BEST MANAGEMENT PRACTICES FOR AGRICULTURAL NONPOINT SOURCE CONTROL

II. COMMERCIAL FERTILIZER

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In Cooperation With:

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STATE-OF-THE-ART REVIEW OF BEST MANAGEMENT PRACTICES FOR AGRICULTURAL NONPOINT SOURCE CONTROL

II. COMMERCIAL FERTILIZER

for the project

RURAL NONPOINT SOURCE CONTROL WATER QUALITY EVALUATION AND TECHNICAL ASSISTANCE

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EXECUTIVE SUMMARY

Accelerated eutrophication is one of the chief water quality problems caused by excessive nitrogen (N) and phosphorus (P) loadings to rural watersheds. Fish kills, nuisance algal blooms, heavy aquatic weed growth, poor taste and foul odors are some of the consequences of eutrophication. Nitrogen contamination of drinking water supplies can increase the rate of "blue baby" incidence in consumer populations. Agriculture is one of the major rural nonpoint sources of nitrogen and phosphorus pollution. Accelerated use of commercial fertilizer over the past few decades has created a great potential for N and P contamination of waterways via cropland surface runoff and groundwater infiltration. It is the intention of this document to identify and discuss the state-of-the-art in best management practices (BMPs) for controlling the pollution of natural waters from agricultural use of commercial nitrogen and phosphorus fertilizers.

Presently, several Rural Clean Water Program (RCWP), Model Implementation Program (MIP) and Agricultural Conservation Program-Special Water Quality (ACP) projects across the United States are designed to demonstrate the effectiveness of various control mechanisms for abatement of agricultural nonpoint source water quality problems. In many cases, programs have been hindered in efforts to achieve water quality goals by a lack of information on the cause-effect relationships between BMPs and water quality. Data from these research efforts may expand current assessments of the applicability of individual BMPs and BMP systems as water quality control mechanisms.

The literature strongly supports soil testing as a key element in proper fertilizer management. Proper utilization of soil test results will greatly reduce the losses of N and P from cropland as correct fertilization and liming rates increase fertilizer uptake efficiency. Spring application of fertilizer for spring and summer crops is recommended over fall application in the humid regions of the Pacific Northwest and the Eastern half of the United States. Split application of nitrogen is a BMP for humid regions and areas of intensive irrigation.

In conjunction with proper fertilization rate and timing, terraces can greatly reduce surface runoff losses of nitrogen. Terraces will increase goundwater levels of nitrate nitrogen in humid regions and heavily irrigated areas if N supply exceeds crop demand. Other soil conservation practices can, in general, reduce nitrogen losses, but data show considerable variability in their effectiveness. Slow-release nitrogen fertilizers and irrigation management can help to reduce losses of N to both surface and ground waters.

Ammonium and urea may be superior to nitrate fertilizers in efforts to reduce nitrate nitrogen leaching.

Terraces can effectively reduce total P losses in all regions of the United States. Crop rotation, rotation grazing and residue management are soil conservation practices that double as P control mechanisms. Though conservation tillage reduces total P losses as compared with conventional tillage, it can cause increased soluble phosphorus losses. Sedimentation basins and flow control measures can help decrease P losses from intensively irrigated cropland.

In regions other than the Corn Belt, little is reported concerning the effectiveness of control mechanisms for nonpoint source fertilizer pollution. The greatest overall need is a series of watershed studies with a holistic approach: surface and subsurface water quality, food supply concerns, economics, agronomic concerns and institutional matters. Data from some of the RCWP, MIP and ACP projects will allow a more refined evaluation of the cost-effectiveness of selected BMPs and BMP systems for water quality control. Reports from smaller scale research are necessary to better assess the merits of various fertilization timing and method schemes. Also necessary is documentation of the relative cost-effectiveness of erosion control versus other management practices for controlling phosphorus losses. The combined use of slow-release nitrogen fertilizers with sediment control practices should be explored for potential of protecting both surface and ground waters.

Conclusions and recommendations regarding best management practices for controlling the inputs from commercial fertilizers to surface and ground waters include:

1. Soil testing is the most important BMP component for all regions of the United States. Soil test results should be used to help determine proper fertilization and liming rates.

2. Proper fertilization rates can reduce potential nitrogen losses by 35-94 percent as compared to excessive rates.

3. Spring nitrogen fertilizer application for spring and summer crops is superior to fall application in regions with wet soils, humid climates and high infiltration. Spring application is highly recommended where practical in the Pacific Northwest and the Eastern half of the nation.

4. Split application of nitrogen can reduce potential nitrogen losses by up to thirty percent as compared to single application. Split application is recommended where practical in the Pacific Northwest, the Eastern half of the nation, and areas of intensive irrigation in other regions.

5. Level terraces can reduce total nitrogen surface losses by as much as 85 percent, but can more than double groundwater nitrate loading

5. (continued)
   as compared to contour farming. Terraces are recommended as nitrogen controls where no potential groundwater problem exists, but contour farming should preferentially be used in the humid Eastern and Pacific Northwest states with groundwater nitrate problems.

6. Drainage control can help reduce nitrate losses by 50-98 percent in wet areas and irrigation tracts. More judicial irrigation management is a BMP for Coastal and Western States under intensive irrigation.

7. Slow-release nitrogen fertilizers can reduce N losses by as much as 95% versus conventional forms, and are recommended for use in all regions of the nation.

8. The use of crop rotations, no-till and conservation tillage may reduce surface N losses by 40 to 85 percent as compared to conventional practices.

9. Broadcast fertilizer should be incorporated whenever possible.

10. Level terraces can reduce total phosphorus losses by as much as 67 percent as compared to contour farming. Terrace systems are a phosphorus control BMP across the nation.

11. Use of rotation grazing, crop rotations, cover crops and conservation tillage can reduce P losses by forty to seventy percent as compared to constant grazing, continuous cropping and conventional tillage practices. These soil conservation practices are nationally recommended as phosphorus control BMPs.

12. Sedimentation basins and flow control can be used to decrease phosphorus losses from irrigation.

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PREFACE

There are currently many programs and projects across the country for reducing nonpoint source pollution from agricultural activities. Public and private monies are being spent to implement agricultural Best Management Practices (BMP's) for improving water quality. To assess these many efforts on a nationwide basis, a joint USDA-EPA project, "Rural Nonpoint Source Control Water Quality Evaluation and Technical Assistance," has been established. This undertaking, commonly known as the National Water Quality Evaluation Project, will assess the water quality and socio-economic effects of BMP use in the rural sector.

This document identifies and discusses the state-of-the-art in Best Management Practices for controlling nonpoint source pollution from agricultural use of commercial nitrogen and phosphorus fertilizers. Any proposals for major changes in commercial fertilizer management must be coordinated with economic realities, production concerns and institutional limitations. Conclusions and recommendations in this document are not intended to reflect economic, production or institutional factors. Therefore, any inferences drawn from these statements should contain appropriate caveats.

The scope of the literature reviewed for this document was restricted to published documents with supporting data. Two computer-based files, the Southern Water Resources Scientific Information Center (SWRSIC) and AGRICultural OnLine Access system (AGRICOLA), were used for a large portion of the literature retrieval. Much additional information was obtained through citations follow-up, and interpretive insight was solicited from NCSU professionals.

SECTION 1

INTRODUCTION

The Federal Water Pollution Control Act Amendments of 1972, P.L. 92-500 set the tone for future water quality management on a national level by calling for the restoration and maintenance of the "integrity of the nation's waters." Nonpoint source pollution control is one of the concerns addressed under areawide waste treatment management in Section 208. Agriculture was isolated as one of the potential nonpoint sources requiring control mechanisms for pollution abatement. As indicated in Table 1, cropland, ranges and pastures contribute most of the nonpoint source nitrogen and phosphorus entering surface waters (4).

Agricultural fertilizer is a major component of nutrient runoff from cropland. As compared with precipitation and native forest it is clear that fertilized land can have minimal or large impact on watershed nutrient levels depending upon management (Table 2). Runoff from agricultural land can carry nitrate concentrations in excess of the drinking water standard (Figure 1) or phosphorus concentrations sufficient to stimulate algal blooms (Figure 2).

The National Eutrophication Survey, 1972-1975, set the basis for evaluating progress in attaining water quality goals (63). Of 574 classified lakes, 78% were determined to be eutrophic and 18% were considered mesotrophic. It was concluded that streams draining agricultural watersheds had, on the average, considerably higher nutrient concentrations than those draining forested watersheds. Mean concentrations of both total phosphorus and total nitrogen were nearly nine times higher in agricultural drainage areas than in forested basins. Furthermore, Corn Belt watersheds had the highest total and inorganic nitrogen concentrations of any agricultural areas.

Several watersheds across the nation suffer from excessively high nutrient concentrations in either surface water or groundwater. The Chowan River has had repeated algal blooms in recent years near its mouth at the Albemarle Sound, North Carolina (99). Cropland runoff accounts for 25 and 20 percent, respectively, of the nitrogen and phosphorus loadings, while animal waste contributes 23 percent of the nitrogen and 12 percent of the phosphorus. Much of the remaining nitrogen (34.6%) and phosphorus (46.8%) comes from forests and wetlands. Mean total P concentrations in agricultural subwatersheds (.08-.66 mg/l) exceed those in a forested subwatershed (.06 mg/l) of the Chowan River, suggesting agriculture as a potential major pollutant source in selected areas (71). Intensive cropping practices are the suspected causes of nutrient enrichment in Saginaw Bay, Michigan (87). Water quality data have shown P concentrations of 5-6 μg/l in Lake Huron, 25-45 μg/l in Western Lake Erie and 50-71 μg/l in Saginaw Bay (87), thus indicating agriculture in Saginaw Bay to be a possible source for Lake Erie nutrient loading.

TABLE 1. ESTIMATED POLLUTANT CONTRIBUTIONS TO SURFACE WATERS FROM SELECTED NONPOINT SOURCES IN THE CONTIGUOUS 48 STATES†

Nonpoint Source Category	Sediment	BOD	Nitrogen	Phosphorus	Acids§	Salinity*
	average load (million tons/yr)					
Cropland	1870	9	4.3	1.56	--	57.3
Pasture and Range	1220	5	2.5	1.08	--	--
Forest	256	0.8	0.39	0.089	--	--
Construction	197	--	--	--	--	--
Mining	59	--	--	--	3.1	--
Urban Runoff	20	0.5	0.15	0.019	--	--
Rural Roadways**	2	0.004	0.0005	0.001	--	--
Small Feedlots	2	0.05	0.17	0.032	--	--
Landfills	--	0.3	0.026	--	--	--
Subtotal	3626	15.8	7.4	2.8	3.1	57.3
"Natural Background"	1260	5.0	2.5	1.1	--	--
Total	4886	20.8	10.0	3.8	3.1	57.3

†83.8 million ha (207 million ac) in public lands (14% of contiguous U.S.), mostly in Rocky Mountain Region, were excluded due to inadequacy of information

§As $CaCo_3$.

*From irrigation return flow.

**Deposition from traffic-related sources.
Adopted from Bailey, G.W. and T.E. Waddell, "Best Management Practices for Agriculture and Silviculture: An Integrated Review," In: Best Management Practices for Agriculture and Silviculture, Ann Arbor Science, Ann Arbor, Michigan, p.37, 1979.

TABLE 2. COMPARATIVE MAGNITUDE OF NONPOINT SOURCES

Source	Total N		Total P		Reference
	mg/	kg/ha/yr[†]	mg/l	kg/ha/yr[†]	
*Precipitation- U.S.	.73-1.27	5.6-10	-	.05-.10	52
Lower Limit for Algal Blooms	-	-	.025	-	73
Maximum Level-Domestic Water Supply	10	-	-	-	73
*Precipitation-Ohio	2.0-2.8	12.8	-	-	92
*Forest-Ohio	.54-.89	2.1	.011-.020	.04	92
*Farmland-Ohio	.90-3.11	5.1	.020-.023	.06	92
*Precipitation-Coastal Delaware	-	44.6-45.4	-	1.45-1.48	75
*Ag. Watersheds-Coastal Delaware	-	14.4-15.7	-	.39-.46	75
*Precipitation-Minnesota	-	-	.011-.042	.10	86
*Forest-Minnesota	-	-	.04-1.2	.08	86
*Upland Native Prairie-Minnesota	-	1.0	-	.13	97
*Grassland (112 kg N/ha)-NC	-	2.3	-	-	40
*Grassland (44 kg N/ha)-NC	-	8.4	-	-	40
*Grassland (rotate graze)-OK	1.52-1.64	1.5	.56-.83	.89	60
*Grassland (cont. graze)-OK	2.58-3.25	6.8	1.29-1.32	3.24	60
*Corn (204 kg N/ha)-Coastal GA	.17-.43[§]	.1-.2[§]	-	-	38
**Corn (204 kg N/ha)-Coastal GA	7.07-10.31[§]	12.4-25.8[§]	-	-	38
*Silvicultural Piedmont-VA	1.1-1.8	2.7	.12-.19	.28	10
*Agricultural Piedmont-VA	1.1-3.2	4.4	.10-.60	.54	10
*Poorly-Drained Coastal Plain-VA	1.7-2.3	1.6	.19-.31	.21	10
*Well-Drained Coastal Plain-VA	1.5-4.1	4.9	.41-.65	.88	10

[†]Normalized to precipitation of 76 cm/yr.

