Section II:
Best Management Practices (BMP'S)

Introduction

In 1986 the Arizona Environmental Quality Act (EQA) was enacted to protect both surface and groundwater quality from point and non-point sources. In this legislation the use of nitrogen fertilizers was recognized as an essential component of agricultural production as well as a potential source of nitrate contamination in groundwater which required some kind of regulation. The Arizona Department of Environmental Quality has proposed rules which regulate nitrogen fertilizer use through six general, goal-oriented Best Management Practices (BMP). These BMPs address the importance of selecting the proper amount, timing and placement of nitrogen, the proper amount and timing of irrigation water and appropriate tillage practices which maximize water and nitrogen uptake by crop plants. It is assumed that compliance with these BMP's would minimize the emission of agriculturally derived nitrates into groundwater supplies without being unduly restrictive for profitable farm operation.

Guidance Practices (GP) are the actual methods which an operator uses to achieve the goals stated under each of the BMPs. These GPs, including such techniques as laser leveling and use of improved irrigation methods, represent the state-of-the-art technologies available to growers. The actual GPs chosen by different farm operators will vary since they depend on such factors as soil type, irrigation method, crops to be grown, available farm equipment, irrigation water quality, land ownership and related economic criteria. The specific BMPs and their relative GPs regarding the rate, timing and placement of nitrogen fertilizers are discussed below. The BMPs and GPs which address irrigation and tillage practices are also listed, but will not be discussed in detail. Contact your local Cooperative Extension agent, USDA-Soil Conservation Service field office, agricultural consultant or irrigation engineer for assistance in implementing these GPs.

BMP 1. Application of nitrogen fertilizer shall be limited to that amount necessary to meet projected crop plant needs.

Common sense dictates and scientific research has found that the amount of nitrogen leached from agricultural fields (i.e. mass emissions of NO_3) is directly related to the amount of nitrogen fertilizer that has been applied (RANN Report. 1979. Nitrate in Effluents from Irrigated Lands. University of California, Riverside). It has also been shown that *potentially leachable soil nitrates increase very rapidly when the amount of nitrogen applied exceeds the amount required to attain maximum or near maximum yield.* This concept is illustrated in Figure

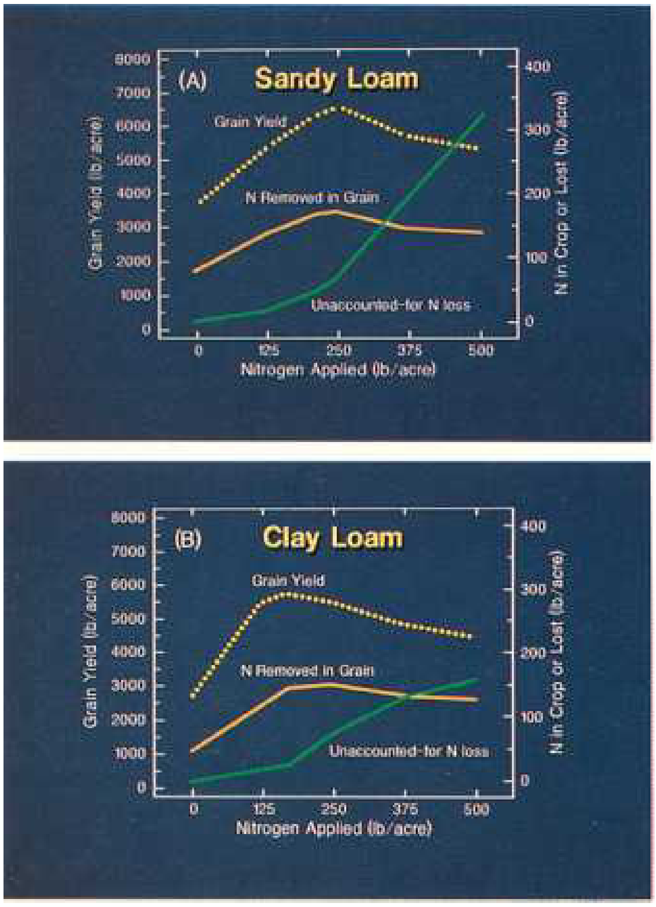

Figure 8.
Grain yields and a partial nitrogen budget for irrigated durum wheat crops receiving varying rates of nitrogen fertilizer when grown on a Casa Grande sandy loam (A) and a Trix clay loam (B).

8 for durum wheat grown on two contrasting soil types. Note the rapid increase in the amount of unaccounted-for nitrogen when the nitrogen fertilizer rate exceeds 250 pounds per acre on the sandy loam soil and 175 pounds per acre on the clay loam soil.

The unaccounted-for nitrogen above the point of maximum grain yield is much higher in the sandy loam soil than in the clay loam. This is most likely the result of much greater leaching losses of nitrate from the more permeable sandy loam soil. Losses due to denitrification (discussed below) would be expected to be higher on the clay loam site. Other nitrogen losses such as ammonia volatilization (see below) were negligible in these two experiments.

Although this BMP is simple to state, it is often difficult to precisely achieve in practice. The total amount of nitrogen contained in the biomass of a crop is largely controlled by the actual crop yield that is attained. High yields require more nitrogen than low yields. Many factors affect crop yield such as genetic potential of the cultivar grown, climate, pest infestations, nutrient deficiencies, irrigation management and other agronomic considerations. Because some of these factors cannot be fully controlled by the farm operator, it is not always possible to accurately predict what crop yield will be attained. The approximate nitrogen content and fertilizer requirements of 30 important Arizona crops are listed in Table 1.

Knowing exactly how much nitrogen fertilizer to apply to attain optimum crop yield is further complicated because of the many possible sources, losses and transformations of plant available nitrogen in irrigated soils. This is shown pictorially in Figure 9. Common sources of nitrogen include plant residues, soil organic matter, animal manures, waste byproducts, nitrogen fixation by microbes, and precipitation, as well as synthetic nitrogen fertilizers. Loss of nitrogen from soils occurs via leaching, denitrification, removal of plant and animal products and ammonia volatilization. The immobilization of mineral nitrogen into the microbial biomass can temporarily cause low levels of plant-available nitrogen in the soil which may restrict crop growth and increase the need for supplemental nitrogen fertilizer.

Denitrification refers to the loss of nitrate or nitrite from soils as the gases nitrous oxide (N_2O) and/or nitrogen (N_2). This microbial process can significantly lower the amount of leachable nitrates in soil but conversely can lead to nitrate depletion and nitrogen deficiency in crops if it occurs prior to the time of high N uptake by the crop. Conditions favoring denitrification include soil moisture content approaching saturation or above, poor aeration, pH above 5.5, temperature between 55 and 140°F, adequate supplies of nitrate (or nitrite) and sufficient water soluble carbon. Clearly these conditions could easily be met in typical basin or furrow irrigated cropping systems used in Arizona. Table 2 lists the interpretive criteria for denitrification potential of soils under these conditions.

Direct losses of ammonia gas (NH_3) can occur when urea or ammonium containing fertilizers are applied to the surface of alkaline soils (i.e. pH > 7). The degree of loss depends on the actual compound used, soil moisture content, temperature, the time lag between application and incorporation and the method of incorporation. Stockpiling of animal manures or leaving manure unincorporated on the soil surface can also result in high losses of NH_3. Anhydrous ammonia, aqua ammonia and ammonium sulfate are also subject to volatilization losses when applied in alkaline irrigation waters. Growers can minimize or eliminate losses of nitrogen due to ammonia volatilization by selecting appropriate application and incorporation techniques as outlined in Table 3.

