertilizer	97	97	97	97	98	98
Manure only	1	1	1	1	1	1
Commercial and manure	16	18	15	17	15	13
Previous soybeans	40	40	44	46	48	50
Previous legume hay and pasture	8	7	8	5	7	7
Assessing nutrient need:			*Percent of planted acres[2]*			
Soil tested	41	41	42	38	42	34
Tested for N	61	60	82	77	54	53
Applied recommended N	na	na	85	87	84	78
Applied > recommended	na	na	5	3	7	7
Applied < recommended	na	na	10	10	9	14
Manure analyzed for manure treated acres	na	na	na	na	6	8
N adjusted for manure-analyzed acres	na	na	na	na	70	na
N adjusted for previous legume	na	na	na	na	53	54
Timing nutrient application:			*Percent of acres receiving commercial fertilizer*			
Nitrogen timing:						
Fall before planting	27	26	23	20	27	30
Spring before planting	57	50	53	51	54	52
At planting	44	48	47	48	43	42
After planting	26	31	31	35	27	29
Phosphate timing:						
Fall before planting	na	na	na	na	25	26
Spring before planting	na	na	na	na	34	31
At planting	na	na	na	na	48	48
After planting	na	na	na	na	2	2
Nutrient placement:			*Percent of acres receiving commercial fertilizer*			
Broadcast (ground)	71	72	69	71	72	73
Broadcast (air)	na	na	1	1	1	1
Chemigation	1	2	1	1	1	1
Banded	43	41	42	42	41	40
Foilar	1	0	0	-	-	0
Injected (knifed in)	55	53	54	47	53	51
Nutrient product selection:			*Percent of tons of nitrogen*			
Anhydrous and aqua ammonia	26	30	29	29	23	26
Urea	3	2	2	3	2	2
Ammonium nitrate	-	-	-	-	-	-
Nitrogen solutions (urea, ammonia, ammonia nitrate)	44	44	47	45	51	49
Mixed NPK fertilizers	24	24	21	23	24	23
N fertilizers mixed with N inhibitors (percent of acres)	8	9	8	5	9	10
Crop selection and management:			*Percent of planted acres*			
Continuous same crop	24	25	23	25	22	21
Corn soybean rotations	40	40	44	46	48	47
Planted after other row crops or small grains	23	16	18	17	17	19
Planted with cover crops	0.5	0.8	0.5	0.5	0.5	0.7

na = no data collected. - means less than 0.5.

[1] For States included, see "Cropping Practices Survey" in the appendix. [2] Indented items are a percentage of previous non-indented item.

Source: USDA, ERS, Cropping Practices Survey data

Table 4.5.5—Nutrient management practices on soybeans, 8 major producing States, 1990-95[1]

Activities and practices	1990	1991	1992	1993	1994	1995
Nutrient sources:	*Percent of planted acres*					
Commercial fertilizer	27	26	27	27	28	28
Manure only	4	6	7	6	8	5
Commercial and manure	2	2	2	1	2	1
Soybeans	12	10	20	11	12	11
Legume, hay and pasture	3	2	3	1	3	2
Assessing nutrient need:	*Percent of planted acres*[2]					
Soil tested	26	28	28	28	30	25
Tested for N	15	16	29	29	43	41
Applied recommended N	na	na	85	87	76	74
Applied > recommended	na	na	5	3	5	7
Applied < recommended	na	na	10	10	18	19
Manure analyzed for manure treated acres	na	na	na	na	5	8
N adjusted for manure-analyzed acres	na	na	na	na	75	na
N adjusted for previous legume	na	na	na	na	16	na
Timing nutrient application:	*Percent of acres receiving commercial fertilizer*					
Nitrogen timing:						
Fall before planting	25	26	33	27	31	35
Spring before planting	50	46	43	51	42	43
At planting	22	24	17	21	24	19
After planting	7	8	8	4	7	8
Phosphate timing:						
Fall before planting	na	na	na	na	42	41
Spring before planting	na	na	na	na	40	42
At planting	na	na	na	na	17	16
After planting	na	na	na	na	3	2
Nutrient placement:	*Percent of acres receiving commercial fertilizer*					
Broadcast (ground)	87	85	89	90	88	88
Broadcast (air)	na	na	na	1	1	2
Chemigation	1	2	1	1	-	-
Banded	14	14	9	9	11	11
Injected (knifed in)	2	4	1	1	2	3
Nutrient product selection:	*Percent of tons of nitrogen*					
Anhydrous and aqua ammonia	7	18	6	5	7	6
Urea	4	7	13	2	6	1
Ammonium nitrate	1	0	0	0	0	-
Nitrogen solutions	15	19	10	25	13	25
Mixed NPK fertilizers	73	57	71	68	74	68
N fertilizer mixed with N inhibitors (percent of acres)	-	-	-	-	-	-
Crop selection and management:	*Percent of planted acres*					
Continuous same crop	6	7	13	6	7	6
Corn/soybean rotation	56	55	36	58	57	63
Planted after other row crops or small grains	31	28	27	28	26	16
Planted with cover crops	3	3	4	3	3	4

na = no data collected. - means less than 0.5.

[1] For States included, see "Cropping Practices Survey" in the appendix. [2] Indented items are a percentage of previous non-indented item.