*Surface Runoff.

[§]NO_3-N.

**Subsurface Flow.

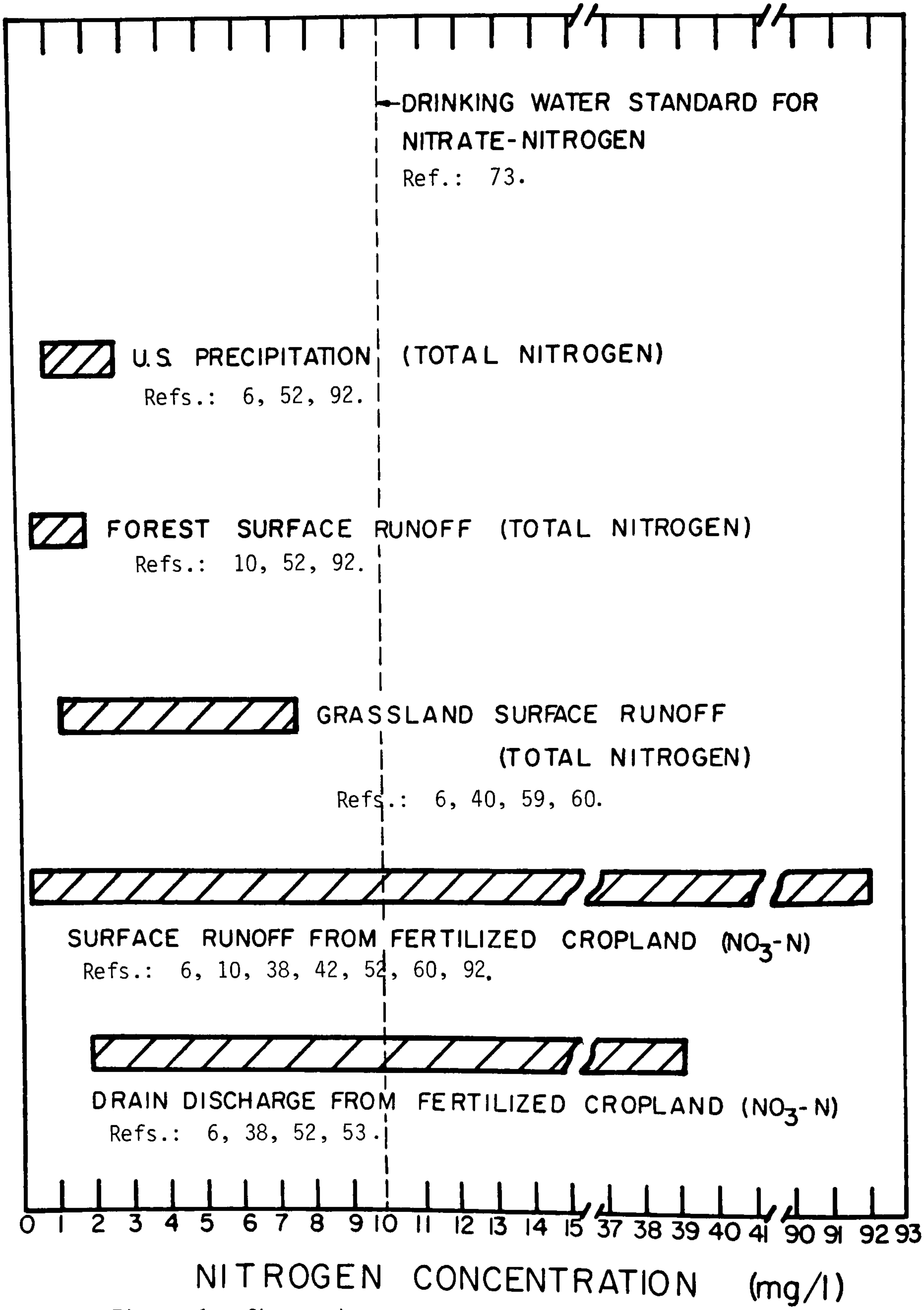

Figure 1. Observed range of nitrogen concentrations from nonpoint sources.

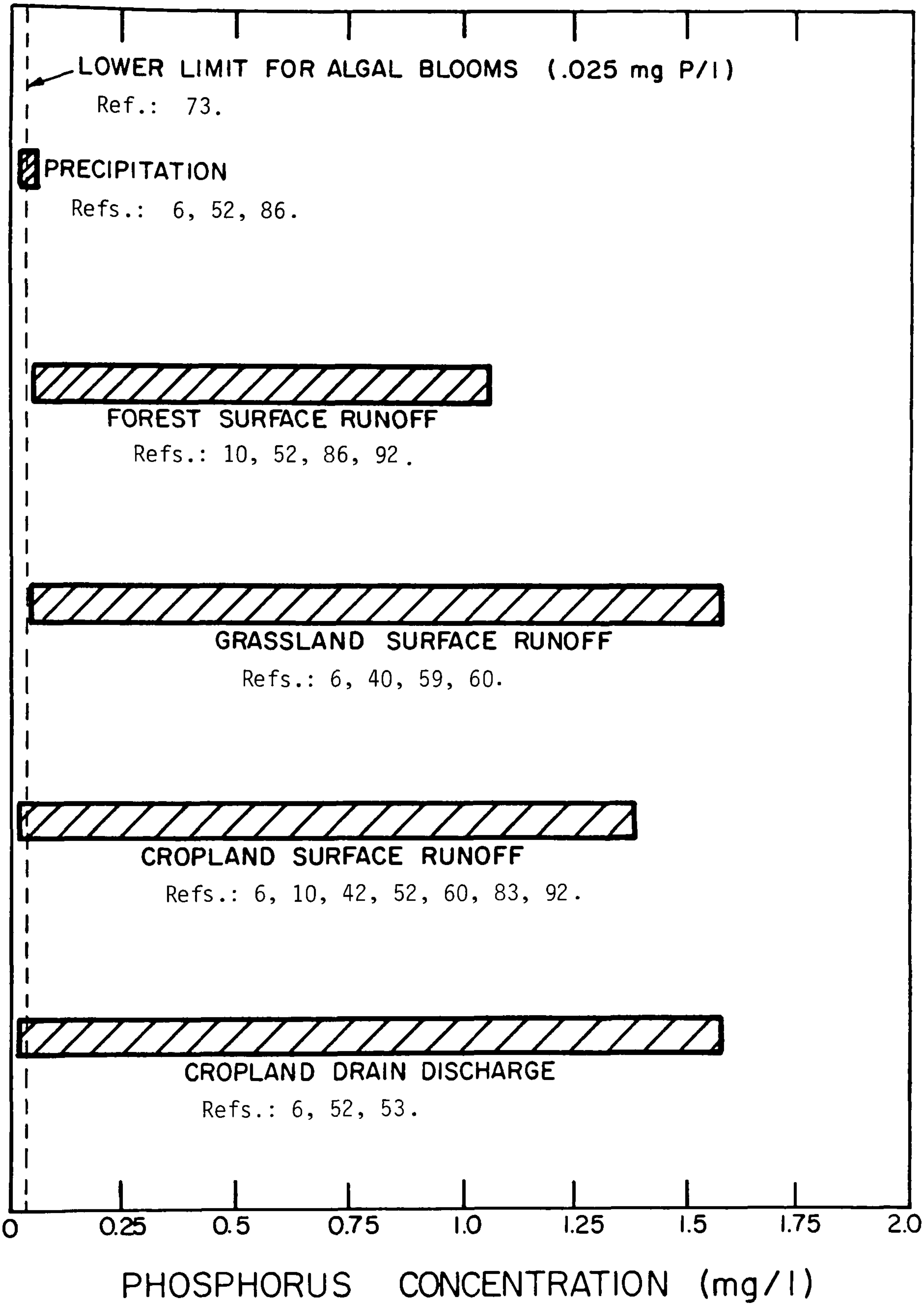

Figure 2. Observed range of total phosphorus concentrations from nonpoint sources.

Groundwater contamination is a problem at Oakwood Lakes and Lake Poinsett, South Dakota where NO_3-N concentrations exceeded 10 mg/l in 25% of well samples taken (3). Irrigated cropland in Long Pine, Nebraska is partially responsible for NO_3-N concentration increases from 1.8 mg/l in 1950 to 8.1 mg/l in 1970 at similar well sites (54). Of 23 domestic wells sampled in 1977-1978, 17.4% had NO_3-N concentrations greater than 10 mg/l. Also in Hall County, Nebraska, 65 of 82 wells sampled in 1979 had NO_3-N concentrations exceeding 10 mg/l (29). Heavy commercial fertilizer applications are held responsible for the average NO_3-N concentrations of 13.6 mg/l for 139 wells sampled in 1980.

Surface water quality data from the Missouri River Basin (57) showed mean concentrations in 1969 of 2.67 mg/l nitrate-nitrogen (NO_3-N) and 1.17 mg/l total phosphorus (P_T). Upper reaches of the basin had as low as .31 mg/l NO_3-N, but downstream near the confluence with the Mississippi River concentrations reached 4.05 mg/l NO_3-N. Missouri River tributaries flowing through Nebraska corn regions had levels as high as 5.42 mg/l NO_3-N.

Trends show that United States farmers have doubled their fertilizer use since 1960 (68). In 1976, U.S. farmers used 49 million tons of fertilizer. Regional data indicate that the Corn Belt and Northern Plains producers have applied the greatest proportions of nitrogen fertilizer (Table 3). The Corn Belt and Pacific regions used more phosphorus fertilizer than other areas in the United States (Table 4) (98). As increased fertilizer use contributes to aquatic nutrient contamination it also creates greater demands for raw materials. Higher energy and capital costs for commercial fertilizer production can place a larger financial burden on the farmer.

Progressing toward a more comprehensive approach to water quality management, the Environmental Protection Agency has proposed a groundwater strategy emphasizing the relationships between groundwater and surface water and those between water quantity and quality (72). Agricultural irrigation accounted for 70% of nationwide groundwater withdrawals in 1975. Fertilizers and animal waste are two possible agricultural sources for contamination of aquifers. As indicated by the above, future agricultural policy can greatly affect both groundwater quantity and quality.

In concurrence with P.L. 92-500, EPA presented water quality criteria for various pollutants (73). No standard was set for phosphate - phosphorus (PO_4-P), but it was concluded that concentrations greater than 100 μg/l may interfere with coagulation at water treatment plants. Furthermore, average concentrations of more than 25 μg/l PO_4-P in lakes and reservoirs at spring turnover may stimulate nuisance algae or aquatic plant growth. Due to the many variables associated with eutrophication, it is at best difficult to set rigid guidelines for phosphate control.

As a safeguard against biological nuisances it has been suggested that PO_4-P concentrations should neither exceed 50 μg/l in any stream at the point where it enters a lake nor exceed 25 μg/l in the lake (55). For streams discharging indirectly to lakes, levels below 100 μg/l PO_4-P should protect the lakes from algal nuisances. Relatively uncontaminated lakes have total phosphorus surface water concentrations of 10-30 μg/l (37).

TABLE 3. REGIONAL CONSUMPTION OF NITROGEN FERTILIZER, 7/1/79 to 6/30/80

Region†	Percentage of U.S. Consumption*					Total N (mt)§
	Anhydrous Ammonia	Ammonium Nitrate	Ammonium Sulfate	Nitrogen Solutions	Urea	
Northeast	0.6	1.5	1.6	3.4	3.4	127,285
Lake States	11.4	4.6	2.7	7.0	16.8	772,518
Corn Belt	36.9	9.5	5.7	33.3	29.0	2,418,998
Northern Plains	27.4	13.9	3.2	13.4	12.1	1,571,978
Appalachian	1.5	12.1	0.6	9.2	3.7	350,747
Southeast	0.9	16.0	1.6	10.8	0.4	358,552
Delta States	1.4	12.2	2.6	1.6	12.9	297,839
Southern Plains	10.0	13.9	16.9	5.4	5.5	687,746
Mountain	4.6	9.7	23.5	4.6	5.7	431,854
Pacific	5.2	6.6	41.3	10.8	9.7	601,698
Total (mt)*	4,979,800	2,396,505	760,743	6,003,080	1,880,029	7,639,323

† Northeast = CT, DE, DC, ME, MD, MA, NH, NJ, NY, PA, RI, VT, WV; Lake States = MI, MN, WI; Corn Belt = IL, IN, IA, MO, OH; Northern Plains = KS, NE, ND, SD; Appalachian = KY, NC, TN, VA; Southeast = AL, FL, GA, SC; Delta States = AR, LA, MS; Southern Plains = OK, TX; Mountain = AZ, CO, ID, MT, NV, NM, UT, WY; Pacific = CA, OR, WA.

* Includes Alaska, Hawaii and Puerto Rico.

§ Determined from average weight percentage of N in fertilizers.

Source: 98.