Table 1. Approximate nitrogen (N) content and fertilizer requirements of important Arizona crops.

Crop	Yield		Total Nitrogen Content of: Harvested Portion		Total Nitrogen Content of: Total Crop		Typical Fertilizer N Rates	
			lb./acre					
Agronomic Crops								
Alfalfa	8,000	16,000	200	400	200	400	0	
Barley	3,000	6,000	60	120	100	170	140	250
Corn, grain	6,000	10,000	115	160	150	275	150	275
Cotton lint, upland	800	1,500	0		110	200	100	250
seed	1,500	2,800	55	100	——		——	
Hay, non-legume	4,000	16,000	80	400	80	400	60	300
Sorghum, grain	4,000	6,000	80	115	120	180	125	200
Wheat, Bread	4,000	8,000	80	150	130	220	125	250
Wheat, Durum	4,000	8,000	110	215	160	290	150	300
Vegetables								
Asparagus	3,000	8,000	15	40			200	350
Broccoli	10,000		90		150	250	175	225
Cabbage	27,000	40,000	125	185	150	220	175	225
Cantaloupe	20,000		32		90		70	150
Carrots	37,000		70		170		75	150
Cauliflower	13,000	20,000	80	125	175	250	175	250
Lettuce	30,000		50		100	125	200	250
Onions	40,000		95		100	125	110	200
Peppers, chile	20,000		50		100	175	100	200
Potatoes	30,000		110		200	300	250	300
Sweet Corn	15,000		60		125		100	200
Watermelon	80,000		70		100	125	90	175
Fruits and Nuts								
Apples	32,000		25				35	120
Grapefruit	20,000		35				110	250
Grapes, table	20,000		20				30	100
Grapes, wine	4,000		5				0	50
Lemons	35,000		65				120	240
Oranges	18,000		35				85	190
Peaches	30,000		45				75	175
Pecans	2,500		60				100	200
Pistachios	1,000		25				100	150
Other Crops								
Bermuda grass	8,000		225		225		100	300

Table 2.
Interpretive criteria for denitrification potential of soils receiving high application rates of water and fertilizer nitrogen (after Lund and Wachtell, 1979. Denitrification Potential of Soils. In, Nitrate in Effluents from Irrigated Lands. University of California, Riverside.)

	Denitrification Potential Rating		
Criteria	Low	Medium	High
Surface soil texture	Sand, loamy sand, sandy loam	Loam, sandy clay loam, silt loam	Silt, clay loam, silty clay loam, sandy clay, silty clay, clay
Organic matter content	<1%	>1%	>1%
Drainage class	Excessively well drained to somewhat excessively well drained	Well drained to moderately well drained	Moderately well drained to very poorly drained
Permeability	Rapid to very rapid	Moderate	Moderately slow to very slow

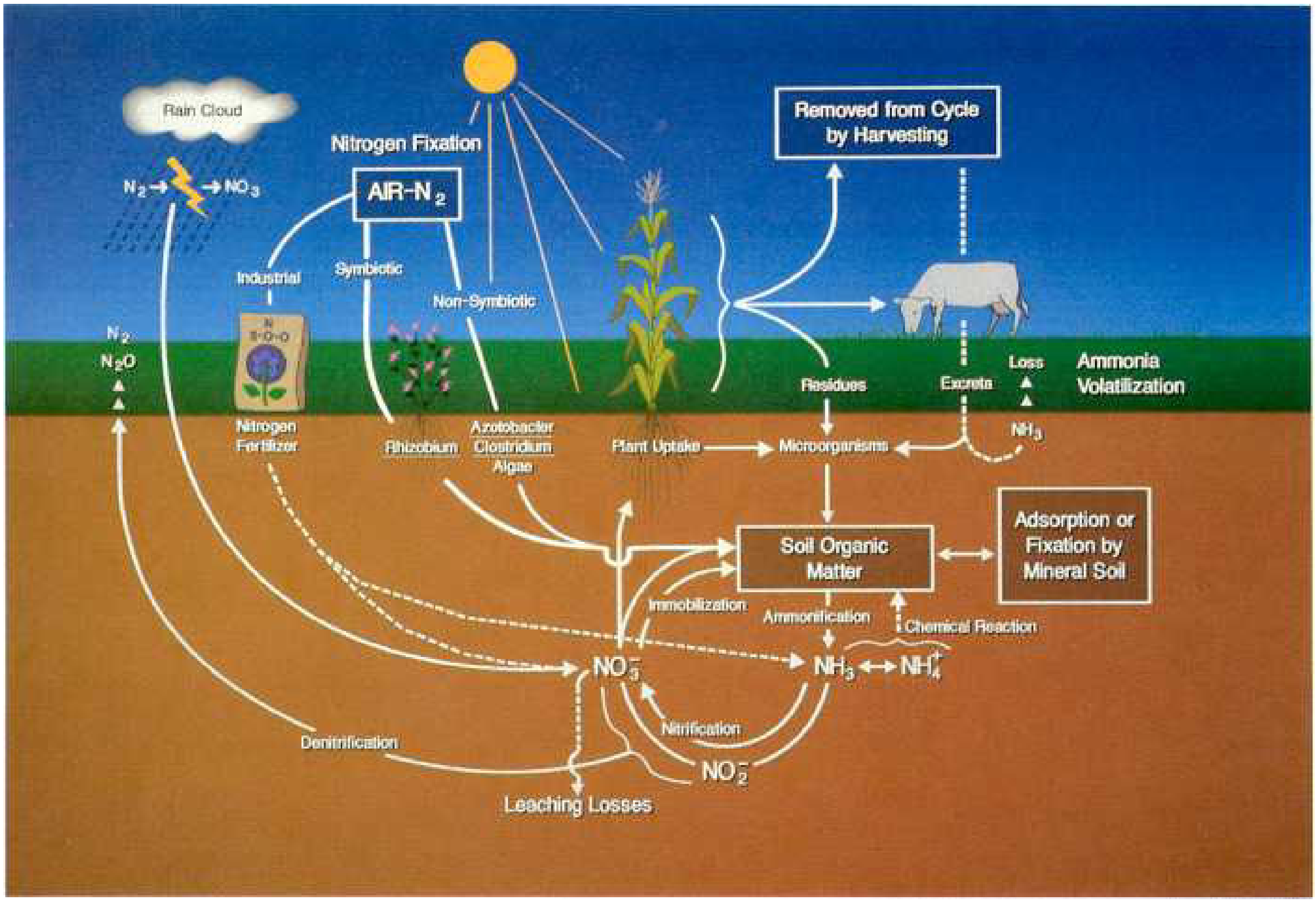

Figure 9. The nitrogen cycle in soils.

The eight Guidance Practices to help insure that nitrogen fertilizer applications correspond to that amount necessary to meet projected crop plant needs include techniques which:

1. accurately assess the potential sources of nitrogen in a specific cropping system (GP 1.1-1.4),
2. preserve the positional availability of applied nitrogen within the root zone of the crop (GP 1.5-1.7), and
3. monitor the nitrogen sufficiency status of crop plants throughout the growing season (GP 1.8).