Source: USDA, ERS, Cropping Practices Survey data.

Table 4.5.6—Nutrient management practices on cotton, 6 major producing States, 1990-95[1]

Activities and practices	1990	1991	1992	1993	1994	1995
Nutrient sources:			*Percent of planted acres*			
Commercial fertilizer	80	82	80	85	87	87
Manure only	0.6	0.9	-	0.6	0.5	-
Commercial and manure	3.3	2.1	3.2	3.0	2.9	2.5
Previous legume hay or pasture	4	4	2	3	2	3
Assessing nutrient need:			*Percent of planted acres*[2]			
Soil tested	28	32	27	28	33	27
Tested for N	95	88	98	94	88	95
Applied recommended N	na	na	76	79	81	73
Applied > recommended	na	na	13	19	9	14
Applied < recommended	na	na	11	8	10	13
Tissue tested	na	na	na	na	12	na
Tested for N	na	na	na	na	96	na
Applied recommended N	na	na	na	na	97	na
Applied > recommended	na	na	na	na	0	na
Applied < recommended	na	na	na	na	3	na
Manure analyzed for manure treated acres	na	na	na	na	23	31
N adjusted for manure-analyzed acres	na	na	na	na	100	na
N adjusted for previous legume	na	na	na	36	na	na
Timing nutrient application:			*Percent of acres receiving commercial fertilizer*			
Nitrogen timing:						
Fall before planting	30	32	30	30	31	32
Spring before planting	42	46	36	43	45	43
At planting	8	11	10	8	7	7
After planting	56	57	59	58	53	52
Phosphate timing:						
Fall before planting	na	na	na	na	40	37
Spring before planting	na	na	na	na	49	47
At planting	na	na	na	na	4	4
After planting	na	na	na	na	11	17
Nutrient placement:			*Percent of acres receiving commercial fertilizer*			
Broadcast (ground)	56	58	55	55	60	55
Broadcast (air)	na	na	5	6	6	3
Chemigation	7	8	6	6	8	6
Banded	24	27	25	24	20	29
Foliar	0	4	3	2	-	-
Injected (knifed in)	45	45	42	45	46	40
Type of nitrogen fertilizer:			*Percent of tons of nitrogen*			
Anhydrous and aqua ammonia	26	30	28	22	25	27
Urea	5	6	3	5	3	2
Ammonium nitrate	2	1	-	-	-	1
Nitrogen solutions	44	36	41	47	52	45
Mixed NPK fertilizers	24	26	27	26	21	26
N fertilizer mixed with N inhibitors (percent of acres)	4	6	3	3	4	na
Crop selection and management:			*Percent of planted acres*			
Continuous crop without cover crop	61	61	66	69	69	68
Continuous crop with cover crop	2	3	2	2	1	1
Cotton-sorghum rotation	8	6	7	12	6	5
Planted after other row crops or small grains	19	17	19	18	18	17

na = no data collected. - means less than 0.5.

[1] For States included, see "Cropping Practices Survey" in the appendix. [2] Indented items are a percentage of previous non-indented item.

Source: USDA, ERS, Cropping Practices Survey data.

Table 4.5.7—Nutrient management practices on fall potatoes, 11 major producing states 1990-95[1]

Activities and practices	1990	1991	1992	1993	1994	1995
Nutrient sources:			*Percent of planted acres*			
Commercial fertilizer	99	99	100	100	100	100
Manure only	-	-	-	-	-	-
Commercial and manure	5.2	4.0	3.5	3.3	2.3	2.3
Previous legume hay or pasture	21	8	5	7	12	10
Assessing nutrient need:			*Percent of planted acres[2]*			
Soil tested	83	84	82	84	85	83
Tested for N	77	77	82	84	92	94
Applied recommended N	na	na	79	77	76	73
Applied > recommended	na	na	9	11	10	10
Applied < recommended	na	na	12	12	14	17
Tissue tested	na	na	na	na	61	na
Tested for N	na	na	na	na	60	na
Applied recommended N	na	na	na	na	83	na
Applied > recommended	na	na	na	na	3	na
Applied < recommended	na	na	na	na	14	na
Manure analyzed for manure treated acres	na	na	na	na	13	43
N adjusted for manure-analyzed acres	na	na	na	na	13	na
N adjusted for previous legume	na	na	na	na	54	na
Timing nutrient application:			*Percent of acres receiving commercial fertilizer*			
Nitrogen timing:						
Fall before planting	16	22	19	20	30	28
Spring before planting	37	41	36	35	43	40
At planting	59	56	53	54	41	46
After planting	52	60	57	57	63	73
Phosphate timing:						
Fall before planting	na	na	na	na	28	27
Spring before planting	na	na	na	na	39	37
At planting	na	na	na	na	41	46
After planting	na	na	na	na	28	30
Nutrient placement:			*Percent of acres receiving commercial fertilizer*			
Broadcast (ground)	na	na	na	na	76	79
Broadcast (air)	na	na	na	na	9	7
Chemigation	na	na	na	na	45	48
Banded	na	na	na	na	51	47
Foilar	na	na	na	na	2	-
Injected (knifed in)	na	na	na	na	6	14
Nutrient product selection:			*Percent of tons of nitrogen*			
Anhydrous and aqua ammonia	5	7	6	8	5	5
Urea	3	3	3	3	2	10
Ammonium nitrate	2	1	-	-	-	1
Nitrogen solutions (urea, ammonium nitrate, ammonia)	44	36	41	47	52	45
Mixed NPK fertilizers	24	26	27	26	22	26
Mixed with N inhibitors (percent of acres)	4	4	2	6	5	na
Crop selection and management:			*Percent of planted acres*			
Continuous same crop without cover crop	1	3	2	3	2	4
Continuous same crop with cover crop	2	2	1	2	1	2
Continuous row crops	14	17	16	16	16	19
Planted after other row crops or small grains	50	44	50	47	51	45

na = no data collected. - means less than 0.5.