TABLE 4. REGIONAL CONSUMPTION OF PHOSPHORUS FERTILIZER, 7/1/79 to 6/30/80

Region[†]	Percentage of U.S. Consumption[*]					Total
	Phosphate Rock	Superphosphates ≤22%	Superphosphates >22%	Ammonium Phosphates	Other Phosphates	P (mt)[§]
Northeast	6.1	1.2	2.8	2.2	4.4	7,286
Lake States	18.1	22.4	12.3	0.7	7.6	28,137
Corn Belt	23.6	3.0	52.0	0.3	4.8	108,558
Northern Plains	1.2	6.0	8.5	3.1	0.9	20,114
Appalachian	4.1	4.8	8.4	0	0.8	17,913
Southeast	4.0	17.3	1.9	5.8	18.3	9,117
Delta States	0	0.9	1.4	0.2	8.4	3,115
Southern Plains	0.3	0.6	3.3	25.1	10.2	22,196
Mountain	17.1	2.3	5.3	16.8	3.5	21,503
Pacific	19.3	41.5	3.8	45.8	39.2	39,737
Total (mt)[*]	21,729	111,089	1,057,832	540,762	320,029	-

[†] Northeast = CT, DE, DC, ME, MD, MA, NH, NJ, NY, PA, RI, VT, WV; Lake States = MI, MN, WI; Corn Belt = IL, IN, IA, MO, OH; Northern Plains = KS, NE, ND, SD; Appalachian = KY, NC, TN, VA; Southeast = AL, FL, GA, SC; Delta States = AR, LA, MS; Southern Plains = OK, TX; Mountain = AZ, CO, ID, MT, NV, NM, UT, WY; Pacific = CA, OR, WA.

[*] Includes Alaska, Hawaii and Puerto Rico.

[§] Determined from average weight percentage of P in fertilizer. "Other Phosphates" not included.

Source: 98.

The maximum permissible NO_3-N concentration in domestic water supply is 10 mg/l (73). Nitrate itself is not toxic at this concentration, but its reduction product nitrite, NO_2^-, can react with hemoglobin in the bloodstream to impair oxygen transport in warmblooded animals. This condition of methemoglobinemia can be hazardous to infants less than three months old. Waters with nitrite-nitrogen (NO_2-N) concentrations of more than 1 mg/l can cause methemoglobinemia in infants.

Warm water fish can tolerate NO_3-N levels up to 90 mg/l (43) and NO_2-N concentrations to 5 mg/l (56) before exhibiting adverse effects. The more sensitive salmonid fishes require NO_2-N concentrations below .06 mg/l for successful habitation (78,79).

Nitrogen forms can also contribute to accelerated eutrophication in streams and lakes. Plants can assimilate both nitrate and ammonium-nitrogen (NH_4-N) for conversion to protein (73). As with phosphorus, it is difficult to set a rigid standard for the nitrogen level that will cause accelerated eutrophication. However, total nitrogen (N_T) concentrations as low as 1-2 mg/l can support algal blooms when other requirements are met.

The above discussion clearly demonstrates the potential for and some consequences of nutrient enrichment of watersheds impacted by fertilized agricultural land. However, agricultural nonpoint source pollution can be minimized through implementation of sound agricultural management practices. It is the intention of this document to identify and discuss the state-of-the-art in best management practices (BMP's) for controlling the pollution of natural waters from agricultural use of commercial nitrogen and phosphorus fertilizers.

SECTION 2

CONTROL MECHANISMS

Nutrients, primarily nitrogen and phosphorus, are of concern from a water quality perspective due to their potential to accelerate eutrophication of streams, lakes, bays, and estuaries. All land, regardless of use, contributes N and P to drainage water (77). The issue facing the agricultural community is the extent to which fertilization increases nutrient loading to receiving waters.

As agricultural land becomes more heavily fertilized the potential for contributing nutrients to surface and ground waters increases. All forms of N and P found in commercial fertilizers are ultimately made available to aquatic organisms. An equitable comprehensive fertilizer management strategy is one which will minimize the potential for nutrient loading to receiving waters while production is maintained at optimal levels for agronomic, economic and food supply concerns.

There are two basic alternatives for minimization of the potential for nutrient enrichment of agricultural watersheds. One can properly apply the correct amount of fertilizer for anticipated yields or keep any excess fertilizer from entering the receiving waters. Proposed Best Management Practices (BMPs) for nutrient control encompass both basic control alternatives. Due to geoclimatic differences, BMPs in one region may not be BMPs in another. For the purposes of this discussion BMPs will be described in terms of their regional and/or national applicability. Regions will be identified by their Soil Conservation Service Land Resource Region letter (Figure 3).

INCREASING FERTILIZER UPTAKE EFFICIENCY

Fertilizer uptake efficiency is expressed as the percentage of applied fertilizer utilized by the crop. Generally, this will range between 50-70%, but it may be greater than 80% under favorable conditions or less than 50% under poor management (67). In most cases, excess nutrients are not as obvious or detrimental to crops as are deficiencies, but the farmer invariably suffers higher fertilizer costs. Eliminating excess fertilizer use is the first step in nutrient control. The following are practices recommended as methods for increasing fertilization efficiencies.

Soil Testing

Regular soil testing is a very important component of soil fertility management. Soil tests are used to estimate the quantity of available plant nutrients and to make recommendations about fertilizer and lime requirements (19). Effective implementation of this fertilizer management BMP component

LEGEND

A	Northwestern Forest, Forage and Specialty Crop Region
B	Northwestern Wheat and Range Region
C	California Subtropical Fruit, Truck and Specialty Crop Region
D	Western Range and Irrigated Region
E	Rocky Mountain Range and Forest Region
F	Northern Great Plains Spring Wheat Region
G	Western Great Plains Range and Irrigated Region
H	Central Great Plains Winter Wheat and Range Region
I	Southwest Plateaus and Plains Range and Cotton Region
J	Southwestern Prairies Cotton and Forage Region
K	Northern Lake States Forest and Forage Region
L	Lake States Fruit, Truck and Dairy Region
M	Central Feed Grains and Livestock Region
N	East and Central Farming and Forest Region
O	Mississippi Delta Cotton and Feed Grains Region
P	South Atlantic and Gulf Slope Cash Crops, Forest and Livestock Region
R	Northeastern Forage and Forest Region
S	Northern Atlantic Slope Diversified Farming Region
T	Atlantic and Gulf Coast Lowland Forest and Crop Region
U	Florida Subtropical Fruit, Truck Crop and Range Region

Figure 3. Land Resource Regions (48).

will minimize the error between optimum and actual rates of fertilizer application (102). Typical soil tests provide information on soil acidity; levels of available phosphorus, potassium and minor nutrients; and soil organic matter. Expensive nitrogen analyses are performed only under special circumstances.

In California sugarbeet production it was found that a combination of soil analysis and crop history to estimate initial N application rates followed by plant analysis to monitor and fine-tune the recommendation led to efficient use of fertilizer (34). Soil sampling to 0.9 meters (3 feet) just after seedling emergence gave the best results. A sampling depth of 0-7.5cm (0-3in) is recommended for soil testing the pastures and meadows of Missouri (46). Nitrogen needs of irrigated grain sorghum in the Central Great Plains can be estimated by utilizing NO_3-N measurements of surface soil samples (64). Grain yield was more strongly correlated with residual plus fertilizer N than with fertilizer N alone. Nitrogen availability indexes were correlated with corn yield in Pennsylvania field testing (22). Soil testing for liming purposes is advised for farmers in many states (1,5,19). For no-till corn in Maryland regular soil testing is necessary to monitor pH in liming programs for acidity control (7).

From the literature it is evident that most regions across the continental United States lend themselves to successful implementation of soil testing as a Best Management Practice component (Figure 4). For the entire U.S. it is recommended that an average of one soil sample be taken for every 30 to 45 acres of harvested crop (102). However, in 1977 an average of only one sample per 104 acres was obtained. As a minimum, it is advised that soil tests be taken once per three-year rotation for field crops (1,19) and once every five years for pastures (19). Due to the preponderance of data supporting the use of soil testing, it is concluded that this practice is a BMP component for all regions in the United States.

Liming

Soils with high levels of exchangeable aluminum, high organic content, or both can be too acidic for efficient farming. Heavy use of ammonium fertilizers also reduces the soil pH. Proper liming to raise pH to optimum levels has numerous benefits including: supplying Ca and Mg, improving the plant efficiency of phosphate use, increasing the ability of legumes to fix atmospheric nitrogen, reducing aluminum toxicity and reducing potash leaching and micro-nutrient deficiencies (5).

North Carolina farmers are advised to soil test and lime routinely to avoid the possibility of a poor harvest due to aluminum toxicity (44). Liming deep-till citrus groves in Florida caused lower percentage tile drainage losses of applied PO_4-P and K, but higher NO_3-N losses than deep-till with no-lime (16). Liming for pH control of no-till corn is essential in both Maryland and Kentucky (7,9). Surface soil tends to acidify under no-till, so liming and perhaps incorporation are necessary for pH balance. Liming is encouraged in Ohio and New York to help obtain top yields from new varieties (1,19).

Figure 4. Land Resource Regions with literature references (///) indicating soil testing as a BMP component.

In general, fields not properly limed can contribute greater amounts of nutrients to streams for two reasons: decreased fertilizer use efficiency and decreased crop yields removing less nutrients at harvest and providing less residue to help control soil and nutrient loss in surface runoff. Literature citing liming as a BMP was not found for all regions (Figure 5), but wherever soil test results indicate a need for lime the recommendation should be followed. In Florida citrus groves liming may help phosphorus control, but could cause nitrate problems in ground and surface waters (16). This example points out the need for local tailoring of this nationally recommended BMP.

Rate of Application

Neither nitrogen nor phosphorus should be applied at rates higher than those recommended from soil tests or legitimate estimates. Commercial fertilizer should be used only to provide those nutrients not present in adequate amounts for optimum production (95). Growers can neither afford to apply excess fertilizer to mask poor management nor to apply inadequate amounts to hold down production costs.

In the San Joaquin Valley of California, fertilizer N was not prevalent in drainage waters unless fields received excessive irrigation and fertilization (66). Studies with sugarbeets showed that the N uptake efficiency declined as the N application rate increased beyond that providing maximum sucrose yield (33). Furthermore, the N pollution potential was lower at the rate which produced the maximum yield. In other sugarbeet testing only one of twenty-one cases showed sugarbeet yield response to fertilizer N when the starter NO_3-N level was 252 kg/ha (225 lbs/acre) or more (34). It was concluded that fertilizer N should not be added to these fields unless later plant analyses show an N deficit. High citrus production is necessary to keep drainage water N levels below 20 mg/l NO_3-N in California (70). With lower yields much more NO_3-N will be leached to groundwaters unless the N fertilization rate (112-168 kg N/Ha) is reduced.

Irrigated grain sorghum yields in the Central Great Plains were best correlated with residual N plus fertilizer N additions, indicating that proper fertilization rates are dependent upon cropping patterns and soils (64). In southern Texas, N application rates for grain sorghum, oats and sudan grass should not normally exceed the plant uptake in the first 2-3 week period (91). For irrigated corn in Kansas the grain removed about 25 percent of N applied at either 50 or 100 kg/ha/yr (61). There was no significant difference between yields from rates of 50 and 100 kg N/ha/yr for either 1976 or 1977. However, soil N content was proportional to the fertilization rate. Fields cropped to a rotation of grain sorghum, cotton and oats in the Texas Blackland Prairie yielded average surface runoff NO_3-N concentrations of only 2.3-2.9 mg/l when proper fertilization rates were followed for the five-year study period (41).

New York farmers are advised to follow soil test results when selecting fertilization rates (19). These soil test recommendations are based upon yield response to added fertilizer. Field studies have shown that N and P losses in surface runoff are correlated with fertilization rates (103). Subsurface N concentration was also strongly related to application rate. In other research

Figure 5. Land Resource Regions with literature references (///) indicating liming as a BMP.

NH_4-N and soluble P concentrations in tile drains were not significantly influenced by fertilization rate (104). However, NO_3-N concentration increased with rate for a given time of application. In another study soluble NH_4-N loading to surface runoff was not correlated with fertilization rate, but soluble inorganic P and NO_3-N loadings were (42). In summary for Land Resource Regions L and R, NO_3-N losses in both surface and subsurface waters were correlated with N fertilization rate, and P losses were correlated with application rate for surface runoff but not for subsurface runoff.

Corn Belt research on the effects of fertilization rate on water quality and corn yield has been very conclusive. The average weighted NO_3-N concentrations in subsurface discharge were 5.8 mg/l and 21.0 mg/l, respectively, for continuous corn watersheds fertilized at 168 kg N/ha/yr and 448 kg N/ha/yr (14). In supporting research, data clearly indicate that NO_3-N leaching below the root zone can result from excessive fertilization (82). This NO_3-N can then enter the groundwater or contribute to subsurface flow. Furthermore, nitrogen applications greater than 168-196 kg/ha increased N runoff losses, but did not significantly improve yields (101).

Other research in watersheds cropped to corn has shown that both N and P loadings are potentially greater from fields under excessive fertilization (12). Phosphorus applications tested were the recommended rate for corn (40 kg P/ha) and an excessive rate of 66 kg P/ha (59 lbs/acre). Runoff studies of fallow plots in Indiana revealed that the average soluble ortho-phosphate concentration in runoff and the extractable P content of sediment were proportional to the rate of fertilizer application (76). In summary, Corn Belt research overwhelmingly leads to the conclusion that excessive fertilization, while having little or no effect on yield, will cause higher levels of nutrient runoff into surface and ground waters.