GP 1.1 Sample and analyze soils for residual nitrate content.

Carryover of residual soil nitrates from the previous growing season can be a significant source of plant available nitrogen. Figure 10 illustrates the effect that initial soil nitrate levels can have on the lint yield of unfertilized Acala cotton.

Soil analysis for residual nitrate content is most appropriately used for annual crops with samples taken just prior to planting. Preplant or starter applications of nitrogen fertilizer can then be based on the nitrate soil test. In perennial crop production, soil testing is generally less reliable for measuring

Table 3.
Relative nitrogen losses by NH_3 volatilization from surface broadcast applications for different application methods and fertilizer materials. (after Rauschkolb et al., 1979. Nitrogen Management Relative to Crop Production Factors. In, Nitrate In Effluents from Irrigated Lands. University of California, Riverside).

Nitrogen source	Nitrogen content	Method of incorporation					Apply in irrigation		Band 4 inches below surface
		None Soil pH		With water Soil pH		Mechanical	Water pH		
	%	<7	>7	<7	>7		<7	>7	
Anhydrous ammonia	82		—				L[#]	H	VL
Aqua ammonia	20		—	—	—	—	L	H	VL
Ammonium sulfate	21	L	H	L	H	L	L	H	VL
Ammonium phosphate	11	L	H	L	M	L	L	M	VL
Ammonium nitrate	33.5	VL		VL	L	VL	VL	VL	VL
Urea-ammonium nitrate	32	VL	M	VL	VL	VL	VL	VL	VL
Urea	45	M	H	VL	VL		VL	VL	VL
Calcium Nitrate	15.5	VL	VL	VL	VL	VL	VL	VL	VL
Potassium Nitrate	13	VL	VL	VL	VL	VL	VL	VL	VL
Manure, dry	1.0	M	H	—		L	—		
slurry	0.2	M	H	VL	L	L	L	H	VL

[*] Dash line indicates that certain applications are not normal cultural practices.
[#] H = losses over 40%, M = losses between 20 to 40%; L = losses between 5 to 20%; and VL = losses less than 5%.

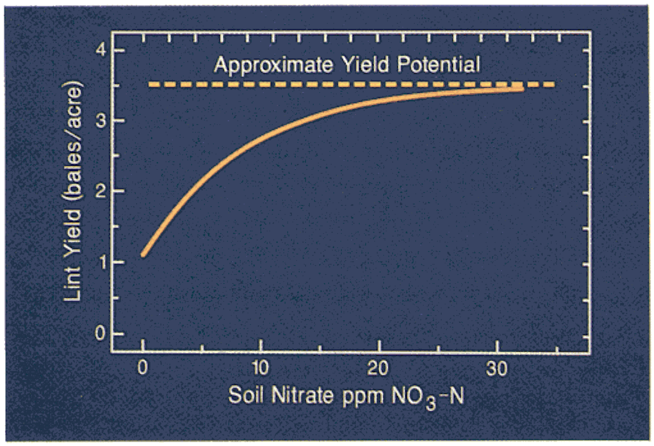

Figure 10.
Relationships between lint yields of unfertilized Acada cotton and NO_3-N content in the soil (dry weight basis) immediately following preplant irrigation (Gardner and Tucker, 1967. Nitrogen Effects on Cotton: II. Soil and Petiole Analysis. Soil Sci. Soc. Amer. Proc. 31:785-791).

the nutrient supplying power of a soil. Leaf tissue analysis and visual observation of plant appearance and vigor are usually recommended for monitoring the nitrogen status of perennial crops. Midseason soil sampling to characterize the nitrogen status of a crop is not recommended. Instead, midseason plant tissue tests, visual observation of crop performance and previous experience should be used as the basis for nitrogen management decisions. Interpretations of preplant nitrate soil test values for specific crops are given in Section III of this report.

A properly taken soil sample is the first prerequisite for determining the residual nitrate content of a particular field. In general a composite sample should consist of 15 to 20 soil cores taken at random from within an area of 40 acres or less. Each sampling area should represent similar past management and soil characteristics. Dissimilar areas should be sampled separately. The normal sampling depth for irrigated conditions is 6 to 9 inches or the plow layer.

The precise location in the field from which individual soil cores are taken is of little consequence in basin or border irrigated fields. However, sampling a furrow irrigated field is best done by taking cores from a position halfway between the top of the bed and the bottom of the furrow if the original orientation of the beds and furrows can be determined. Proper soil sampling techniques in drip irrigated fields are less well defined. Under these conditions samples should be taken from soil directly below the driplines or emitters since root activity is highest in this zone of frequently moistened soil. Samples should be immediately air dried and placed in a clean container prior to submission to a suitable soil testing laboratory.

GP 1.2 Test irrigation water for nitrogen content and for compatibility with ammonia containing nitrogen sources applied using fertigation.

Some irrigation water supplies contain appreciable amounts of nitrogen which should be considered when formulating a nitrogen management plan. Most ground and surface waters contain primarily nitrate nitrogen (NO_3-N) while effluent or recycled water can contain both nitrate and ammonium nitrogen (NH_4-N).

After analyzing water for ammonium and/or nitrate content, the quantity of nitrogen applied in the water is calculated as follows:

$$\text{N applied in lbs. per acre-ft. of water} = (NO_3\text{-N} + NH_4\text{-N in ppm}) \times 2.7 \qquad \text{Eq. 1}$$

For example, an irrigation water containing 10 ppm NO_3-N and no NH_4-N will supply 27 pounds of nitrogen for each acre foot of water applied to the crop.

Nitrogen losses from ammonia volatilization can exceed 50% when anhydrous or aqua ammonia are applied in alkaline irrigation waters high in bicarbonate content (HCO_3). To reduce this and other water quality problems, sulfuric acid may be added to the irrigation water to neutralize bicarbonate and/or counteract the alkalinity produced by ammonia additions. Once the bicarbonate content of the water has been determined and the rate of ammonia nitrogen to be applied has been chosen, the total amount of sulfuric acid required is obtained from Tables 4 and 5. Site specific sulfuric acid requirements for neutralizing bicarbonates can be obtained using the software package, WATERTST which is available through the University of Arizona Cooperative Extension.

The amount of acid used must not result in excess acidity (pH below 6.5) which can cause corrosion of concrete-lined ditches. After thorough mixing, the pH of the treated water can be checked using a simple swimming pool test kit or litmus paper.

CAUTION:
Sulfuric acid is extremely dangerous and corrosive. It should be used with utmost care by experienced personnel with proper equipment.

Table 4.
Quantities of 95% sulfuric acid required to neutralize 90% of the bicarbonates (HCO_3^-) in irrigation water. Additional acid will be required for waters containing carbonate (CO_3^{2-}) (after Doerge and Stroehlein, 1986. Sulfuric Acid for Soil and Water Treatment. University of Arizona, Cooperative Extension Bulletin 8622).

HCO_3^- Content*	Acid Required	
ppm	— *per acre foot of water* —	
	lbs.	gallons
50	103	7
100	206	13
200	412	27
400	824	55

**from water analysis*

Table 5.
Quantities of 95% sulfuric acid required to neutralize ammonia or aqua ammonia fertilizer in irrigation waters (after Doerge and Stroehlein, 1986. Sulfuric Acid for Soil and Water Treatment. University of Arizona, Cooperative Extension Bulletin 8622).