[1] For States included, see "Cropping Practices Survey" in the appendix. [2] Indented items are a percentage of previous non-indented item.

Source: USDA, ERS, Cropping Practices Survey data.

Table 4.5.8—Nutrient management practices on winter wheat, 11 major producing States 1990-95[1]

Activities and practices	1990	1991	1992	1993	1994	1995
Nutrient sources:			*Percent of planted acres*			
Commercial fertilizer	83	83	84	86	86	86
Manure only	-	-	-	-	0.6	1.3
Commercial and manure	1.8	2.7	2.1	2.6	1.8	1.2
Previous legume hay and pasture	4	1	1	-	1	1
Assessing nutrient need:			*Percent of planted acres[2]*			
Soil tested	17	19	23	22	20	22
Tested for N	92	92	95	93	91	91
Applied recommended N	na	na	77	77	78	63
Applied > recommended	na	na	7	9	7	15
Applied < recommended	na	na	16	15	15	21
Manure analyzed for manure treated acres	na	na	na	na	na	12
N adjusted for manure-analyzed acres	na	na	na	na	13	na
Timing nutrient application:			*Percent of acres receiving commercial fertilizer*			
Nitrogen timing						
Fall before planting	68	73	73	72	76	77
At planting	22	22	21	22	23	23
After planting	44	45	47	44	42	47
Phosphate timing:						
Fall before planting	na	na	na	na	57	57
At planting	na	na	na	na	38	38
After planting	na	na	na	na	7	7
Nutrient placement:			*Percent of acres receiving commercial fertilizer*			
Broadcast (ground)	na	na	na	na	58	62
Broadcast (air)	na	na	na	na	3	3
Chemigation	na	na	na	na	1	1
Banded	na	na	na	na	19	21
Injected (knifed in)	na	na	na	na	46	46
Nutrient product selection:			*Percent of tons of nitrogen*			
Anhydrous and aqua ammonia	43	43	46	45	47	46
Urea	12	10	9	6	5	5
Ammonium nitrate	1	2	2	2	1	3
Nitrogen solutions (ammonia, urea, ammonium nitrate)	21	24	22	24	24	24
Mixed NPK fertilizers	23	21	22	24	24	24
N fertilizer mixed with N inhibitors (percent of acres)	2.6	2.3	1.9	1.3	2.0	na
Crop selection and management:			*Percent of planted acres*			
Continuous same crop	51	40	40	39	43	45
Wheat/fallow/wheat	na	21	20	23	23	19
Idle or fallow	27	34	23	23	21	18
Double-cropped soybeans	2	2	2	1	1	1

na = no data collected. - means less than 0.5.
[1] For States included, see "Cropping Practices Survey" in the appendix. [2] Indented items are a percentage of previous non-indented item.
Source: USDA, ERS, Cropping Practices Survey data.

Of the acres soil-tested for nitrogen, farmers typically reported applying the recommended amount for the soil and crop. Whether nitrogen tests help reduce nitrogen fertilizer use depends in part on the nitrogen recommendations provided to farmers by the State Extension Service or fertilizer dealers. However, Schlegel and Havlin (1995) found that the nitrogen rates recommended by typical models were sometimes 30 to 60 percent higher than the profit maximizing rate.

The nutrient content of any manure applied, if known, allows farmers to better determine nutrients needed from other sources. However, manure analysis occurred on only 8 percent of corn and soybean acres receiving manure in 1995, and on only 12 percent of wheat acres (tables 4.5.4-4.5.8). Previous legumes, an additional source, were credited by farmers in determining commercial nutrient needs on only about half of crop acres with previous legumes.

Timing nutrient application. Timing nitrogen applications to the biological needs of a crop leaves less nitrogen available for loss and can reduce total amount applied. Optimum times for fertilizer application vary by crop, texture of soil, climate, and stability of fertilizer (Aldrich, 1984). For example, corn requires most of its nitrogen supply in midsummer. Nitrogen applied either in the fall or early spring is more readily lost to the environment than when applied at or after planting, and farmers often apply a larger amount to make up for the anticipated loss. Splitting nitrogen fertilizer into various applications at and after planting can reduce nitrogen loss by as much as 40 percent without reducing crop yields (Meisinger and Randall, 1991). However, fall and early spring applications are still prevalent, and may be increasing for some crops. Over two-thirds of winter wheat acres and 20-35 percent of corn, soybean, cotton, and potato acres were fertilized in the fall before planting during 1990-95. The trend appears to be increasing for potatoes and winter wheat. Another 35-57 percent of soybean, cotton, potato, and corn acres received fertilizer in the spring before planting. The only major field crop with increases in after-planting applications was fall potatoes, and this at the expense of at-planting application.