In northern Alabama, growers are encouraged to not exceed fertilization rates recommended on the basis of soil test results (11). Despite the fact that tobacco is a large cash crop in North Carolina, excess fertilization is not a safe practice for ensuring high yields (31). Excess N can ruin the quality of tobacco by browning the leaves, increasing the nicotine level and by delaying maturity to the point where chance of leaf disease is increased. Higher N levels will also reduce yields, while excess P will cause P buildup in the soils (18).

In Georgia, total Kjeldahl nitrogen (TKN) concentrations in surface runoff from watersheds cropped to corn were related to N application rate (49). Fields fertilized at the recommended rate did not contribute large quantities of N to runoff. Alabama corn studies (80) showed that corn utilized 95% of fertilizer N applied at 168 kg/ha, but only removed 50-65% of N applied at 336 kg/ha. Of course, plant density will affect the nutrient uptake efficiency at a given fertilization rate. In Maryland, N fertilization rates are similar for both conventional and no-till corn, but more N can be added to no-till corn if expected yields are higher (7).

In every research effort cited, data led to the conclusion that excessive application of N fertilizer will rarely increase crop yield or quality, but will always increase the likelihood that N will be leached into surface and ground waters. Research further supports the conclusion that excessive P application will cause greater surface runoff losses of P and P buildup in the soil. In short, extra amounts of fertilizer will not ensure better crop yields, but will increase both the cost to the grower and the potential contamination of surface and ground waters (Table 5). Therefore, proper fertilization rate is a BMP both for those regions which have generated literature on the topic (Figure 6) and for the rest of the United States.

Timing

Timing of fertilizer application may be the most critical factor in determining nutrient utilization efficiency and crop yield (50). Each plant has a unique pattern of nutrient absorption (102), and it is possible to maximize plant utilization of nutrients by applying fertilizer near the time of maximum growth (89). Variables such as crop and soil type, date of planting and climate affect the optimum timing of nutrient application (102), so it is crucial that individual farmers manage their fertilization schedules to best match application with the peak demands of their specific crops in their unique situations.

For California sugarbeets researchers recommend the use of petiole samples taken two and four weeks before midseason to determine supplemental N needs (34). In essence, starter N applications are based upon soil tests and fine-tuned before midseason based upon petiole analyses. Earlier work determined that the N uptake efficiency for sugarbeets did not vary significantly among treatments when 135 kg N/ha (120 lbs/acre) was applied in single dose at planting or thinning, split equally between thinning and layby, or split equally among planting, thinning and layby (33). This research, however, did not demonstrate the optimal fertilization rate for each of the timing options examined. Therefore, the advantages of adjusting timing remain a question in California, but the use of pre-midseason petiole analyses suggests that split application is a BMP for beet production.

Texas growers are urged to apply nutrients at or near the time of crop need (94). Fall application of N is discouraged for areas of high rainfall and infiltration. Fertilization schedules should be planned in advance and followed closely when possible. Nitrogen applications for grain sorghum, oats and sudan grass in Texas should be as near to planting as possible (91). No applications are advised before rainy periods or during the period between October and February.

Minnesota field experiments on irrigated corn showed that split application of N (179 kg N/ha and 269 kg N/ha) caused minimal changes in the aquifer NO_3-N concentration while single applications increased the NO_3-N concentration by 7 (179 kg N/ha) and 10 (269 kg N/ha) mg/l (24). The single N application also caused a much higher concentration of NO_3-N below the root zone. It is possible that long term studies would show even more significant differences between single and split applications because recovery of fertilizer N was 52.1% for split application and only 30.4% for single application.

TABLE 5. POLLUTION POTENTIAL VERSUS FERTILIZATION RATE

Crop	Comments	Annual Fertilization Rate	Annual Nutrient† Loss (% Reduction for Low Rate vs. High Rate) Total	Surface	Subsurface	Drains	Available§	Reference
			——— kg/ha ———					
Corn	contour, conventional till	448-N, 66-P	50.2 N_T	1.1 NO_3-N	20.7 NO_3-N	-	-	12
		174-N, 40-P	28.1 N_T (44)	.6 NO_3-N (53)	6.7 NO_3-N (67)			
				-	-	-	-	
		448-N, 66-P	.95 P_T					
		174-N, 40-P	.60 P_T (64)					
Corn	approximate contour planting	447-N	-	-	-	-	239-278 N_T	82
		178-N					16-24 N_T (90-94)	
Corn	plant population varied	336-N	-	-	-	-	118-168 N_T	80
		168-N					8-34 N_T (80-93)	
Corn	irrigated	150-N	-	-	-	-	97 N_T	62
		50-N					35 N_T (64)	
Wheat/Beans/Corn	3 yr. rotation	243-N, 32-P	-	-	-	2.75 NO_3-N*	-	104
		86-N, 12-P				.46 NO_3-N* (83)		
Sugarbeets	112-N=optimum for sugar	280-N	-	-	-	-	170 N_T	33
		224-N					128 N_T	
		168-N					92 N_T	
		112-N					60 N_T (65,53,35)	

† N_T = total nitrogen, NO_3-N = nitrate nitrogen, P_T = total phosphorus.

§ (Fertilizer applied - Fertilizer uptake by crop).

* Weekly discharge.

Figure 6. Land Resource Regions with literature references (///) indicating proper fertilization rate as a BMP.

Two studies in New York have shown that N should not be applied between October and May because crop uptake is low and deep seepage is abundant (42,103). Nitrate loading in surface runoff was correlated with heavy fall fertilization before wet periods, but neither NH_4-N nor inorganic P surface loadings were related to time of application (42).

In the Corn Belt, N losses can be reduced significantly by delaying major N applications until after the root system is developed for rapid N uptake and after soil water levels decline to allow more storage for rainfall events (101). By applying 25% of N in bands at planting and 75% in bands at sidedressing, N losses will be reduced as N use efficiency increases. Furthermore, similar yields can be obtained under either conventional till or no-till with 25% less N than presently applied (134-156 kg N/ha).

Corn yields in North Carolina were comparable for fields fertilized with a split application of 116 kg N/ha (130 lbs/acre) and fields receiving 160 kg N/ha (180 lbs/acre) in a single application (45). In Georgia, runoff loadings of plant nutrients from corn fields can be reduced by shifting fertilization dates to periods of rapid plant canopy development and to periods of less intense rainfall (49). For tobacco production it is best to add the recommended rate of fertilizer during the early stages of development and later replace any leaching losses with more fertilizer (30,31). Though most of the data for Land Resource Region P represent production concerns instead of water quality concerns, efficient fertilizer use will make less fertilizer available for runoff and leaching.

No-till corn in Maryland yields better when N is applied at the time of peak demand (7). Though more research is needed in this area, peak demand seems to occur at five to six weeks after planting, or when the corn is 12-18 inches tall. When N was applied in April, conventional till corn out-yielded no-till corn, but when N was added in June the trend was reversed. In conclusion, it is best to split N applications to Maryland corn by adding 27-36 kg N/ha (30-40 lbs/acre) as a starter and the remainder as sidedress after five to six weeks.

December nitrogen application to sandy corn fields in North Carolina resulted in considerable leaching of N (39). Corn yields were much lower on sandy fields fertilized in December as compared to those fertilized at planting or at sidedressing. Pre-plant application was just as effective as sidedressing on sandy soils. Corn yields on Piedmont soils were affected little when N was applied in December versus preplant or sidedressing.

As compared with application rate, the data base for drawing conclusions regarding fertilization timing is small. However, production and water quality data from three Land Resource Regions support as a BMP the exclusion of fall application for spring and summer crops (Figure 7). Common regional characteristics which most effect the preclusion of fall application are wet soils requiring drainage and heavy rainfall and infiltration patterns. Therefore, regions which contain much drainable wet land (84) and humid climates (25) are projected not to be suitable for fall fertilization (Figure 7).

Split applications of N fertilizer are supported by the literature as a BMP in several regions (Figure 8), though much research is necessary to draw

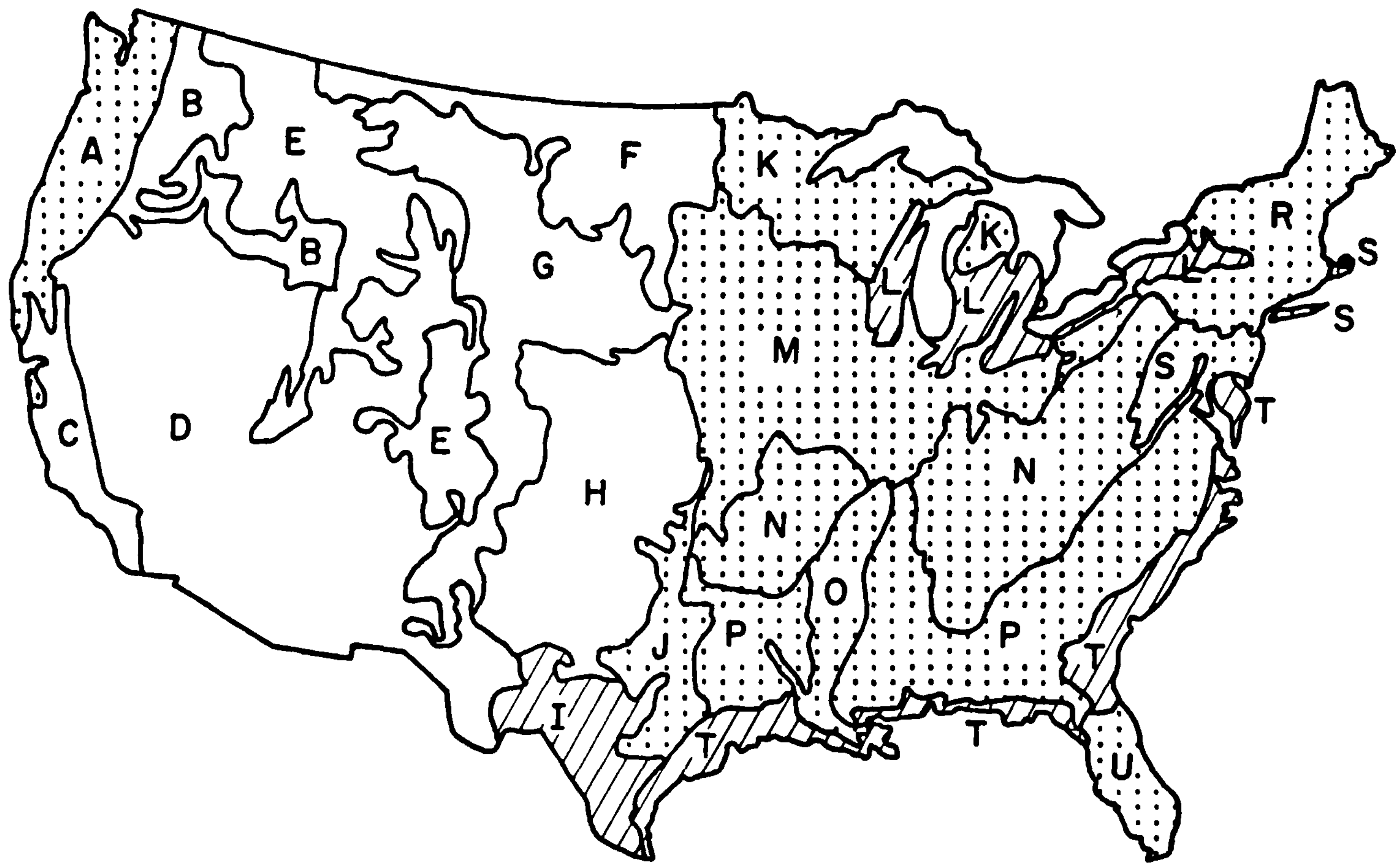

Figure 7. Land Resource Regions with literature references (///) and projections (:::) indicating elimination of fall application as a BMP for spring and summer crops.