Rate of NH_3-N Applied	Acid Required	
lbs. N/acre-ft.*	lbs./acre-ft.	gal./acre-ft.
20	74	5
40	147	10
60	221	14
80	294	19
100	368	24

**calculated according to actual N use, lbs. NH_3/acre foot = lbs. N/acre foot x 1.22*

GP 1.3 Apply organic wastes to croplands.

Animal manures have been used for centuries to supply significant amounts of nitrogen and other nutrients needed for crop growth. In addition, sewage sludge is increasingly being disposed of on agricultural lands. Their use can increase the tilth, aeration, water and nutrient holding capacities, infiltration rate, organic matter content and microbial activity of soils. The successful use of organic wastes requires careful attention to the following six factors:

1. Nutrient content of the organic waste
2. Rate of mineralization
3. Salt content
4. Toxic elements
5. Method of application and timing of incorporation
6. Weed seeds

- **Nutrient Content of the Organic Waste**

Wastes can vary considerably in nitrogen content depending on the type and age of animal, feeding rate, type of ration and methods of storing and handling of the waste before and after application to the soil or the source of a municipal waste. Average values for moisture and nutrient contents of some common manure and waste materials are listed in Table 6. To determine the amount of nitrogen applied a farm operator must know both the amount of waste applied and its nitrogen content. This requires a laboratory analysis for the total nitrogen content (organic + NH_4-N plus NO_3-N) and the use of a well calibrated application system.

- **Rate of Mineralization**

Organic wastes must be decayed by soil microbes before the nitrogen (and most other nutrients) they contain will become available to plants. This release of available nitrogen from previously unavailable forms is called "mineralization."

The rates of nitrogen mineralization for various waste materials can differ greatly and are given as decay series. A decay series estimates the percentage of mineralization that will occur in the years following a manure application. For example, a decay series of 0.35, 0.10, 0.06, 0.05 means that following a liquid sludge application, 35% of the nitrogen is mineralized the first year, 10% of the residual (that

Table 6.
Average moisture and nutrient contents in several animal manures and waste materials. (after California Fertilizer Association, 1985. Western Fertilizer Handbook, 7th Edition and Fuller. 1984. Use of Feedlot Manure and Municipal Sewage Sludge on Arizona Irrigated Land. Tech. Bull. No. 255. University of Arizona).

Source	Moisture Content	Nutrient Content*		
		Nitrogen	Phosphorus	Potassium
	%	*lbs. per ton*		
Beef feedlot	68	12.4	10.3	11.7
Dairy	79	11.2	4.6	12.0
Liquid dairy	91	4.8	0.1	4.6
Swine	75	10.0	6.4	9.2
Liquid swine	97	0.2	0.1	0.2
Horse	70	13.8	4.6	14.4
Sheep	65	28.0	9.6	24.0
Poultry (no litter)	54	31.2	18.4	8.4
Poultry (liquid)	92	3.2	0.8	5.8
Sewage sludge	98	3.2	1.0	0.2

**expressed as N, P_2O_5 and K_2O respectively. Actual moisture and nutrient content may vary considerably above or below these values.*

Table 7.
Input of six manure or waste materials needed to maintain an annual mineralization rate of 200 lbs. nitrogen per acre (after California Fertilizer Association, 1985. Western Fertilizer Handbook, 7th Edition).

Material and Decay Series	Lbs. N/Ton	Annual Application Rate Year				
		1	2	3	4	5
		tons/acre				
Poultry manure, 1.6% N 0.90, 0.10, 0.075, 0.05	32	6.9	6.2	5.7	5.4	5.5
Fresh bovine waste, 3.5% N 0.75, 0.15, 0.10, 0.075, 0.05	70	~~3.8~~	3.0	2.7	2.5	2.4
Dry corral manure, 2.5% N 0.40, 0.25, 0.06, 0.03	50	10.0	3.8	6.2	4.8	5.8
Dry corral manure, 1.5% N 0.35, 0.15, 0.10, 0.075	30	19.0	10.9	9.0	8.0	10.8
Dry corral manure, 1.0% N 0.20, 0.10, 0.075, 0.05	20	50.0	25.0	18.8	18.5	27.5
Liquid sludge, 2.5% N 0.35, 0.10, 0.06, 0.05	50	11.4	8.2	7.1	6.3	7.3

which was not previously mineralized) is released in the second year, 6% the third year and so on. If the nitrogen concentration of a waste material and its decay series are known, the amount of waste needed each year to supply a constant amount of nitrogen can be calculated. Table 7 lists the approximate application rates of six waste materials needed to maintain an annual mineralization rate of 200 lbs. nitrogen per acre.

- **Salt Content**

Manures obtained from concentrated animal feeding operations, such as cattle feedlots are usually high in salt content. Most dairy and feedlot manures contain 5 to 10% salt (50,000 to 100,000 ppm). If large (20 tons/acre) and/or frequent applications of manure are made to farmland the risk of salt injury to crop plants increases. This is especially true for salt sensitive plants such as lettuce, tree fruits and nuts.

Recommended management practices for applying animal manures to cropland include:

- Use well-aged manures rather than fresh manures taken directly from feedlots.
- Apply up to 5 tons/acre of dry matter per year or 10 tons/acre every other year.
- Use supplemental nitrogen fertilizers only as required based on tissue tests, plant performance and previous experience.
- Plow or roto-till manure into the soil, irrigate and wait at least 30 days before planting.
- Do not apply manure where water penetration is poor.
- Monitor soil salinity and sodium levels using periodic soil analyses.

- **Toxic Elements**

Sewage sludge and other industrial waste products are being applied to croplands in increasing quantities. This could be a concern if they contain high levels of boron, cadmium, lead, zinc or other heavy metals which might be toxic to plants or animals. Potential users must carefully weigh the economic and agronomic advantages of disposing of sewage sludge on agricultural lands against the potential hazards presented to public health and the environment. The use of sewage sludge may also restrict future crop or land use options. Those interested in applying municipal wastes to croplands are encouraged to obtain *Guidelines for the Agricutural Land Application of Sewage Sludge* from the Arizona Department of Environmental Quality, or other relevant publications recommended by that office.

Recommended guidelines for applying municipal or industrial waste products include:

- Ensure that the soil pH remains above 6.5 to minimize leachability of trace metals and their uptake by plants.
- Observe the cumulative loading limits for soil applications (Table 8).
- Utilize crops which exclude heavy metals from the whole plant, or harvested plant parts such as grain, seed or fruit crops.
- Plant fiber or other non-edible crops in treated fields.
- Employ sound soil management practices which reduce runoff and erosion.
- Monitor toxic element applications and accumulation in soil and plant tissue using periodic laboratory analysis for elements of concern.

Table 8.
Maximum allowable cumulative metal applications of five heavy metals for soils of varying cation exchange capacity (CEC) (Arizona Department of Environmental Quality, 1989. Guidelines for the Agricultural Land Application of Sewage Sludge).