Economic considerations lead many farmers to apply nitrogen before planting during the fall and spring rather than during the growing season (Feinerman et al., 1990; Huang et al., 1994). For example, uncertain weather conditions may shorten the window (time) in which fertilizer can be applied during the growing season, increasing the risk of yield loss from inadequate nitrogen availability. Such risk is magnified for farmers with shorter growing seasons. The opportunity cost of labor and application arrangements may be significantly higher during the late spring and growing season than during the fall. Also, fertilizer pricing patterns (lower in the fall than spring) tend to encourage fall application rather than spring or growing-season application.

Nutrient placement. For crops surveyed in the Cropping Practices Survey, broadcasting was the most common method of applying fertilizers. Broadcasting keeps down the cost of field operations but broadcast nitrogen is more susceptible to loss to the environment. In contrast, banded applications—including the use of injection, knifed-in, or side dressing (see glossary)—place nitrogen fertilizer closer to the seed or plant for increased crop uptake (Achorn and Broder, 1991). Banded practices can increase the efficiency of nitrogen fertilizer use. Injection of an ammonia type of nitrogen (such as anhydrous ammonia) into the soil can reduce leaching and volatilization by as much as 35 percent compared with broadcast application (Achorn and Broder, 1991) and can result in a yield increase of as much as 15 percent (Mengel, 1986). The operation cost (variable and fixed) of injection applications is higher than for broadcast applications, but the overall cost (operation and nitrogen fertilizer) is lower.

Precision farming, also referred to as site-specific farming, is a promising new technology for improving nutrient application timing, rate, and placement. This technology divides whole fields into small areas and uses a variable-rate fertilizer spreader and a global positioning system to apply the exact amount of nutrient needed at each specific location. Precision farming requires equipment for testing soils, locating position, and monitoring yields; a computer to store data; and a variable-rate applicator (see the chapter on Farm Machinery for more detail). A preliminary estimate of additional field operation costs of precision farming for corn is about $7-$8 per acre (Lowenberg-DeBoer and Swinton, 1995).

Precision farming has the potential to improve net farm income by: (1) identifying places in a field where additional nutrient use will increase yield, and thus farm income, by more than the added cost; and (2) identifying places where reduced input use will reduce costs while maintaining yield. Precision farming has the potential to reduce off-site transport of agricultural chemicals with surface runoff, subsurface drainage, and leaching (Baker and others, 1997). Two years of Kansas field data indicate less total nitrogen fertilizer use with precision farming than with conventional nitrogen management (Snyder and others, 1997). However, precision farming is too new an information technology to assess how it affects long-term yield, fertilizer use, farm-level productivity, and the enironment.

Nutrient product selection. Nitrogen fertilizers can be ranked according to their chemical stability in the soil—an important factor in determining potential for environmental harm. Ammonium nitrate is the least stable in soil, followed by nitrogen solutions, anhydrous ammonia, urea, and ammonia-based fertilizer with an added nitrification inhibitor (Fertilizer Institute, 1982; Aldrich, 1984). For areas where cropland is vulnerable to leaching (sandy soils), ammonia-based fertilizer can minimize nitrogen loss. For areas where ammonia volatilization is a problem (areas with hot, dry air and moist soils), a nitrate-based fertilizer is preferable.

Nitrogen stabilizers or inhibitors (urease inhibitors and nitrification inhibitors) delay the transformation of nitrogen fertilizer from ammonia to nitrate and help match the timing of nitrate supply with peak plant demand (Hoeft, 1984). The potential benefit from nitrification inhibitors is greatest where soils are either poorly or excessively drained, no-till cultivation is used, nitrogen is applied in the fall, crops require a large amount of nitrogen fertilizer, and excessively wet soil conditions prevent the application of nitrogen in the growing season (Hoeft 1984; Nelson and Huber, 1987; Scharf and Alley, 1988). The greatest potential benefit occurs only when nitrification inhibitors are used at or below the optimal nitrogen application rate. A nitrification inhibitor added to anhydrous ammonia is most widely used in corn production. However, recent surveys reveal that corn growers in the Corn Belt are likely to apply more nitrogen fertilizer when a nitrification inhibitor is used. Such a practice not only diminishes the economic benefit associated with the use of a nitrification inhibitor, but also increases the amount of residual nitrogen left on the field for leaching (Huang and Taylor, 1996). During 1990-95, farmers used nitrification inhibitors on acreage ranging from 2 percent of winter wheat to 10 percent of corn (tables 4.5.4-4.5.8). No trends are evident.

Crop selection and management. Crops in rotation with a nitrogen-fixing legume crop can reduce nitrogen fertilizer needs and use. In addition, crops in rotation reduce soil insect species, improve plant health, and increase nitrogen uptake efficiency. Legume crops at the early stage of growth absorb residual nitrogen in the soil and therefore minimize nitrate leaching. Even with these benefits, however, crop rotations are often less profitable than monoculture particularly when crop production is subsidized by farm programs. For example, a corn-soybean rotation was shown to be less profitable than continuous corn production under farm programs that included loan rates and deficiency payments (Huang and Lantin, 1993; Huang and Daberkow, 1996). Nevertheless, more than 40 percent of corn on nonirrigated land is in rotation with soybeans or other crops to buffer uncertain markets and to aid in pest control (see chapter 4.3, *Cropping Management*, for more detail on rotations and the economic factors that influence crop choice).