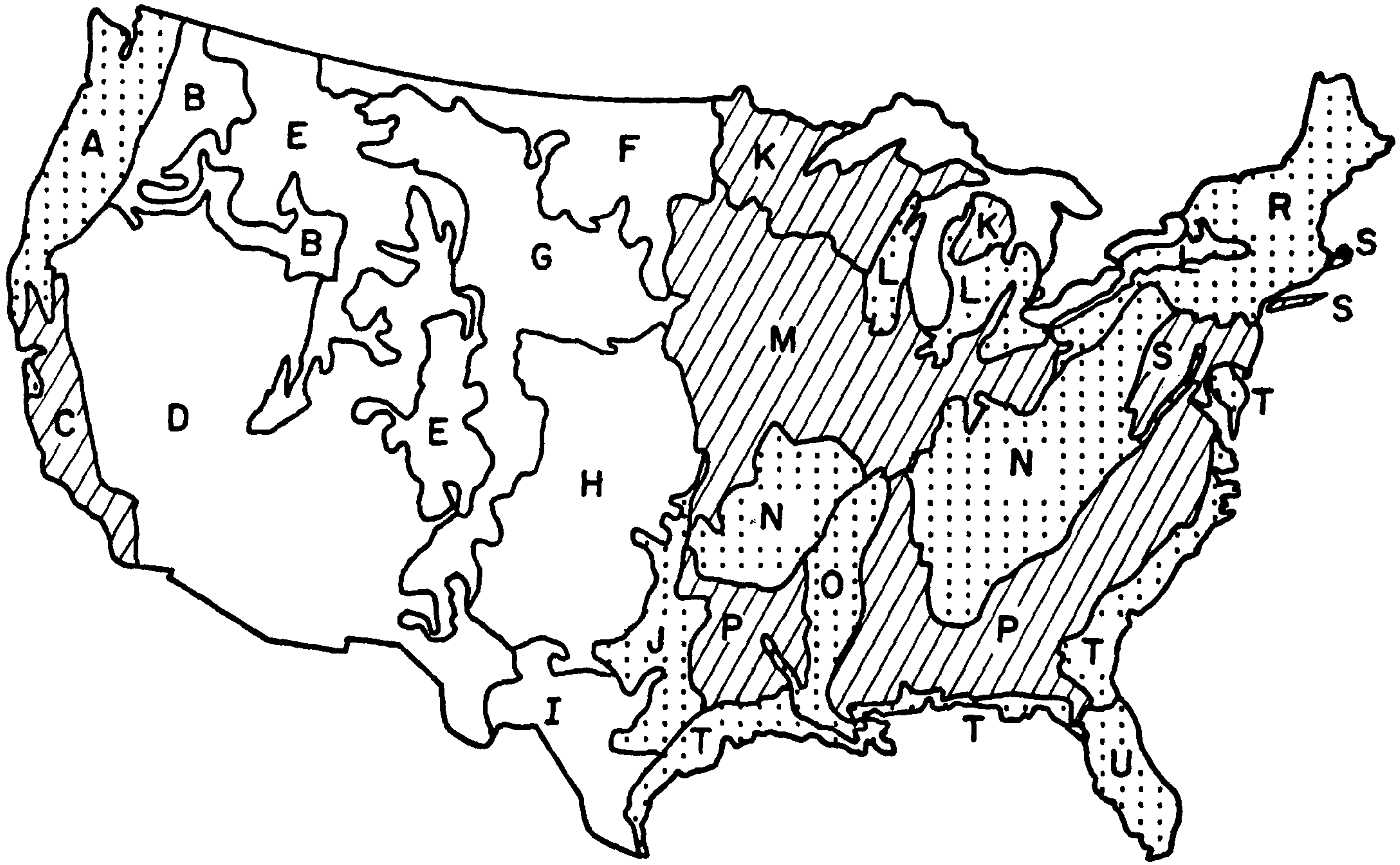

Figure 8. Land Resource Regions with literature references (///) and projections (:::) indicating split application as a BMP.

strict guidelines for application schedules. Available data do indicate that split application of fertilizer can reduce the amount of leachable nitrogen as compared to single application (Table 6). Therefore, split applications are recommended as a BMP for all humid regions (Figure 8) and areas of intensive irrigation in other regions.

CONTROLS FOR NITROGEN LOSS

Method of fertilizer application and farm management practices can significantly affect N losses from agricultural lands (102). Irrigation practices may also impact the percentage of applied fertilizer lost to runoff or leaching. This section covers those practices which are intended to reduce N losses regardless of N form. Different regions may experience very different water quality problems and may require varied control mechanisms.

In California, sugarbeet uptake of N is more rapid when fertilizer is placed 24 centimeters to each side of the rows as opposed to placement halfway between rows (33). Several recommendations were made for reducing nitrogen losses in drainage waters of the irrigated San Joaquin Valley in California (66). Ammonia and urea are the preferred forms of N fertilizer as both will be leached less rapidly than nitrate fertilizers. In cases where N is very mobile it is best to split fertilizer applications and place the nutrients in bands near the greatest root zone density. Excessive deep percolation can be avoided by adjusting irrigation practices to just meet the evapotranspiration requirements of the crops. Finally, the quantity of N leached to the tile drains may be reduced if farmers grow high N requirement plants on fine textured soils. Other methods are designed to remove N from tile drainage before it reaches receiving waters. Algal stripping, in which aerated shallow ponds remove N through sedimentation and algal productivity, can reduce drainage water nitrogen concentration from 20 mg/l to 3-5 mg/l at a 1971 cost of $45 per acre foot (74). Anaerobic deep ponds with filters decreased drainage water N concentration from 20 mg/l to 2 mg/l or less through bacterial denitrification at a cost of $30 per acre foot.

The effects of intensive irrigation of sandy soils in Nebraska further emphasize the need for better irrigation management as outlined for the San Joaquin Valley (57, 61). Data indicate that an increase in irrigation was the greatest cause of steadily increasing NO_3-N concentrations in the groundwater. Research in Texas supports the conclusion that subirrigation with fertilizer placement above the subirrigation lateral is superior to both furrow and sprinkler irrigation from the standpoint of minimizing fertilizer NO_3-N movement below the root zone (65). Nitrate passing below the root zone can be removed by either subsurface runoff or groundwater infiltration. Simultaneous knifed applications of N and P produced consistently higher winter wheat yields than either broadcast or band applications (51). Simultaneous dribble application of liquid N and P provided good yields, and N-serve™ increased wheat yields in this Kansas study. Results from plot studies in Texas showed that both N-serve™ and sulfur coated urea reduced NO_3-N leaching by inhibiting the release of NO_3-N from applied fertilizer (91). For any fertilization timing program for grain sorghum, oats and sudan grass it is suggested that ammonium, urea, N-serve or sulfur

TABLE 6. SPLIT NITROGEN APPLICATION VERSUS SINGLE NITROGEN APPLICATION

Crop	Comments	Fertilization Timing	Annual† Leachable N_T (kg N/ha)	%Reduction of Leachable N_T Due to Split	Reference
Corn	Irrigated, 179 kg N/ha/yr	Single	124	-	24
		Split	86	31	
Sugarbeets	135 kg N/ha/yr	Single-Planting	87.2	-	33
		Single-Thinning	83	-	
		Split-Thinning & Layby	86.3	none	
		Split-Planting, Thinning & Layby	87.8	none	

† Applied N minus N recovered by plant.

coated urea be used instead of nitrate fertilizers.

In an Oklahoma cropland and rangeland study it was determined that alfalfa is an economically effective control of sediment and total nutrient loads, but the resultant increase in soluble NO_3-N concentration could present water quality problems (60). It was also shown that total Kjeldahl nitrogen (TKN) concentration in runoff from irrigated cotton is positively correlated with sediment loss, so sediment control measures should decrease TKN losses. From other Oklahoma research it was concluded that fertilization will initially increase nutrient concentrations in surface runoff from grasslands (59). However, increased plant cover resulting from fertilization may eventually decrease nutrient losses by decreasing runoff volume and soil erosion. Broadcast fertilizer on grazing lands will be lost to surface runoff at a rate of up to 5% of that applied at rates to 75 kg N/ha (67 lbs/acre). Nitrogen losses from a rotation of grain sorghum, cotton and oats in the Texas Blackland Prairie consisted largely of organic nitrogen bound to sediments (41). Under good fertilization and management practices NO_3-N losses to surface runoff were relatively low. In summary, nitrogen losses from agricultural lands in the Southwestern prairies can be minimized by controlling sedimentation and following soil test results for proper fertilizer application rates.

In New York it was shown that soil and nutrient losses are greater from continuous corn fertilized with just mineral fertilizer when compared versus either corn fertilized with mineral fertilizer, manure and crop residue or corn in crop rotation (103). A crop rotation of corn, small grain and alfalfa produced the smallest losses of soil and nutrients in surface runoff. Crop residue incorporation reduced surface losses, but increased infiltration and NO_3-N leaching. Efficient use of manure both as a source of crop nutrients and as a soil physical conditioning agent is encouraged (103). Ammonium and nitrate concentrations in tile drainage from wheat, corn and bean plots were not affected by residue management or by cover crop establishment (104). Corn, forage, small grain and soybean growers in New York are advised to band and sidedress fertilizer to best meet economic and water quality objectives (19). Data from Ontario, Canada show that heavily fertilized coarse-textured soils have great potential for NO_3-N leaching to receiving waters (29). In summary for the Lakes States, a trade-off seems to exist between controlling nitrogen losses to surface waters and to groundwater. Manure and residue incorporation, crop rotations and cover crops will reduce surface losses of N, but possibly increase N losses to ground water.

There exists a wealth of published Corn Belt research from which conclusions regarding N control can be drawn. Studies addressing surface runoff losses of N demonstrate conclusively that most of the total N lost in surface runoff is associated with sediment losses (2, 8, 12, 15, 81, 97). Therefore, sediment control practices should effectively reduce total N losses in surface runoff. Compared to conventional tillage corn, no-till corn yields less sediment, particulate N and total N (101). Level terraces in Iowa watersheds cropped to corn effectively reduced surface runoff, erosion and particulate nitrogen loads, whereas contoured watersheds were not as effective in controlling N losses (12, 14). Also in Iowa, conservation tillage effectively reduced total N loads by controlling erosion (8). Both a level terraced watershed with corn and a pasture watershed lost much less N to surface runoff than contoured watersheds as sediment and water losses were reduced significantly (81).

Using data from other research, it was determined that crop residues are important both as nutrient sources and as erosion controls (35). Corn residues contain 62-71 kg N/ha (55-63 lbs/acre), and soybean residues contain 68-73 kg N/ha in the Corn Belt. In this region there exists an opportunity to balance N gains and losses through conservation tillage and residue management. A balanced nutrient budget on the farm will not necessarily help to improve water quality unless nutrient losses are minimized. The above research indicates that conservation tillage can reduce N losses to receiving waters.

In simulated rainfall studies in Minnesota, it was shown that fertilization method can be varied to control N losses in surface runoff (96). In this test of four methods, total nitrogen loadings were lowest from fields with fertilizer broadcast onto a plowed surface. When fertilizer was broadcast onto oats stubble and incorporated by plowing down and disking, N loads were the same as for the check (plowed and disked, no fertilizer) plot. Nitrogen losses were not controlled when fertilizer was broadcast and disked on a plowed surface. The greatest N loads came from plots upon which fertilizer was broadcast on a disked surface. Seasonal studies have shown that the largest fraction of annual N loss from corn plots occurs during the period covering planting to crop establishment (April-June) (2, 15). Level terraces effectively reduced N losses in one study (2), and a corn-oats-hay rotation controlled sediment losses more effectively than continuous corn in other plot research (15). However, this rotation is generally not considered economically feasible.

While controlling surface runoff losses of nitrogen, many control mechanisms simultaneously increase NO_3-N leaching into groundwaters. In Missouri it was determined that most applied fertilizer is carried downward into the soil with precipitation instead of being washed away in surface runoff (85). Iowa research on watersheds cropped to corn revealed that subsurface NO_3-N losses account for 84-95% of the average annual soluble N discharged by stream flow (12, 14). Furthermore, though they reduced particulate N losses in surface runoff, level terraces yielded greater subsurface discharge of NO_3-N than did contoured watersheds. Tile effluent from corn fields in Ohio carried the greatest amount of N to receiving waters in June when flow was high and corn was not yet established (53).

As for the Lakes States, it appears that individual nitrogen control mechanisms in the Corn Belt can either reduce surface runoff losses or groundwater infiltration, but not both. Sediment control measures, especially level terraces, are very effective in reducing total N losses in surface runoff, but also promote increased infiltration and the resultant leaching of available NO_3-N.

In rain simulator studies of corn plots in Indiana, 170 kg N/Ha (152 lbs/acre) was applied before each of five tillage systems to test their effects on surface runoff (77). Both coulter-plant and chisel-plant systems were effective in controlling sediment loss and particulate nitrogen loading. Till-plant and disk-coulter-plant practices were less effective in controlling sediment and associated nutrient loss. Conventional till-plant plots yielded the greatest sediment and particulate N runoff losses, but had the smallest soluble N loadings. In general, those practices which effectively reduced sediment and particulate N loadings also caused the greatest losses of soluble N. In northern Alabama researchers concluded that most N is lost with sediments (11). Subsurface soluble NO_3-N concentrations were as much as five times as great as those found in surface runoff. Sulfur coated urea pellets did not help control N runoff, possibly because pellets were washed away with other runoff. In cases where sulfur coated urea is used, it is probably best to incorporate the fertilizer. In summary for Land Resource Region N, it is very likely that surface losses of N will be reduced at the expense of increased subsurface leaching of NO_3-N when sediment control practices are installed to control nutrient losses.

Louisiana plots seeded to pearl millet were used to determine the runoff loads of different blends and types of fertilizer (21). Nitrogen loads from both the high (33.3-8.7-16.6 as N-P-K) and low (8-3.5-6.6 as N-P-K) blends were low, but losses were generally greater from the higher analysis source. Four (1974) to 37 (1973) times less N was lost from plots fertilized with incorporated sulfur-coated urea as compared to plots with incorporated uncoated urea. It appears that incorporation of slow-release N fertilizer is a BMP in the silt loams of the Mississippi Delta.