Metal	Maximum Allowable Cumulative Metals Application		
	CEC* <5 sand & sandy loam	CEC 5-15 loam	CEC >15 clay & clay loom
		lbs. per acre	
Lead	500	1000	2000
Zinc	250	500	1000
Copper	125	250	500
Nickel	50	100	200
Cadmium	5	10	20

**Cation Exchange Capacity, or CEC is defined as the amount of poitively charged molecules (cations) that a soil can adsorb at a particular pH. Many heavy metals as well as some plant nutrients (e.g. calcium, magnesium and potassium) are present in the soil as cations.*

- **Method of Application and Timing of Incorporation**

Animal manures and wastes should be injected or uniformly broadcast on cropland at recommended rates and then incorporated into the soil as soon as possible. Plowing or roto-tilling of the soil following surface applications of manure is recommended. Subsurface injection of fluid materials generally does not require additional tillage operations.

Immediate mixing with the soil will greatly reduce odor, nitrogen losses due to ammonia volatilization and the potential for ground and surface water contamination resulting from runoff. The effect of an increasing time lag between surface application and incorporation of manures is shown in Table 9.

Table 9.
The effect of time lag between surface application and incorporation of poultry and other manures on the percent of manure nitrogen which is available to crop plants (after Pennsylvania Department of Environmental Resources. 1986. Field Application of Manure.)

Time of Incorporation	Percent of Manure Nitrogen Available	
	Poultry	Other
Immediate	75	50
After 2 days	45	35
After 4 days	30	30
After 7+ days	15	20

- **Weed Seeds**

Manures can contain seeds from weeds which may prove difficult to control. The use of well-aged manures in preference to freshly excreted materials will help reduce the likelihood of weed infestations from manure applications. This is because heat generated in manure stockpiles will decrease the viability of weed seeds that may be present. Careful attention to the origin and quality of animal feedstuffs may also help reduce the severity of manure transmitted weed problems.

GP 1.4 Use application equipment which has been properly calibrated.

Fertilizer application equipment should be maintained and calibrated to distribute known amounts of material uniformly. Charts and calibration guides supplied from equipment manufacturers are excellent starting points. However, actual measurement of the amount of fertilizer applied to a known area is required for true calibration.

The procedure used for calibrating fertilizer application equipment depends on whether the material is applied directly to the soil or if it will be introduced into the irrigation water (fertigation). When fertilizer is to be soil-applied it is necessary to measure the amount of fertilizer which is applied to a known field area. This can be accomplished in two ways. The first method involves the catching and weighing of the fertilizer which is delivered when the application equipment passes over a known area (i.e. a swath of known length and width). The rate of nutrient application to a test area can be calculated from the following equation:

$$\text{Nutrient rate applied in lbs./acre} = \frac{\text{Lbs. fertilizer applied} \times \text{Nutrient analysis of fertilizer (\%)}}{(\text{Length of swath in ft.} \times \text{Width of swath in ft.})/435.6} \qquad \text{Eq. 2}$$

Example:
If a drop spreader applies 2.5 lbs. of urea (46% nitrogen) to a test swath that is 100 ft. long and 10 feet wide the nitrogen application rate is:

$$\text{N Rate} \quad \frac{2.5 \times 46}{(100 \times 10)/435.6} = 50 \text{ lbs. N/acre}$$

The nutrient contents of commonly used dry and fluid nitrogen fertilizer sources are listed in Tables 10 and 11, respectively.

If it is inconvenient to catch and weigh dry fertilizer materials, a second calibration method for direct soil applications can be used. This method involves placing a known amount of fertilizer in the application equipment, spreading the material over a known field area and then remeasuring the amount of fertilizer that remains. The rate of nutrient application can be calculated as follows:

$$\text{Nutrient Rate Applied in lbs./acre} = \qquad \text{Eq. 3}$$

$$\frac{(\text{Initial fertilizer weight in lbs.} - \text{Remaining fertilizer weight in lbs.})}{\text{Acres covered} \times 100} \times \text{Nutrient analysis of fertilizer (\%)}$$

Table 10.
Composition and nutrient content of dry nitrogen fertilizer materials commonly used in Arizona.

Dry Material	Analysis*	Nitrogen Composition NH_3/NH_4	NO_3	Urea	Nutrient Content N	P_2O_5
		%			lbs./ton	
Urea	46-0-0	0	0	46	920	0
Ammonium sulfate	21-0-0	21	0	0	420	0
Ammonium nitrate	33.5-0-0	16.8	16.7	0	670	0
Calcium nitrate	15.5-0-0	0	15.5	0	310	0
Ammonium phosphate sulfate	16-20-0	16	0	0	320	400
Monoammonium phosphate	11-53-0	11	0	0	220	1060
Diammonium phosphate	18-46-0	18	0	0	360	920

*percent N, P_2O_5 and K_2O respectively.

Table 11.
Composition and nutrient content of fluid fertilizer materials commonly used in Arizona.

Fluid Material	Analysis#	Nitrogen Composition NH_3/NH_4	NO_3	Urea	Nutrient Content N	P_2O_5	Density
		%			lbs./gal		
Urea ammonium nitrate	32-0-0	7.8	7.8	16.4	3.54	0	11.06
Anhydrous ammonia	82-0-0	82	0	0	4.21	0	5.13
Ammonium nitrate	20-0-0	10	10	0	2.10	0	10.50
Ammonium polyphosphate	10-34-0	10	0	0	1.10	3.74	11.00
Calcium ammonium nitrate*	17-0-0	6	11	0	1.70	0	10.00
Ammonium polysulfide	20-0-0-40S	20	0	0	1.94	0	9.70
Aqua ammonia	20-0-0	20	0	0	1.52	0	7.60
Ammonium thiosulfate	12-0-0-26S	12	0	0	1.32	0	11.00

#percent N, P_2O_5 and K_2O respectively.
**approximate values*

Example: If a drop spreader were loaded with 500 pounds of ammonium sulfate (21% N) and had 107 pounds remaining after treating exactly 1.1 acres, the nitrogen application rate is:

$$\text{N Rate} = \frac{(500 - 107) \times 21}{1.1 \times 100} = 75 \text{ lbs. N/acre}$$

When fluid fertilizers are applied to cropland using fertigation, the calibration procedure will depend on the irrigation system that is used. The metering of fluid fertilizers into unpressurized irrigation systems, such as open ditches is often accomplished by placing the discharge hose from a fertilizer supply tank into the irrigation water and controlling the flow with an adjustable hose clamp.

The proper fertilizer flow rate from the supply tank can be calculated as follows:

Eq. 4

$$\begin{array}{c} \text{Flow rate} \\ \text{(ozs./min.)} \end{array} \quad \frac{\text{Desired nutrient rate in lbs./acre}}{\text{Nutrient content of fertilizer in lbs./gal.}} \times \frac{\text{No. acres x 2.133}}{\text{Injection period in hours}}$$

OR

Eq. 5

$$\begin{array}{c} \text{Flow rate} \\ \text{(mls./min.)} \end{array} \quad \frac{\text{Desired nutrient rate in lbs./acre}}{\text{Nutrient content of fertilizer in lbs./gal.}} \times \frac{\text{No. acres x 60.52}}{\text{Injection period in hours}}$$

Example: What flow rate of urea ammonium-nitrate (UAN-32) should be used to fertigate 10 acres at the rate of 25 lbs. N/acre with an injection time of 5 hours?

$$\begin{array}{c} \text{Flow rate} \\ \text{(ozs./min.)} \end{array} \quad \frac{25}{3.54} \times \frac{10 \times 2.133}{5} = 30.1 \ \frac{\text{ozs.}}{\text{min.}}$$