Planting cover crops between crop seasons can prevent the buildup of residual nitrogen. Planting cover crops also can reduce nutrient loss by minimizing soil erosion. Small grain crops and hairy vetch are both nitrogen-scavenging cover crops. Because the economic benefit of planting cover crops is limited for field crops, the practice has not been widely adapted by U.S. farmers. During 1990-95, only 1-4 percent of major field crop acres had previous cover crops (tables 4.5.4-4.5.8).

Irrigation management. Improved irrigation practices can help farmers irrigate crops more uniformly and control the quantity of irrigation water in the soil (see chapter 4.6, *Irrigation Water Management*, for more details). The quantity of water in the soil affects the nutrient concentration in the soil and the rate of nutrient movement to the root zone (Rhoads, 1991). Too much irrigation water can promote nitrogen leaching, reduce nutrient concentration in the soil, and lower plant uptake. Too little irrigation water can stunt plant growth and reduce crop yield. Irrigation efficiency can be improved, for example, by switching from gravity irrigation to sprinkler irrigation, by scheduling irrigation according to plant need, and by using improved gravity irrigation practices such as a surge system or shorter irrigation runs. The cost of irrigation improvements can be substantial, but the economic benefit from saved irrigation water and increased yield in some areas may offset the cost.

Manure and organic waste management. Manure is a good source of organic matter for the soil. In some cases, it can also be an economical, though limited, source of plant nutrients. The organic matter in soil provides a steady supply of nutrients to the plant, and conditions the soil for the plant to achieve higher yields. However, the nutrients contained in the organic matter can also be lost to the environment through soil ersion. Because of its bulk, the economic benefit of manure is limited by available storage and reasonable transport distance (Bouldin et al., 1984). The benefit of manure varies by region; application of manure in corn production is profitable for farmers in Iowa (Chase et al., 1991). Transfer of poultry litter from the litter-surplus areas to litter-deficiency areas in Virginia is economically viable (Bosch and Napit, 1992). Most feedgrain and confined-livestock farms can benefit from manure use for crop production (Gollehon and Letson, 1996). Managing nutrients in manure for crop use requires testing manure for its nutrient content, planning its efficient use in crop production, and storing it to minimize nutrient loss until the time of the crops' greatest need. (USDA, NRCS 1992). During 1990-95, manure application to major field crops ranged from 2-3 percent of winter wheat to 13-18 percent of corn acres (tables 4.5.4-4.5.8).

Improving Nutrient Management

Federal and State governments play an important role in helping reduce agricultural nonpoint pollution of water resources (EPA, 1991). EPA establishes minimum water quality standards and regulates animal waste discharges from large confined livestock operations under the Clean Water Act. States regulate input use and use zoning, land acquisition, and easements to preserve areas deemed important for protecting water resources.

Society, acting through government, can (1) adjust the anticipated costs or benefits of certain production practices through education, technical assistance, and by taxing inputs or by offering subsidies for practice adoption; (2) restrict or regulate certain production practices, such as the use of highly leachable fertilizers in vulnerable areas; (3) help create markets for pollutants; and (4) invest in research and development to find production practices that are less environmentally damaging. Approaches 1 and 3 are economic or incentive-based approaches and are often preferred because they allow maximum flexibility in meeting environmental goals at minimum cost.

USDA prefers voluntary, incentive approaches to deal with agricultural water pollution. This preference is based on the inherent difficulty in regulating nonpoint sources of pollution, and on the belief that when educated about the problems and provided technical and financial assistance, farmers will make improvements in production practices to achieve conservation and environmental goals. In passing the Federal Agriculture Improvement and Reform Act of 1996, Congress reaffirmed its preference for dealing with agricultural resource problems using voluntary approaches.

Efficiency of Financial Incentive Programs

A recent study of USDA's Water Quality Incentives Projects (WQIP)—which provided producers with financial assistance to make changes in nutrient and other management systems to restore or enhance water resources impaired by agricultural source of pollution— found that practices requiring minor, inexpensive changes in existing farm operations tended to be adopted more frequently than those involving more expensive changes (Feather and Cooper, 1995). Belief that adoption will increase profits was found to be the most common reason for adoption: familiarity with the improved management practice was found to be the second most important reason for adoption followed by beliefs that the practice improves on-farm water quality.

To determine the sensitivity of adoption to WQIP incentive payment levels, non-adopting producers were asked if they would adopt improved management practices given various hypothetical incentive payments. In many cases, the incentive payments required to achieve a 50-percent adoption rate were much greater than the actual payments for these practices. Practices requiring larger incentive payments were typically those which involved expensive changes in the farm operation.