For small acreages of North Carolina tobacco the application of fertilizer in two bands ten days after transplanting consistently provides the highest yields and reduces the chances of early leaching (18). For larger acreages upon which an extra trip over the fields is impractical, two bands of fertilizer at planting will guarantee good yields. Broadcast and single band applications are not recommended for consistent yields. Subsurface leaching of NO_3-N is very possible under high moisture conditions in the Southern Coastal Plain as water passes readily through sandy surfaces to the relatively impermeable clay horizon (38, 93). In a Georgia Coastal Plain watershed planted to corn, subsurface drainage accounted for 80% of the total runoff and 99% of the total NO_3-N loading (38). Weighted average NO_3-N concentrations in subsurface drainage (5.8-12.6 mg/l NO_3-N) were much higher than those in surface runoff (0.11-3.0 mg/l). In other Georgia research a double-cropped watershed with graded terraces and a grassed waterway controlled N losses more effectively than a similar watershed with no conservation practices (49). Both watersheds were cropped to corn and received split N applications (140 kg N/ha). Ammonium and TKN loads were 35-40% less from the conservation watershed, but NO_3-N losses did not differ significantly between watersheds. Reduced sediment loss was largely responsible for the smaller N losses form the conservation watershed.

Maryland no-till corn studies have resulted in a few conclusions regarding proper fertilization techniques (7). Since urea is not incorporated in no-till volatilization losses can be high. Therefore, as regards fertilizer uptake efficiency, ammonium nitrate appears to be superior to unincorporated urea. If an applicator is available, urea can be injected several inches below the soil surface to improve fertilizer uptake efficiency. Also, liquid N fertilizer should not be sprayed over the top of growing plants.

Several research efforts support the conclusion that excess fertilizer on well-drained Atlantic Coast soils will be leached to groundwater over the winter months (23,26,27,39). Nitrate concentration in North Carolina coastal ground-water reaches its peak in the winter (26), and drainage control with flashboard risers can be used to reduce NO_3-N entry into surface waters by reducing flow through the tile lines in moderately well-drained soils (27). In poorly drained coastal soils most NO_3-N was lost through denitrification (23), but attempts to increase denitrification by raising the water table failed (27). Data indicate that NO_3-N leaching from Atlantic Coast soils can be controlled by matching fertilizer applications with crop needs and minimizing water transport through drainage lines, especially during winter months.

In a major effort to determine the effectiveness of soil and water conservation practices (SWCPs) for pollution control on non-irrigated field crops in the Eastern half of the United States (28), the following conclusions were made regarding N control:

1. Contouring, terraces, sod-based rotations, conservation tillage and no-tillage significantly reduce edge-of-field losses of particulate N because they reduce erosion.

2. Sod-based rotations significantly reduce losses of soluble N in surface runoff.

3. Contouring, terraces, conservation tillage and no-tillage moderately reduce soluble N losses in surface runoff by reducing surface runoff. These practices may increase soluble N losses in subsurface drainage.

4. Management of N fertilizer applications to meet crop needs can reduce soluble N losses in both runoff and percolation.

5. The effects of SWCPs on N runoff losses show significant yearly variations.

From the many research efforts conducted across the United States it is possible to draw both hard and tentative conclusions regarding national BMPs for nitrogen control. The following are hard conclusions based upon a large quantity of research:

1. Sediment control mechanisms, especially terraces, will significantly reduce total nitrogen loadings to surface waters (Table 7).

2. Unless fertilizer management is altered to increase plant uptake efficiency, sediment control mechanisms will cause increases in NO_3-N leaching to subsurface waters as surface runoff losses are reduced (Figure 9).

3. Intensive irrigation increases the probability of NO_3-N leaching to groundwaters. By adjusting irrigation practices deep percolation and NO_3-N leaching can be reduced (Figure 10)

TABLE 7. TERRACE VERSUS CONTOURING AS NITROGEN CONTROLS

Crop	Comments	Practice	Annual Nutrient† Loss (% Reduction vs. Other Practice)			Reference
			Total	Surface kg/ha	Subsurface	
Corn	448 kg N/ha/yr 3 year study	Level Terrace*	16.2 N (59)	.1 NO_3-N (89) .2 NH_4-N (75)	13.1 NO_3-N .5 NH_4-N	12
	450 kg N/ha/yr	Contour*	39.9 N	1.2 NO_3-N .8 NH_4-N	5.4 NO_3-N (58) .1 NH_4-N (74)	
Corn	168 kg N/ha/yr 39 kg P/ha/yr	Terrace§, pipe outlets & mulch till	-	.2 NH_4-N (18) 7.2 Sediment-N_T (15) 1.8 NO_3-N 9.2 N_T	-	2
		Contour*	-	.3 NH_4-N 8.5 Sediment-N_T .4 NO_3-N (76) 9.2 N_T	-	

N_T = total nitrogen, NO_3-N = soluble nitrate nitrogen, NH_4-N = soluble ammonium nitrogen.

Conventional Till.

Terrace installation partly responsible for heavy nutrient losses in first year of 4-year study.

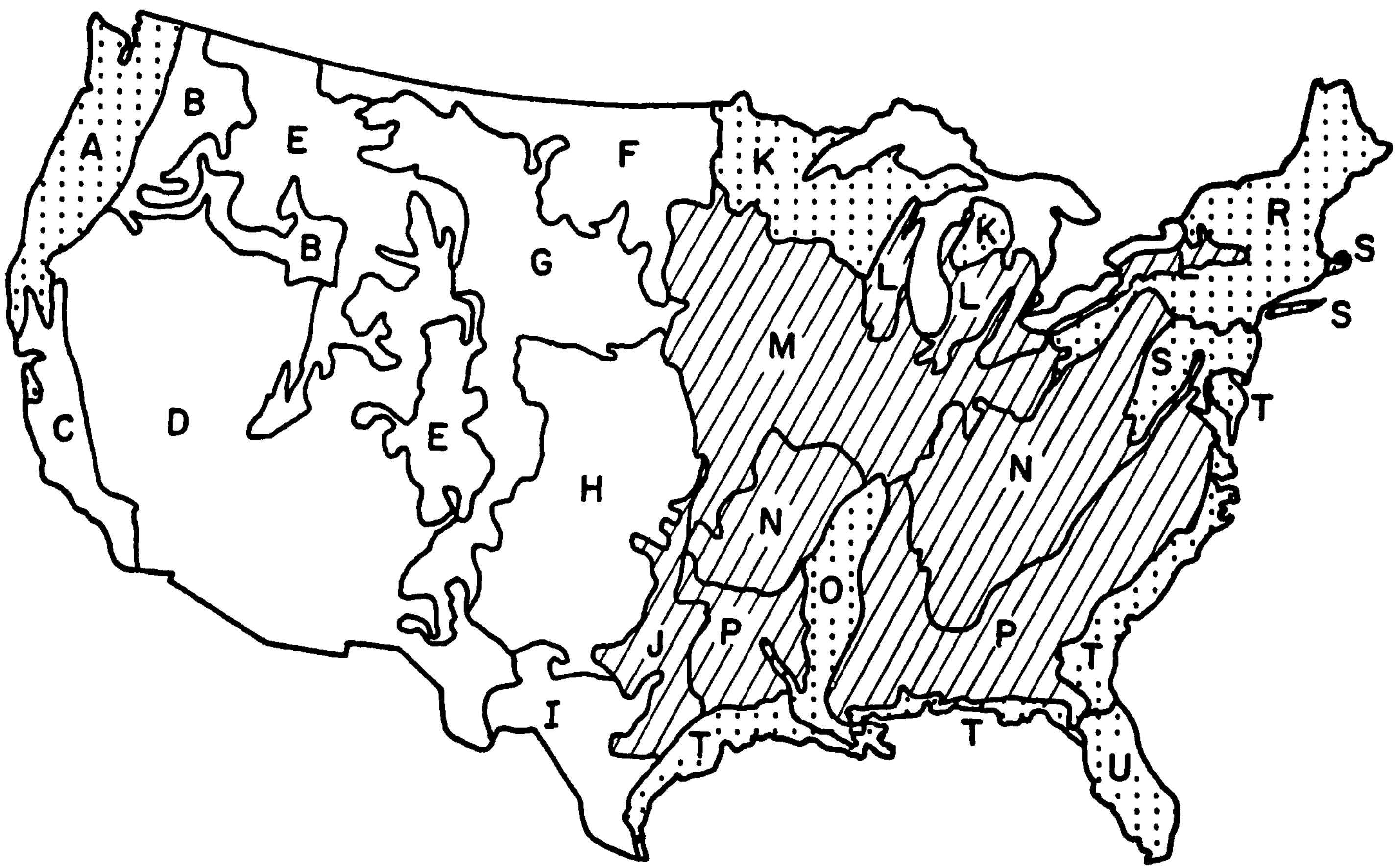

Figure 9. Land Resource Regions with literature references (///) and projections (:::) indicating increased NO_3-N leaching coinciding with sediment control.

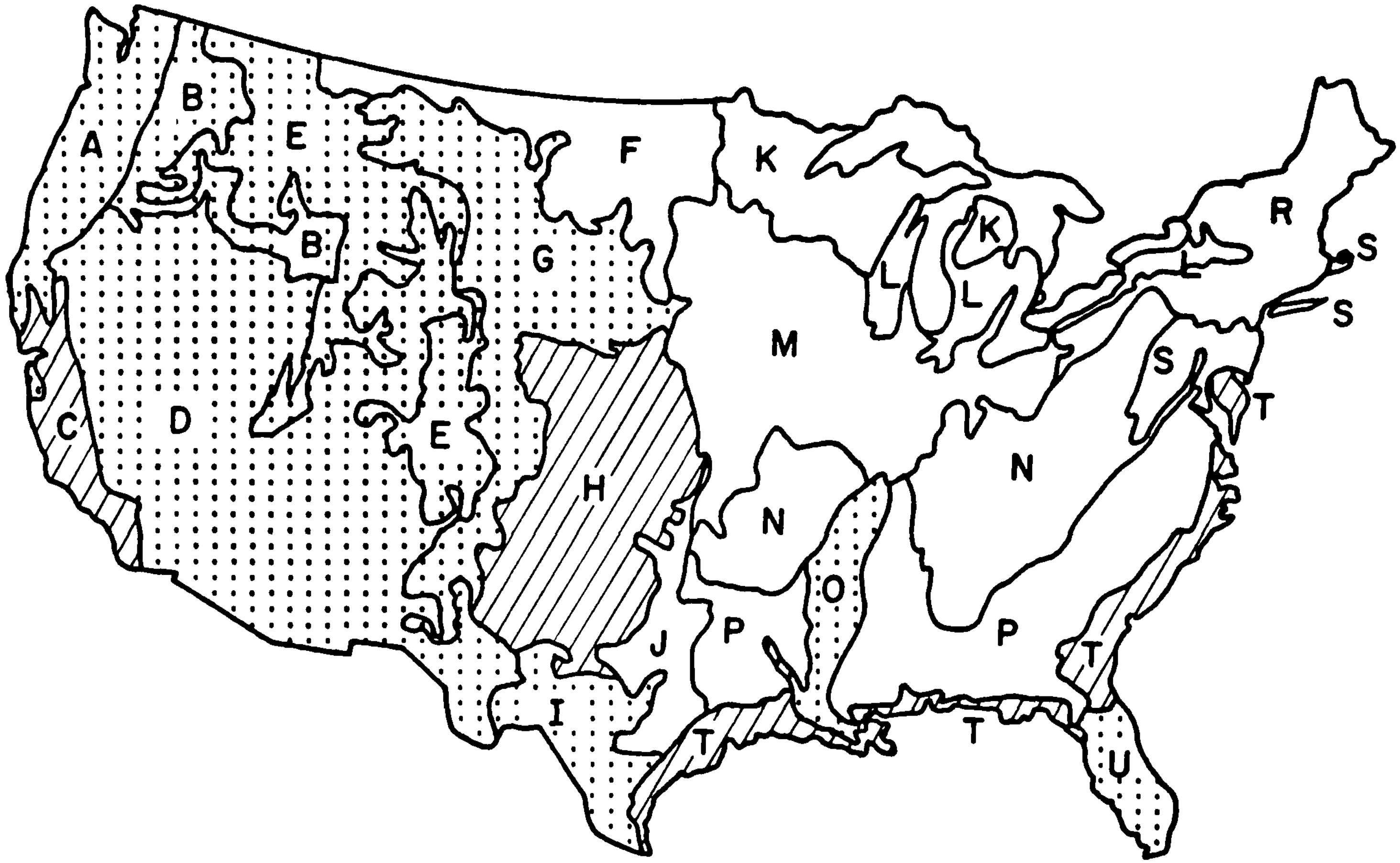

Figure 10. Land Resource Regions with literature references (///) and projections (:::) indicating irrigation management can reduce NO_3-N leaching to groundwater.

3. (continued) - (Table 8).

4. If incorporated, slow-release nitrogen fertilizer can effectively be used to reduce nitrogen losses to surface and ground waters (Figure 11) (Table 8).