For drip, trickle or other nonmoving pressurized systems little or no calibration is required. Once the rate of nutrient application per acre is determined, the required amount of fluid fertilizer material can simply be injected at any time the system is fully charged and operating normally. Injection should be completed prior to the end of the irrigation set to permit complete flushing of all lines and emitters. The amount of fertilizer material needed can be calculated as follows:

Eq.

$$\begin{array}{c} \text{Total fertilizer} \\ \text{required in gal.} \end{array} = \frac{\text{Desired nutrient rate in lbs./acre}}{\text{Nutrient content of fertilizer in lbs./gal.}} \times \text{No. acres}$$

Example: How many gallons of urea ammonium-nitrate (UAN-32) would be needed to supply 40 lbs N/acre for 25 acres?

$$\text{Total fertilizer required} = \frac{40}{3.54} \times 25 = 282.5 \text{ gal.}$$

If nutrients are to be injected into moving sprinkler systems Equation 6 can again be used to calculate the total amount of fertilizer material needed. However, with these systems fertilizers must be continuously injected from the start of fertigation until the system has covered the entire field. There is little danger of foliar burning from sprinkler applied nutrients due to the high rates of dilution which normally occur. For example, the injection of 10 lbs. N, as ammonium nitrate, into one acre inch of water would increase the salinity of the water by about 130 ppm or 0.2 dS/m.

GP 1.5 Add the seasonal nitrogen fertilizer requirement in multiple applications.

Ideally nitrogen from all sources should be provided to the crop at a rate which just equals its nitrogen uptake requirements. In contrast, large applications of nitrogen fertilizers which greatly exceed the immediate requirements of the crop will remain unutilized in the soil for a period of time. During this interval the unused nitrogen will be subject to leaching, denitrification and other mechanisms of nitrogen loss. This is depicted in Figure 11. The red shaded areas indicate periods where nitrogen supply exceeds the nitrogen demand of the crop. The potential for nitrogen loss during the growing season is obviously much reduced where split application techniques are used.

An example of the real benefits of applying nitrogen fertilizer in several small split applications versus a large single application is shown in Figure 12. In these experiments 150 lbs. of nitrogen was applied to durum wheat crops grown on a clay loam soil either as a single preplant application or as four split applications between planting and the "boot" growth stage. Greater rates of nitrogen were applied in adjacent plots to determine the maximum grain yield potential when the supply of nitrogen was not limiting. The grain yield attained with these split applications was very nearly equal to the maximum yield potential at this site. In contrast, the grain yield obtained following a single application of 150 lbs. N/acre represented a 27% reduction below the yield potential. Even greater benefits of using split N applications would be expected on sites with sandier, more permeable soils.

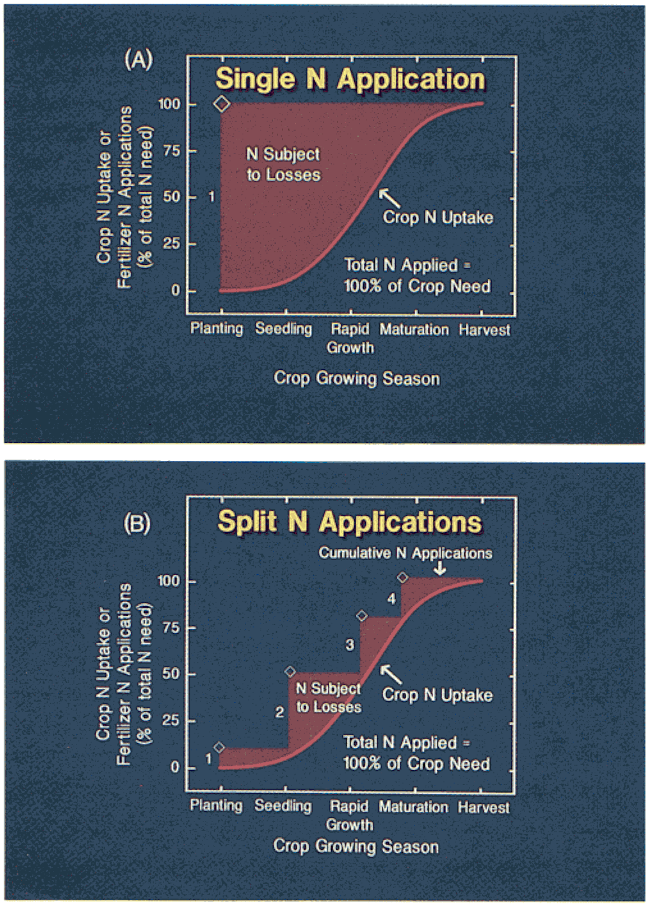

Figure 11.
General estimations of potential soil nitrogen losses occurring when nitrogen fertilizer is applied in a single (A) or in split applications (B).

Clearly the convenience of making fewer fertilizer applications during the crop growing season must be balanced by the possible yield losses and unavoidable nitrate leaching losses which occur when nitrogen applications greatly precede the time of utilization by the crop. However, there is a limit to the number of applications per crop that will be required for efficient nitrogen use based on the permeability (i.e. leachability) of the soil and the method of irrigation used. Table 12 lists the minimum number of nitrogen applications required on various soil types. These estimates assume that nitrogen is supplied from soluble fertilizer materials and at rates which are not excessive.

Table 12.
The minimum number of nitrogen applications per season recommended for varying soil types. Splitting the total nitrogen requirement into more than 5 to 10 events per season may not be possible unless a high frequency watering system, such as drip or sprinkler irrigation is used.

Soil Texture*	Recommended Number of N Applications per Crop
clay, sandy clay, silty clay, clay loam silty clay loam	1 - 2
silt, silt loam sandy clay loam	2 - 4
sandy loam, loamy sand	3 - 5
sand	8 - 15

*can be obtained from soil survey reports published by the Soil Conservation Service

Dividing the total amount of nitrogen to be used during a growing season into several applications will only provide for efficient nitrogen use if the total amount applied is not excessive. *Multiple applications of nitrogen which greatly exceed the requirements of the crop will still be highly inefficient.* This is demonstrated in Figure 8 where all nitrogen fertilizer amounts applied to durum wheat (up to 500 lbs./acre) were split into four applications during the growing season.

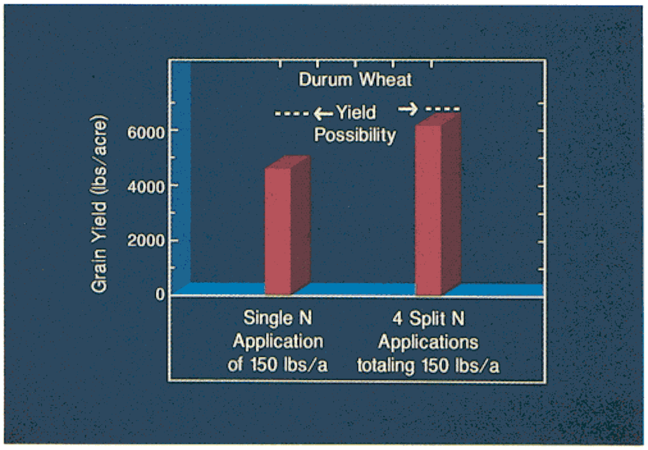

Figure 12.
Grain yields of durum wheat resulting from single and split applications of 150 lbs. nitrogen fertilizer per acre from experiments conducted on a Pima clay loam soil.