The results of this study have several policy implications. First, the efficiency of financial incentive programs may be increased by targeting practices providing the largest reduction in pollution per dollar of incentive payment. Second, educational programs seem to be most successful with practices that involve small, inexpensive changes in the operation and are profitable to the producer. Water-quality benefits influence adoption decisions, but profitability is the most important factor. Thus, educational programs without substantial incentive payments may have limited success encouraging practices involving large expenditures. Third, both educational and financial incentive programs should recognize that large regional differences in adoption exist over geographical areas. Instead of implementing a uniform program across the nation, region specific programs may be more effective. Lastly, using both educational and financial incentives requires fewer resources and may be more successful than implementing each program separately. A financial incentive program, for example, could be combined with an educational program targeting different practices. These two programs could be combined by requiring producers to enroll in the educational program in order to receive incentive or cost-sharing payments.

Adjusting the anticipated costs or benefits of production practices. USDA provides educational, technical, and financial assistance to encourage adoption of nutrient management and other less polluting practices (see chapter 6.2, *Water Quality Programs*). Education helps farmers understand the need for improved practices and demonstrates the practices in operation while technical assistance helps install and implement the practices. Financial assistance can help offset the added cost or risk associated with practice adoption (see box, "Efficiency of Financial Incentive Programs").

The Federal Agriculture Improvement and Reform Act of 1996 established the Environmental Quality Incentives Program (EQIP) in USDA to replace most previous financial assistance programs and to better target assistance to areas most needing actions to improve or preserve environmental quality. One half of EQIP funding is to be directed to conservation practices relating to livestock production including waste and nutrient management improvement. The program may emphasize extensive or management type practices that are more cost effective than intensive structural type measures. Such direction would favor improved nutrient management. (See chapter 6.1, *Conservation and Environmental Programs Overview* for more information on EQIP).

The relative costs of nutrient management practices can be adjusted through input or discharge taxes, such as a tax on nitrogen applied in excess of nitrogen removed (Huang and LeBlanc, 1994). In effect, the residual nitrogen tax is an effluent tax, which induces farmers to adopt improved practices to reduce the residual. Also, it can generate revenue to support development and promotion of improved practices. A nitrogen fertilizer tax in Iowa generates revenue for research and extension activities in water quality improvement. More than $15 million of tax revenue is generated annually and used to develop and promote alternative farming practices to reduce nitrate leaching.

Regulatory approaches. Regulatory approaches can impose a lower cost on farmers than do fertilizer or discharge taxes (Huang and Lantin, 1992) and can be a least-cost approach for society when unseasonal weather occurs (Baumol and Oates, 1988). Laws and programs that limit farm nutrient use in the interests of the environment— including the Clean Water Act—are described in detail in chapter 6.2, *Water Quality Programs*. Imposing restrictions on nitrogen fertilizer use can affect farmers differently, depending on current production practices (Huang, Shank, and Hewitt, 1996).

Several States have established a regulatory agency to control nitrate leaching. Currently, 13 States require that livestock farms have comprehensive nutrient management plans that account for all sources of nutrients and that match nutrient application and availability to crop need (USDA, NRCS 1995b). In 1969, Nebraska created 24 multipurpose Natural Resources Districts (NRD's) and gave them authority to levy a local property tax to fund a wide variety of services to protect Nebraska's natural resources (Nebraska Association of Resources Districts, 1990). One district, the Central Platte NRD, suffers a high level of nitrate-nitrogen in the ground water (CPNRD, 1993, 1995). Three phases of regulation were established, depending on the groundwater nitrogen level, potential impact on municipal water supply, and nitrogen levels in the zone between crop roots and ground water. Restrictions on fertilizer use increase with each phase. Nearly all farm operators have complied, completing reports on nitrogen use, taking necessary soil and water tests, and cutting back their use of commercial nitrogen fertilizer. Since the regulatory program was established in 1987, nitrate concentrations in the ground water in some areas in the Central Platte Basin have been stabilized (CPNRD, 1995).

As animal operations become larger, more States are looking at ways of protecting the environment from animal waste. Large confined animal operations can present major water quality problems, and operations greater than 1,000 animal units are subject to point-source permits under the Clean Water Act. However, these permits address only storage of manure on the site, and not disposal. In 1993, Pennsylvania became the first State to pass a comprehensive nutrient management law aimed at concentrated animal operations. Animal operations with over two animal units per acre of land available for spreading must have a farmlevel nutrient management plan that demonstrates that waste is being safely collected and disposed of (Beagle and Lanyon, 1994). Land-use laws that affect agriculture are being used by municipalities, counties, and other local governments. Zoning ordinances are used in many areas, especially around the rural-urban fringe, to ban confined animal operations.

Establishing markets for pollutants. Another way to improve nutrient management is to facilitate the transfer of manure from those farms that have excess to those that need additional nutrients. This can be done by establishing a market for trading manure products and for gathering and exchanging technical information. A successful market for the poultry litter has been established in Arkansas, the largest broiler-

Glossary

Plant tissue analysis—A test that uses chlorophyll (or greenness) sensing to detect nitrogen deficiency during the plant glowing period. Correction of any nitrogen deficiency is then made through chemigation or other foliar application (Sander et al., 1994).

Nutrient recommendations—The rate of the plant nutrient to be applied is the difference between the amount of nutrients required by the crop based on a realistic yield goal and the amount of the nutrients already available for plant uptake, as determined by soil nutrient tests and nutrient credits for other sources. Many land grant universities provide nutrient recommendations based on information obtained from long-term field trials.