Other conclusions regarding nitrogen control mechanisms are based upon less firm data, and are therefore tentative:

1. Crop rotations, no-till and conservation tillage may reduce surface runoff N losses (Table 9).

2. Banding or other directed placement of fertilizer may increase fertilizer uptake efficiency.

3. Contour practices may moderately reduce surface runoff N losses.

4. Broadcast fertilizer should be incorporated.

5. Where NO_3-N leaching is a problem it may be better to use ammonium and urea instead of nitrate fertilizers.

CONTROLS FOR PHOSPHORUS LOSS

In order to better evaluate the relative merits of phosphorus control mechanisms, it is necessary to characterize the water quality impacts of the various P forms. Soluble ortho-phosphate is completely available for algal growth, and soluble organic P and polyphosphate are readily converted to ortho-phosphate (89). However, in water with less than .1 mg/l dissolved inorganic P it has been determined that only about fifty percent of this P is available to algae (20). Separate reports have indicated that approximately twenty percent of all particulate P is available to algae (20, 36). Once a water quality problem is effectively assessed, it is then possible to determine whether P control mechanisms should be directed toward the soluble, particulate or total P fraction.

Idaho research on irrigated lands showed that most P in irrigation and surface drainage waters is associated with sediment (17). Both total unfiltered P and total ortho-phosphate (ortho-PO_4) concentrations were correlated with sediment concentration, but dissolved ortho-PO_4 losses were not related to sediment runoff. Phosphorus runoff from irrigated tracts can be limited by minimizing the quantity of surface drainage water and by using sediment retention basins or low slope drains.

As noted for N control, simultaneous knifed applications of N and P were superior to both broadcast and band applications for winter wheat production in Kansas (51). The researchers credit the higher yields from knifed applications both to the deeper placement of N and P which insured more moisture for nutrient uptake and to a possible change in P chemistry produced by high concentrations of NH_4-N in the phosphorus retention zone. Higher

TABLE 8. EFFECTIVE NITROGEN CONTROL MECHANISMS

Control Mechanism	Comments	Annual Nutrient[†] Loss (% Reduction vs. Other Practice)		Reference
		Surface	Drains	
Flashboard Riser Drain Control	Mod. well-drained soils	-	1-7 kg NO_3-N/ha (72-98)	27
None	Mod. well-drained soils	-	25-40 kg NO_3-N/ha	
Flashboard Riser Drain Control	Poorly drained soils	-	12-15 kg NO_3-N/ha (50)*	27
None	Poorly drained soils	-	25-30 kg NO_3-N/ha	
Sulfur-Coated Urea	Rye grass, 224 kg N/ha/yr, incorporated	1.1-2.1 kg N§/ha (57-95)	-	21
Uncoated Urea		4.9-21.9 kg N§/ha	-	

* NO_3-N loss calculated from reported 50% reduction vs. drain with no controls.

† NO_3-N = soluble nitrate nitrogen, NH_4-N = soluble ammonium nitrogen.

§ NH_4-N + NO_3-N + urea; losses for 48-51 days during late fall and early winter.

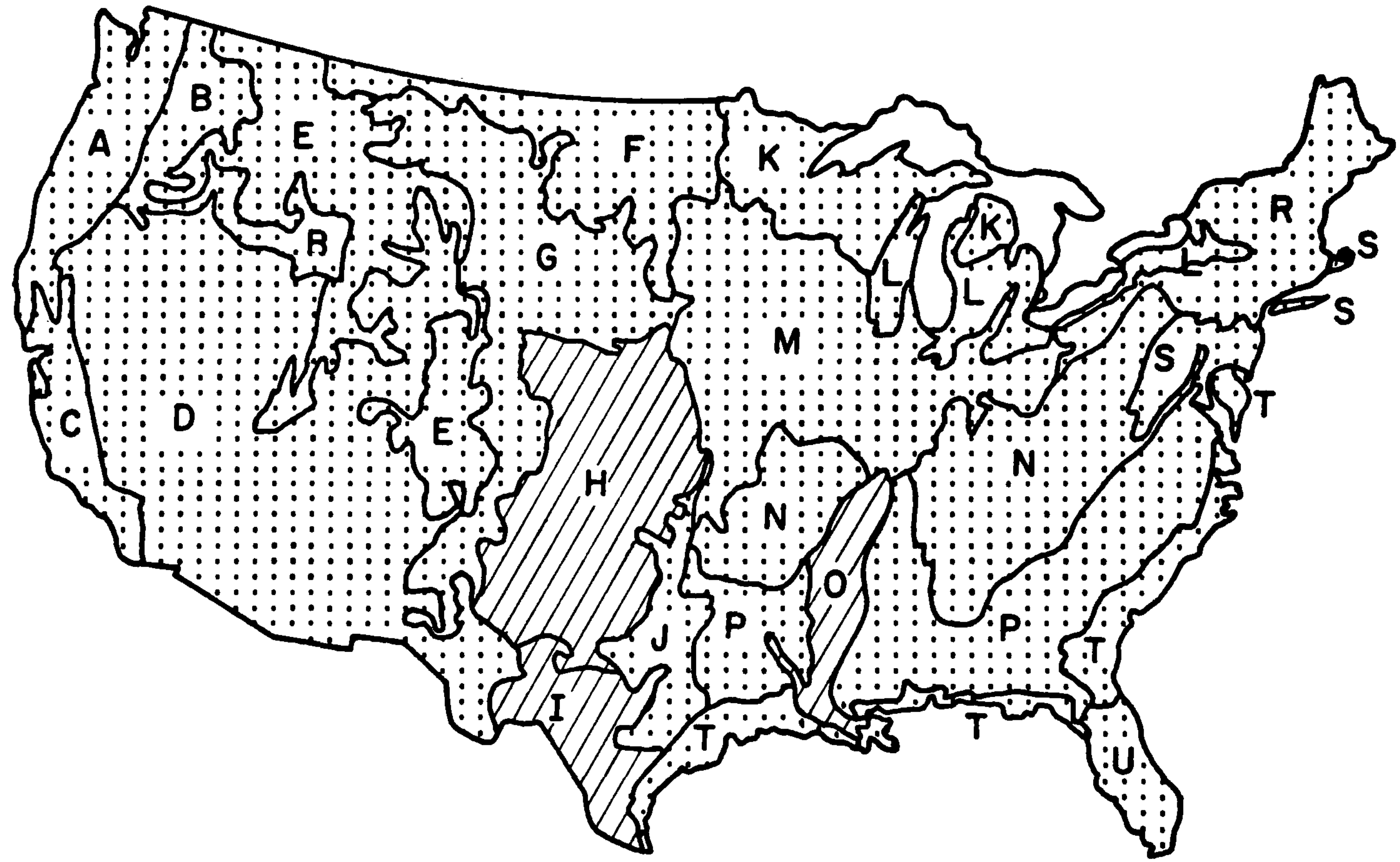

Figure 11. Land Resource Regions with literature references (///) and projections (:::) indicating slow-release fertilizer can reduce N losses.

TABLE 9. CONSERVATION PRACTICES AS NITROGEN CONTROLS

Crop	Comments	Practice	Annual Nutrient[†] Surface Loss (% Reduction vs. Other Practice)	Reference
Corn	112 kg N/ha/yr & 29 kg P/ha/yr[*]	Continuous	1.2 kg NO_3-N/ha .7 kg Org-N/ha .4 kg NH_4-N/ha 23.6 kg N_T/ha 21.2 kg Sed. Org-N/ha	15
	56 kg N/ha/yr & 29 kg P/ha/yr[*]	Rotation	.4 kg NO_3-N/ha (64) .3 kg Org-N/ha (54) .2 kg NH_4-N/ha (51) 14.2 kg N_T/ha (40) 13.0 kg Sed. Org-N/ha (39)	
Corn/Beans/Wheat	3 year rotation	No Residue or Cover Crop	6.0 kg NO_3-N/ha .5 kg NH_4-N/ha	42
		Return Residue & Cover Crop	1.2 kg NO_3-N/ha (80) .5 kg NH_4-N/ha (0)	
Pasture	No Fertilizer	Continuous Grazing	7.4 kg Org-N/ha 9.7 kg N_T/ha 1.8 kg NO_3-N/ha .4 kg NH_4-N/ha	60
		Rotation Grazing	1.3 kg Org-N/ha (82) 2.1 kg N_T/ha (78) .5 kg NO_3-N/ha (74) .3 kg NH_4-N/ha (38)	

* Recommended rate, fall plow, spring broadcast and disk.

† N_T=total nitrogen, NO_3-N=soluble nitrate nitrogen, NH_4-N=soluble ammonium nitrogen, Org-N=soluble organic nitrogen, Sed. Org-N=sediment associated organic nitrogen.

soluble P concentrations were found in surface runoff from fertilized (75 kg P/ha broadcast) Oklahoma rangeland watersheds than from unfertilized watersheds (59). Elevated soluble P concentrations from fertilized watersheds persisted for at least one year, but the total amount of P lost to surface runoff will probably not exceed five percent at rates to 75 kg P/ha.

Research in Wisconsin showed that the greatest total P loads from plots occurred with the greatest sediment losses (100). In short, sediment control practices were determined to have the greatest potential for reducing P losses from Wisconsin glacial till farmlands.

New York investigations showed that soluble P concentrations in tile drains were not significantly influenced by residue and crop cover practices (104), but soluble inorganic P loads in surface runoff were smaller when residue was returned and cover crops were used as compared to no residue or cover crop (42). Furthermore, P transport was far greater in surface runoff than in subsurface flow (103). Most lost P is associated with sediment, and total P losses are directly correlated with surface runoff volume.

Corn Belt research has provided the most data regarding P control mechanisms. Several studies have shown that most P lost in surface runoff is associated with sediments (2, 12, 15, 85, 97). Level terraces were effective in reducing P discharge from corn fields via surface runoff (12). Soluble P loads in subsurface discharge represented a very small fraction of the annual fertilizer application. Total surface P loads were nine times less from Iowa watersheds with level terraces as compared to contoured watersheds (83). The larger terraced watershed lost eight times less surface runoff and nineteen times less sediment than the contoured watershed. Other Iowa research showed that disking, ridge-plant and coulter tillage practices reduced total P surface runoff loads as compared with conventional tillage, chisel-plow and till-plant practices (8). Conservation tillage did not affect soluble P loads, but soluble P concentrations in surface runoff increased as residue cover increased. Studies in Minnesota (97) and Missouri (85) both showed that erosion control practices can be used to effectively reduce P losses in surface runoff.

Seasonal studies in Land Resource Region M showed that most P from corn fields is lost with sediment during the critical erosion period from planting to two months later (2, 15). Once again, level terraces were very effective in reducing P discharges in surface runoff (2).

In a Minnesota plot study of four broadcast fertilizer placement options, P losses were smallest from plots where fertilizer was broadcast onto a plowed surface (96). Incorporation by plowing and disking over oats stubble also effectively controlled P discharges, while both disking broadcast fertilizer and broadcasting fertilizer onto a disked surface were ineffective.

More than 95% of total P lost from Alabama cotton, corn, millet and soybean plots was associated with sediment (11). Therefore, growers are encouraged to use erosion control practices to reduce P runoff. In an Indiana study of the effects of tillage practices on P losses from corn plots it was found that coulter-plant and chisel-plant systems controlled soil erosion more effectively than either till-plant or disk-coulter-plant systems (77). Conventional tillage caused the greatest soil and water runoff. Discharges of soluble P from the various systems ranked in the order: coulter-plant>>till-plant>chisel-plant>disk-coulter-plant>>conventional-plant. Runoff loads of P associated with sediment decreased by tillage practice in the following order: conventional>till-plant>disk-coulter-plant>coulter-plant>chisel-plant. For control of total P load in surface runoff the systems ranked in order of decreasing effectiveness: chisel-plant>disk-coulter-plant>till-plant>coulter-plant>conventional-plant. In Ohio, 85-100 percent of P lost from pastured watersheds is soluble (69).

For Louisiana plots seeded to pearl millet, phosphorus losses were slightly greater from the higher analysis fertilizer source than from the lower analysis source, but all losses were considered to be small (21). Mean monthly phosphate concentrations in submerged and open tile drains in Florida were higher for citrus plots treated with shallow-tillage (.19-.90 mg PO_4-P/l) than for plots under deep-till with and without liming (<.4 mg PO_4P/l) (16). From these sandy Florida plots 14.2 percent of applied P was lost from shallow-till treatment, whereas lower percentages were lost from deep-till (3.4 percent) and deep-till with lime (2.0 percent).

For non-irrigated field crops in the Eastern half of the United States, the following conclusions were drawn regarding the effectiveness of soil and water conservation practices (SWCPs) for phosphorus pollution control (28):

1. Contouring, terraces, sod-based rotations, conservation tillage and no-tillage significantly reduce edge-of-field losses of particulate P because they reduce erosion.

2. Sod-based rotations significantly reduce losses of soluble P in surface runoff.

3. Practices such as no-tillage and conservation tillage which involve residue management have an uncertain effect on losses of soluble P in surface runoff.

4. SWCPs such as contouring and terraces which are not based on residue management, moderately decrease losses of soluble P in surface runoff.

A review of the literature regarding phosphorus control mechanisms has shown that very strong conclusions are based upon very little data (Figure 12). With the exception of the Corn Belt, the use of erosion control practices to limit P losses has virtually been assumed because most P is associated with sediment in surface runoff. Very few studies have addressed P leaching into groundwater and subsurface flow as related to surface runoff controls. As a result of the inability to uncover a large quantity of literature regarding P control mechanisms, few conclusions can be drawn about their effectiveness:

1. Level terraces effectively reduce total P losses by limiting

Figure 12. Land Resource Regions in which significant phosphorus control research is available (///).