GP 1.6 Apply nitrification inhibitors in combination with ammoniacal (NH_4^+) fertilizer formulations.

Nitrification (Figure 9) is the biological conversion of ammonium nitrogen into nitrate as outlined below:

$$\underset{\text{ammonium}}{NH_4^+} \quad \underset{\text{oxygen}}{2O_2} \xrightarrow[\text{microbes}]{} \underset{\text{nitrate}}{NO_3^-} + \underset{\text{hydrogen}}{2H^+} + \underset{\text{water}}{H_2O} \qquad \text{Eq. 7}$$

This conversion takes place very rapidly in moist, well aerated soils of pH 6 to 8 with temperatures between 50 and 100°F.

Ammonium nitrogen is relatively immobile in the soil and is not subject to leaching losses. Thus a slowing of the nitrification process can conserve applied nitrogen fertilizer within the root zone by reducing the potential for leaching and denitrification losses of nitrate.

Nitrification inhibitors are chemical compounds which are selectively toxic to the soil microorganisms which are responsible for conversion of ammonium to nitrate. The effectiveness of these compounds in improving nitrogen use efficiency under field conditions is quite variable. In general these materials are most effective when conditions for nitrate losses are high. These include their use on sandy, very permeable soils, with large or frequent irrigation events and with shallow rooted crops. Some of the most common nitrification inhibitors currently available are listed in Table 13.

Table 13.
Common nitrification inhibitor materials. Consult and carefully follow the recommendations of the manufacturer. Other products not mentioned may also be equally suitable.

Compound	Trade Name
	Thio-sul®
	Guardian®
	N-Serve®
	Dwell®
	N-Hib Calcium™

General guidelines for the use of nitrification inhibitors in combination with ammonium containing fertilizers are listed below.

1. Thoroughly mix into or coat dry ammonium-fertilizers with the inhibitor. Use a compatible formulation when mixing inhibitors with fluid nitrogen materials.
2. Apply treated ammonium fertilizers in a subsurface band, injection or sidedressing. Avoid broadcast or water run applications.
3. Carefully follow use guidelines and application rates recommended by the manufacturer.
4. Avoid mid- to late-season applications of inhibitor treated materials which would remain unavailable to the crop during the period of maximum nitrogen uptake.
5. Excessive nitrogen applications will offset the benefits of inhibitors. Carefully match the nitrogen fertilizer rate with plant needs.

Certain crops such as corn, sorghum and wheat may also benefit from the use of nitrification inhibitors due to enhanced ammonium uptake. However, maximum yield benefits may only be 10 to 15% and may require several applications of the inhibitor. To realize these benefits the treated ammonium fertilizer must be placed directly into the plant root zone to permit immediate availability of the NH_4^+ ion. Subsurface drip irrigation systems are well suited to this type of application if listed on the product label.

GP 1.7 Use slow-release nitrogen fertilizers.

Most commercial nitrogen fertilizers are compounds which are either highly water soluble or react very rapidly to produce plant available forms of nitrogen once they are added to the soil. This property of rapid availability is conducive to high nitrogen use efficiency when applications are properly timed to coincide with periods of maximum plant need. In some situations however, it may be desirable to have sources capable of releasing nitrogen over an extended period of one to six months.

"Slow-release" fertilizers are most useful for crops that have prolonged periods of modest nitrogen need, such as turfgrass, that would otherwise require repeated applications of conventional water-soluble products. These materials probably offer other advantages including less chance of over-

Table 14. Categories and descriptions of commonly-used slow-release nitrogen fertilizers.

Category	Name	N Content
		%
Low solubility substances requiring decomposition	Urea-formaldehyde (ureaform)	38
	Crotonylidene diurea (CDU)	28
	Isobutylidene diurea (IBDU)	32
	Ethylene diurea (Urea-Z)	33 - 38
	Triazines (cyanuric acid, ammeline, ammelide, melamine)	32 - 66
	Methylene urea	30 - 40
Soluble products treated to impede dissolution	Osmocote	14 - 18
	Sulfur coated urea (SCU)	36 - 38
	Coated ammonium sulfate	20 - 32
	Coated urea	24 - 30
Sparingly soluble minerals	Magnesium ammonium phosphate (MagAmp)	8

stimulation of vegetative growth, reduced potential for leaching losses of nitrate on highly permeable soils and decreased hazard of injury to germinating crops.

The major disadvantages of these products are their high unit cost and the unpredictability of their nitrogen release characteristics. Environmental factors such as soil temperature, moisture content and aeration, and the size and integrity of fertilizer particles all can affect nitrogen release rates. The decision to use slow-release and/or conventional nitrogen fertilizers will be highly site specific, depending on local conditions and management objectives. In most cases slow release nitrogen sources will be most practical for use with turf, floriculture, nursery stock and high-value row crops. A brief listing and description of the more common types of slow-release fertilizers is given in Table 14.

GP 1.8 Use appropriate plant tissue analysis procedures with annual and perennial crops to guide nitrogen fertilizer applications.

The use of various plant tissue analysis procedures can be helpful in monitoring the nitrogen status of numerous commercial crops. However, for plant analysis to be useful, careful attention must be paid to the stage of plant growth, the specific plant part which is sampled and the type of the plant, i.e. annual or perennial.

Plants absorb virtually all of their nitrogen supplies through their root systems, primarily in the form of nitrate (NO_3). The ammonium (NH_4) form is also readily used by most plants but is rapidly converted in the soil to nitrate through microbial nitrification. Plants usually retain excess nitrates for later use in specific storage organs such as leaf petioles in cotton, leaf midribs in lettuce and lower stem tissue in small grains. As plants mature these readily available stores of nitrate are then converted into amino acids and ultimately into proteins. These proteins are the building blocks used in forming all plant parts such as leaves, stems, flowers and fruiting structures.

- **Annual crops**

In annual plants the nitrate content in specific storage organs gives the clearest indication of the nitrogen status of these plants. Nitrate tissue testing methods measure the current, readily available supply of nitrogen in the plant. Therefore, periodic sampling and analysis of plant tissue during the growing season can track the nitrogen status from the seedling stage through harvest. This can be useful in both monitoring the inseason nitrogen fertilizer needs of the crop, or simply evaluating the adequacy of a particular nitrogen fertilizer program.

A generalized interpretation of plant nitrate concentrations is shown in Figure 13. Levels of nitrate in the indicator tissues such as petioles, midribs or stems are normally high (with adequate soil fertility) early in the season during vegetative growth. Nitrate levels then decline as the season progresses as plants expend their nitrate reserves to form fruiting structures which are typically high in nitrogen content. An exception to this rule is any crop which is harvested during the vegetative portion of its life cycle such as lettuce or other leafy vegetables. Thus it is essential to know the stage of growth and the vegetative/fruiting status of the crop in question when interpreting plant nitrate test results. Specific interpretations are given for individual crop species in Section III of this guidebook.

Figure 14 illustrates the patterns of petiole nitrate levels observed in upland cotton plants receiving deficient to slightly more-than-adequate nitrogen supplies. Lint yields suffered when petiole nitrate levels remained in the Warning and Deficient zones throughout the season. Optimum lint yields were achieved when petiole levels remained in the optimum or lower portions of the adequate ranges. Increasing nitrogen supplies above that required for optimum nitrogen nutrition did increase petiole nitrate levels on all sampling dates but did not enhance lint yields.