Credits for other nutrient sources—Other sources of nutrients include nitrogen from legumes planted in the previous crop, nitrate in irrigation water and precipitation, and nitrogen, phosphorus, and potassium in animal manure and other (such as municipal) wastes.

Split applications—Total fertilizer for crop need is split into several applications during the growth of the crop.

Chemigation—Nitrogen solutions applied through irrigation water.

Broadcast applications—Fertilizer broadcast in either granule or liquid form on all field surfaces. Most ground broadcast equipment for granular fertilizer uses one or two disks to broadcast fertilizer in 12- to 15-meter swaths. Nitrogen solutions are broadcast using various types of spray nozzles. Aircraft is used for aerial application.

Injection, knifed-in, or incorporation—Nitrogen fertilizer is injected or knifed-in usually 12-24 cm below the soil surface. It can also be incorporated into the soil by tillage. High-pressure liquid nitrogen such as anhydrous ammonia is the most common form of nitrogen injected into the soil. Nitrogen solutions in low-pressure liquid form are also injected into the soil.

Side-dressing or banded application—Granule or liquid nitrogen fertilizer is placed to one side of the plant or placed every other row at planting or during the growing season.

Precision (prescription or site-specific) farming—A large field is divided into small grids according to soil and nutrient conditions. Various rates of nutrients are applied to those grids according to their nutrient status by using locator equipment.

Nitrification inhibitors—Chemical compounds that can be added to the ammonia fertilizers to slow the conversion of ammonium nitrogen to nitrate nitrogen which is susceptible to leaching. N-inhibitors can be used with manure and other forms of organic nitrogen fertilizer.

Urease inhibitors—Chemical compounds that can be added to urea to slow the conversion of urea to ammonium and therefore to slow nitrate leaching.

Slow-release nitrogen fertilizer—Fertilizer coated with chemicals that can retard release of nitrogen from applied fertilizer and prolong the supply of nitrogen for plant uptake.

Rotating crops: A multi-year crop sequence, for example, nonlegume crops then legume crops.

Improved irrigation practices—Use of improved gravity irrigation, a sprinkler irrigation system, soil moisture testing, and an irrigation schedule to tailor irrigation to crop needs and to apply irrigation water uniformly.

Factors influencing vigorous crop growth—Selecting disease- and insect-resistant plant, planting a crop at optimal time, and using integrated pest management can improve plant health and increase nitrogen uptake and thus reduce nitrogen available for leaching.

Cover crops—Planting a cover crop after harvest to take up residual nitrogen and therefore minimize leaching.

Crop residues—Incorporation of crop residual into the soil helps immobilize residual nitrogen.

producing State. In 1991, Winrock International began a project aimed at transferring excess litter in the western part of the State to rice farmers in eastern Arkansas as a natural soil amendment to improve the fertility of zero-grade rice fields where topsoil has been scraped off (Winrock International, 1995). Rice straw, in turn, is an important bedding material for poultry houses in western Arkansas. A poultry litter hotline was launched in 1993 to link prospective buyers and sellers. Also, Tyson Foods, the largest poultry processor, approved the same trucks delivering clean bedding from the Delta area to its contracted poultry farms to back-haul litter from the poultry farms to the Delta rice farms, reducing the cost of transporting litter. An average of 30 litter buyers and sellers are listed on the hotline through the year, with double that number in December and January. The litter market has increased incomes of both poultry farmers and rice farmers, while mitigating water quality problems in western Arkansas.

Research, development, and demonstration. The Federal Government also plays a major role in research, development, and demonstration of improved nutrient management. During 1991-94, USDA funded various Hydrologic Unit Area (HUA) and Demonstration Projects (DP), which helped farmers to implement improved nutrient management over a wide range of geographic settings, agricultural types, and water quality problems across the Nation (USDA, NRCS, 1995a). Case studies of eight DP's and eight HUA's found reductions in annual nitrogen application because of the improved nutrient management practices. Also, USDA, in cooperation with the U.S. Geological Survey, U.S. Environmental Protection Agency, and State experiment stations, established various Management Systems Evaluation Areas (MESA's) to better understand the linkages between farming practices and water quality in the Midwest (ARS, 1995). Nutrient management is the major focus of these projects, which include monitoring activities, modification of farming systems, alternative and new farming practices, site-specific management, nitrogen testing, and socioeconomic studies of farming systems.

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Recent ERS Research on Nutrient Management

"On-farm Costs of Reducing Residual Nitrogen on Cropland Vulnerable to Nitrate Leaching," *Review of Agricultural Economics*, Vol. 18, No. 4, Sept. 1996 (Wen-yuan Huang, David Shank, and Tracy Irwin Hewitt). A farm-level dynamic model considering nitrogen carryover effects was used to analze the costs to a farmer of complying with a restriction on nitrogen fertilizer use on cropland vulnerable to nitrate leaching. While the theoretical results were indeterminate, empirical results from an Iowa case study indicated that a fertilizer use restriction on cropland highly vulnerable to leaching will have a smaller compliance cost than on cropland with a moderate leaching potential.