1. (continued)
   water and sediment runoff (Figure 13) (Table 10).

2. Soil conservation practices such as residue management, sod-based rotations and rotation grazing can decrease total and soluble P losses in surface runoff (Table 11).

3. Conservation tillage practices generally reduce total P discharge as compared with conventional tillage.

4. Conservation tillage practices can increase soluble P losses as compared with conventional tillage.

5. Sedimentation basins and flow control can be used to decrease P losses from irrigation systems.

SUMMARY

A discussion of the various control mechanisms for N and P losses leads to the conclusion that an integrated system of BMPs is best in most cases. Soil testing is a must for every BMP system. Nitrogen and phosphorus application rates should not at any time exceed the assimilative capacity of the crop. Where possible, timing of nitrogen application should be matched with maximum plant nutrient demand. Methods of N and P application that best place these nutrients within reach of a crop will decrease potential losses to surface and ground waters. Where nutrient application rate, timing and method best match crop needs little N and P is available to pollute receiving watersheds. Such a situation minimizes the need for erosion control practices to control N and P losses.

While it is obvious that the technology exists for reducing agricultural N and P discharges to receiving waters, any proposals for major changes in commercial fertilizer management must be assimilated with economic realities, production concerns and institutional limitations. Conclusions and recommendations in this document do not adequately reflect economics, production or institutional concerns. Therefore, any inferences drawn from these statements should contain appropriate caveats.

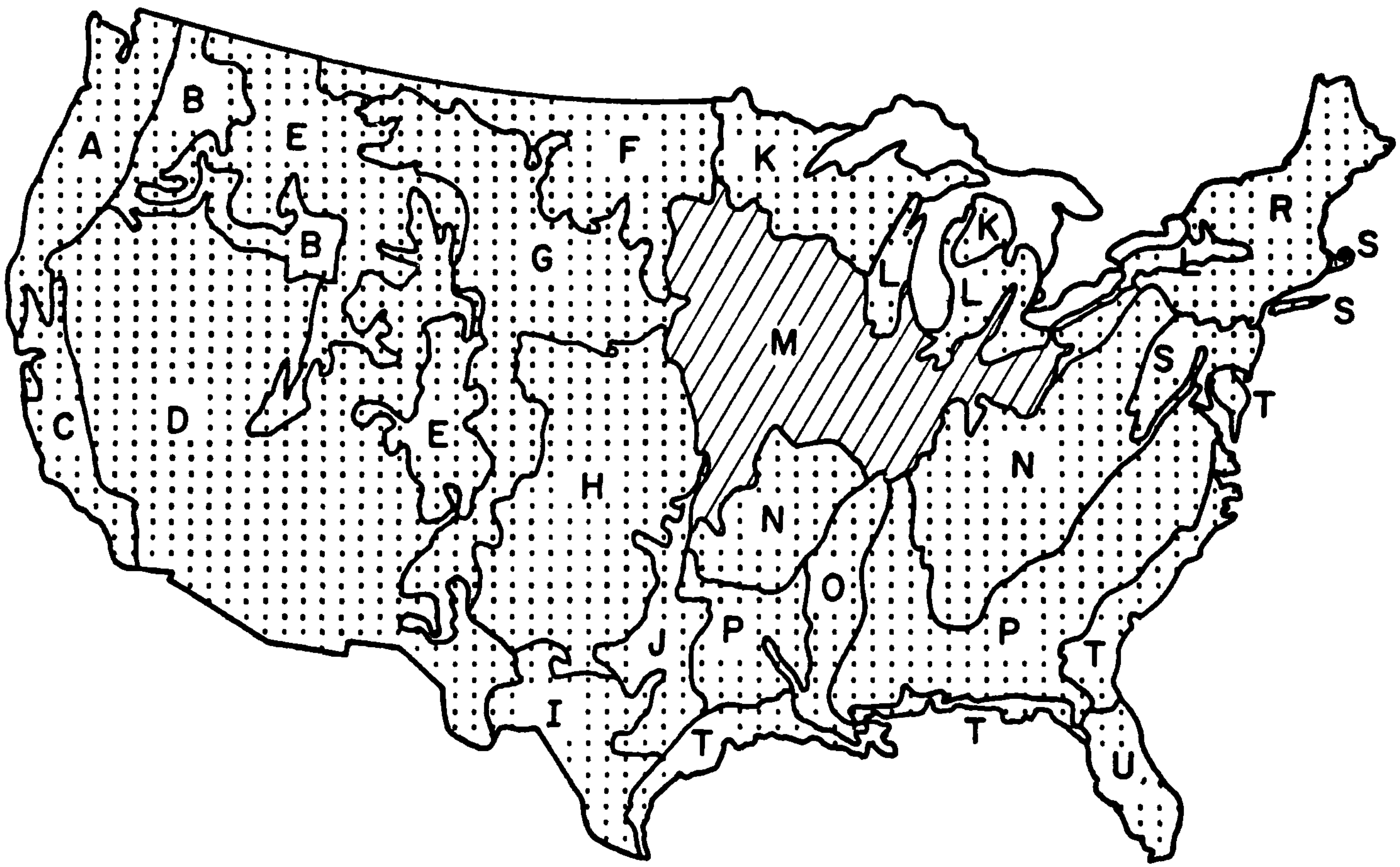

Figure 13. Land Resource Regions with literature references (///) and projections (:::) indicating terraces as a P control BMP.

TABLE 10. TERRACE VERSUS CONTOURING AS PHOSPHORUS CONTROLS

Crop	Comments	Practice	Annual Nutrient[†] Loss (% Reduction vs. Other Practice) Total	Surface	Subsurface	Reference
			kg/ha			
Corn	448 kg N/ha/yr & 82 kg P/ha/yr	Level Terrace, Conventional Till	.37 P_T (67)	.04 Sol. P (74)	.26 Sol. P	12
	450 kg N/ha/yr & 84 kg P/ha/yr	Contour, Conventional Till	1.14 P_T	.15 Sol. P	.05 Sol. P (82)	
Corn	168 kg N/ha/yr 39 kg P/ha/yr	Terrace[§], pipe outlets & mulch till	-	.12 Sol. P .33 P_T .20 Sed. P (2)	-	2
		Contour, Conventional Till	-	.08 Sol. P (38) .28 P_T (13) .21 Sed. P	-	

[†] P_T = total phosphorus, Sol. P = soluble phosphorus, Sed. P - sediment associated phosphorus.

[§] Terrace installation partly responsible for heavy nutrient losses in first year of 4-year study.

TABLE 11. CONSERVATION PRACTICES AS PHOSPHORUS CONTROLS

Crop	Comments	Practice	Annual Nutrient[†] Surface Loss (% Reduction vs. Other Practices)	Reference
Corn	56 kg N/ha/yr & 29 kg P/ha/yr*	Rotation	.17 kg Sol. P/ha (48) 3.14 kg P_T/ha (43)	15
	112 kg N/ha/yr & 29 kg P/ha/yr*	Continuous	.33 kg Sol. P/ha 5.55 kg P_T/ha	
Corn/Beans/ Wheat	3 year rotation	Return Residue & Cover Crop	.13 kg Sol. P/ha (48)	42
		No Residue or Cover Crop	.25 kg Sol. P/ha	
Pasture	No Fertilizer	Rotation Grazing	1.27 kg P_T/ha (72) .13 kg Sol. P/ha (variable)	60
		Continuous Grazing	4.60 kg P_T/ha .14 kg Sol. P/ha	

† P_T = total phosphorus, Sol. P = soluble phosphorus.

* Recommended rate, fall plow, spring broadcast and disk.

SECTION 3

RESEARCH NEEDS

Much is now known about the types of nutrients washed from agricultural land, but in regions other than the Corn Belt little is reported concerning the effectiveness of control mechanisms for nonpoint source fertilizer pollution. The greatest overall need is a series of watershed studies with a holistic approach: surface and subsurface water quality, food supply concerns, economics, agronomic concerns and institutional matters. If the goal is to achieve water quality improvement without putting a large burden upon agriculture, the cost-effectiveness of BMPs for water quality control must be known. The International Joint Commission has recommended that further research be done to determine the costs of BMPs for incremental water quality benefits (90).

To answer the more specific questions regarding the effectiveness of BMPs it is necessary for other regions to perform systematic studies similar to the Corn Belt efforts. Long-term comparisons are needed to assess the water quality benefits of implementing various BMPs and BMP systems. Both the International Joint Commission (90) and Cornell University (28) suggest further research to determine if soil and water conservation practices can simultaneously serve both soil conservation and water quality goals. Cornell also recommends field and modeling studies to explore the transport of pollutants from field to stream or aquifer and their subsequent fate (28). Better understanding of the effects of various timing and method schemes for fertilization can be obtained from systematic research designed to eliminate as many experimental variables as possible. The use of slow-release nitrogen fertilizers should accompany sediment control practices to determine if both surface and ground waters can be protected while allowing farmers reasonable latitude in fertilization rates.

The end result of systematic research directed toward answering an array of questions regarding BMPs is a predictive capability for assessing the total costs and benefits associated with alternative management schemes. Appropriate planning decisions can become more commonplace as investigations provide data to more completely piece in the BMP puzzle.

SECTION 4

CURRENT RESEARCH

Presently there are several regional projects directed toward evaluating agricultural nonpoint source control mechanisms. These projects are largely funded through the U.S.D.A. and U.S.E.P.A., but planning and operational functions are performed at all levels of government. It is the intention that these projects exhibit the holistic approach toward water quality management.

The Lake Herman Model Implementation Project in South Dakota is focusing on abatement of a water quality problem created by sedimentation and associated nutrient discharge. Several federal, state and local agencies are cooperating in an effort to monitor water quality changes associated with the implementation of sediment control structures. Provided that economics, land use and water quality data are good, this project should provide conclusions regarding the cost-effectiveness of sediment controls for nutrient control.

A number of Rural Clean Water Programs across the United States are dealing with nutrients as pollutants. It is estimated that 31% of the P loading to the Lower Manitowoc watershed in Wisconsin is associated with cropland erosion. Fertilizer management and several soil conservation practices are some of the BMPs for this project. Since 52% of the P loading is from livestock wastes, it may only be possible to see the water quality effects of commercial fertilizer management within the context of an overall BMP system approach.

Prairie Rose Lake in Iowa has had algal blooms and has lost some of its desirable fish-species due to sedimentation and associated nutrient transport. Best Management Practices for this project include soil and water conservation practices, animal waste management and fertilizer management. Due to the animal waste input and the lack of intensive water quality monitoring, the water quality effects of commercial fertilizer management will not be isolated.

Groundwater has been contaminated with increasing NO_3-N levels in the Long Pine Creek Watershed, Nebraska. Irrigation return flow, croplands, rangelands and livestock confinements are some of the primary sources of pollution. Interactions between surface and ground waters will be observed for this watershed as fertilizer management and erosion control BMPs are implemented. To further evaluate BMP effectiveness, selected fields will be monitored throughout the project.

Surface waters of Lake Poinsett and Oakwood Lakes in South Dakota are hypereutrophic, while the underlying Big Sioux aquifer has excessively high NO_3-N levels in many areas. Cropland and animal waste management practices are being implemented to control N, P, and sediment loadings to the lakes and groundwater. Terraces are being located in areas where it is believed they will not contribute to the groundwater nitrate problem. It will be interesting to see if any controls other than very strict fertilizer management can be used to solve both surface and ground water nutrient problems simultaneously.

Intensive cropping in the Saginaw Bay A.C.P. Special Project watershed is held responsible for the high nutrient loadings to Lake Huron. Nearly ninety percent of the project area is cropland. Much can be learned about the relative advantages of different tillage practices from this project as side-by-side comparisons are set up in different areas.

The Chowan River project in North Carolina offers data regarding small watershed responses to fertilizer management and soil conservation practices. Specific BMPs will not be evaluated, but the combined water quality effects of soil testing, no-till planting, field borders, grassed waterways and fertilizer management may be seen.

Results from Black Creek indicate that it is possible to conserve soil within the limits adequate for maintaining the soil resource, but still not meet water quality goals (47). Data also show that nitrate loss is not controlled with sediment controls. In general, results from Black Creek support the conclusion that the most successful approach for minimizing nutrient losses in surface runoff from cropland combines soil erosion control with fertilizer incorporation.

Discussion of the current major research efforts clearly demonstrates that the holistic approach is now being utilized. As the joint USDA-EPA efforts in the RCWP progress, data will be available for analyses of water quality changes versus land use changes, institutional problems and successes, implementation costs, production changes, and general project acceptance. If funding persists, the long-term costs and benefits of BMPs can be assessed. An evaluation of the cost-effectiveness of erosion control systems for improving water quality should result from these large research efforts. Unfortunately, it does not appear that the alternative of fertilizer management will be evaluated on a cost basis because it does not seem to be the major focus in any of the projects. When the data from all major projects are finally analyzed there should be enough information on specific practices to allow a greater understanding of how the whole agricultural management system can be altered to effect changes in water quality.

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