"Incentive Payments to Encourage Farmer Adoption of Water Quality Protection Practices," *American Journal of Agricultural Economics*, Vol. 78, No.1, Feb. 1996 (Joseph C. Cooper and Russ W. Keim). This paper uses both a bivariate probit with sample selection model and a double hurdle model to predict the impacts of different incentive payments on farmer adoption of integrated pest management, legume crediting, manure tests, split applications of nitrogen, and soil moisture testing. The results can be used to aid decisions on how to allocate program budgets among the preferred production practices.

"Economic and Environmental Implications of Soil Nitrogen Testing: A Switching-Regression Analysis," *American Journal of Agricultural Economics*, Vol. 77, No. 4, Nov. 1995 (Keith O. Fuglie and Darrell J. Bosch). A simultaneous equations, or "switching-regression," model is developed to assess the impact of soil nitrogen (N) testing on N use, crop yields, and net returns in corn growing areas of Nebraska. The results indicate that when there is uncertainty about the quantity of available carryover N, testing for N enables farmers to reduce fertilizer use without affecting crop yields. However, the value of information from N tests depends critically on cropping history and soil characteristics.

"The Role of Planting Flexibility and the Acreage Reduction Program (ARP) in Encouraging Sustainable Agricultural Practices," *Journal of Sustainable Agriculture*, Vol. 7, No. 1, Sept. 1995 (Wen-yuan Huang and Stan G. Daberkow). This article examines the impact of increasing planting flexibility (P) on program participation, farm income, crop diversity, and government payments. For a representative western Corn Belt farm, increasing P to more than 63 percent with zero ARP would result in farmers being better off in switching from continuous corn to a corn-soybean rotation. However, increasing the P and reducing the ARP may sacrifice some environmental benefits.

Voluntary Incentives for Reducing Agricultural Nonpoint Source Water Pollution. AIB-716, May 1995 (Peter M. Feather and Joeph Cooper). This report examines the success of existing incentive programs in achieving adoption of manure crediting, legume crediting, split N application, irrigation scheduling, and deep soil nitrate testing. Results indicate large incentive payments may be necessary to achieve high adoption levels, and adoption rates differ both across practices and across geographic areas. Programs involving cost-sharing and incentive payments could be more successful if incentives were altered to account for these differences.

"Voluntary Versus Mandatory Agricultural Policies to Protect Water Quality: Adoption of Nitrogen Testing in Nebraska," *Review of Agricultural Economics*, Vol 17, No. 1 Jan. 1995. (Bosch, D. L., Z. L. Cook, and K.O. Fuglie). This article evaluates the effectiveness of regulation versus a combination of voluntary incentive approaches for increasing Nebraska farmers' use of soil and/or tissue testing on the fields planted to corn. The results indicate that while regulation leads to higher levels of N test adoption, it does not have an "educational" effect on adopters. Educational programs may be needed to complement regulations to ensure that farmers change their behavior to achieve the goals of water quality protection programs .

"Market-Based Incentives for Addressing Non-point Water Quality Problems: A Residual Nitrogen Tax Approach," *Review of Agricultural Economics*, Vol. 16, No. 4, Sept. 1994(Wen-yuan Huang and Michael LeBlanc). This study analyzes the implications of a tax scheme which would penalize farmers for applying nitrogen in excess of a crop's nitrogen uptake and reward them for growing crops that capture and utilize residual soil nitrogen. Corn production is used to illustrate the differential impacts of residual nitrogen tax on farm income in Corn Belt States.

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Recent ERS Research on Nutrient Management (cont.)

An Economic Analysis of Agricultural Practices Related to Water Quality: the Ontario (Oregon) Hydrologic Unit Area. ERS Staff Report No. AGES-9418. June 1994 (C. S. Kim, Ronald Fleming, Richard M. Adams, Marshall English, and C. Sandretto). This report evaluates the effects of adopting Best Management Practices (BMPs) on groundwater quality in Ontario (Oregon) area by incorporating time lags associated with nitrate leaching and groundwater flow. Results indicate that Federal drinking water standard of no more 10 ppm nitrate in groundwater may be accomplished in 12 years by adopting improved irrigation systems such as auto-cutback systems or solid-set sprinkler systems. However, the adoption of both improved irrigation systems and nutrient management systems, such as side-dressing and ceasing fall fertilization, would be necessary to meet the strict Oregon drinking water standard of 7 ppm.

"The Role of Information in the Adoption of Best Management Practices for Water Quality Improvement." *Agricultural Economics*, No. 11 April 1994. (Peter M. Feather and Gregory S. Amacher). This paper tests the hypothesis that a lack of producer information regarding both the profitability and the environmental benefits of adopting improved practices may be a reason why widespread adoption of these practices has not occurred. A two-stage adoption model is specified and estimated using data from a survey of producers. The results indicate that producer perceptions play an important role in decision to adopt. Changing these perceptions by means of an educational program may be a reasonable alternative to financial incentives.

Timing Nitrogen Fertilizer Applications to Improve Water Quality. ERS Staff Report No. AGES-9407, February 1994 (Wen-yuan Huang, Noel D. Uri, and LeRoy Hansen). Analytical models are developed to determine the necessary conditions for the optimal timing of nitrogen fertilizer application. The empirical results explain various observed timings of nitrogen fertilizer application to cotton in Mississippi, and provide an estimate of a farmer's cost in complying with a restriction on the timing of nitrogen fertilizer application.

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