The analysis of total nitrogen content in the leaf or whole plant tissues of annual plants can also give an indication of their nitrogen status. However, this approach is generally less helpful than nitrate test procedures in that samples are normally taken too late in the season to allow corrective action.

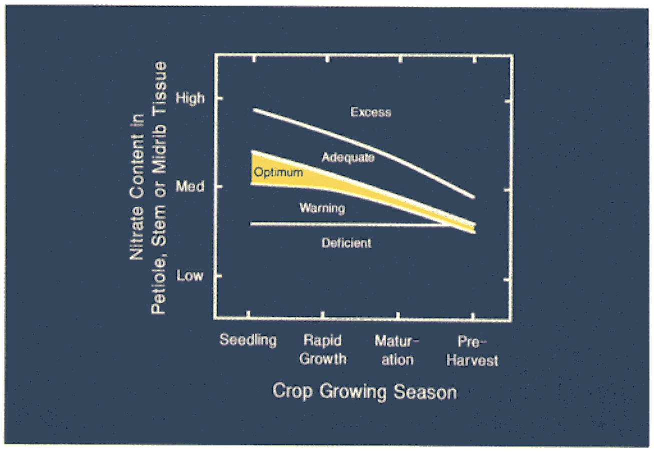

Figure 13.
Generalized interpretation of plant tissue NO_3-N levels in annual crops.

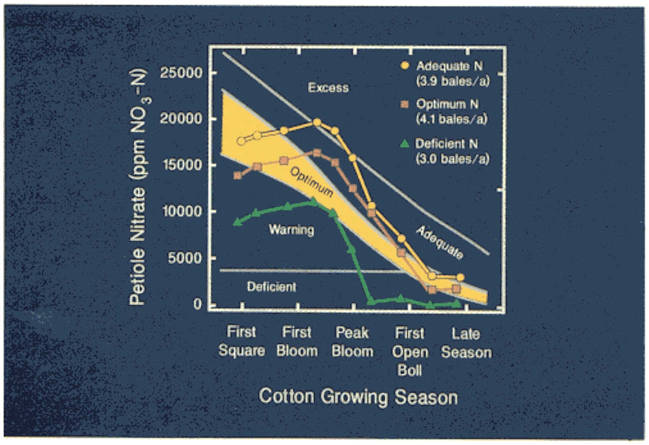

Figure 14.
Graphical interpretation of petiole NO_3-N levels in Upland cotton receiving varying levels of nitrogen fertilizers.

- **Perennial crops**

Nitrogen accumulation and utilization in perennial plants are much more complicated than in annual plants and a different approach to nitrogen tissue testing is recommended. Tree fruit, nut and vine crops accumulate nitrogen in roots and stems prior to dormancy for use in the following growing season. These stores of reserve nitrogen are usually present in more complicated organic forms and are located in plant parts which would be too difficult or unduly destructive to sample directly. Thus, for most perennial crops a sample of plant tissue is taken only once during the middle of a growing season. The tissue collected is usually entire leaves taken from nonfruiting or first year growth. This tissue is then normally analyzed for total nitrogen content. The single exception among perennial plants is the sampling of grape petioles for nitrate analysis. Guidelines for how and when to sample perennial crops for nitrogen testing are given in Section III.

More care is needed when interpreting nitrogen tissue tests for perennial versus annual crop plants. Other factors such as stand age, vigor, visual appearance, fruit load, pest infestations and climatic variation must also be considered when evaluating the nitrogen status of perennial crops. Field experience and familiarity with the effects of all factors which influence the nitrogen status of perennial plants are particularly helpful in making sound management decisions for these crops.

BMP 2. Application of nitrogen fertilizer shall be timed to coincide as closely as possible to the periods of maximum crop plant uptake.

The accumulation of nitrogen in the biomass of crop plants occurs at varying rates during the growing season. Factors such as plant age, soil nitrogen supplies, pest infestations, climatic variations, and soil moisture status can all affect the rate of daily nitrogen uptake, expressed in pounds of nitrogen taken up per acre per day. Nitrogen flux is another term for daily nitrogen uptake. The maximum potential rate of nitrogen uptake is determined by the stage of growth and the genetic characteristics of the crop being grown.

A generalized pattern of daily nitrogen uptake rates observed in annual plants is shown in Figure 15. Periods of lowest nitrogen uptake occur during the seedling and preharvest periods. Early in the season plants are small and nitrogen demand is low. During the maturation period prior to harvest, crop root systems are declining in their ability to take up nutrients and water and intraplant nitrogen demands are often satisfied by simply transporting stored nitrogen from leaves, stems and other storage organs into the maturing fruiting structures and seeds.

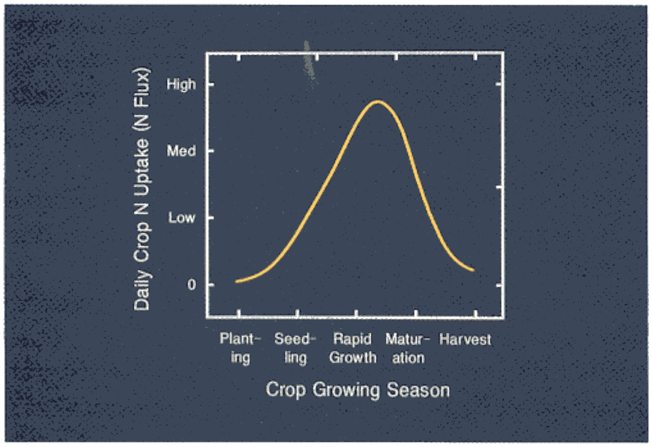

Figure 15.
Generalized pattern of daily nitrogen uptake (N flux) by annual crops.

The period of highest nitrogen demand typically occurs during the middle of the season when vegetative structures are growing rapidly and fruiting structures are also developing. This would correspond to the peak bloom and jointing growth stages in cotton and small grains, respectively. Crops which are harvested during the vegetative portion of their growth cycle can exhibit high rates of nitrogen uptake right up until harvest. Examples of these crops would include lettuce, broccoli, cauliflower and other nonfruiting vegetables. Nitrogen uptake patterns for individual crops are presented in Section III.

Proper timing of nitrogen applications must also account for the inevitable lag time between the fertilizer application and when the nitrogen it contains is both chemically and positionally available for uptake by plant roots. The chemical form of the nitrogen that is applied, the method of incorporation or placement of the fertilizer, the irrigation system used and soil moisture and temperature characteristics all influence the duration of the "application-to-available" time lag.

A mobile form of nitrogen (e.g. nitrate or urea) applied in irrigation water will have the shortest lag time before becoming available to plants. These forms move into the rooting zone immediately and will be available for root uptake within 1 to 2 days after irrigation. Nitrogen injected or sidedressed into the root-zone will also become available in about this same time period.

Immobile ammonium forms of nitrogen which are water run in furrow or flood systems will remain adsorbed in the surface 0.5 to 1 inch of soil and must be converted to nitrate via nitrification (see p. 18) before moving into the root zone with subsequent irrigations. The time required for this conversion is usually 7 to 20 days depending on soil temperature.

The longest delay in nitrogen becoming available occurs when organic or slow release nitrogen fertilizers are added to the soil. Manures, sewage sludge and other sources of organic nitrogen must first be decomposed by soil microbes before the nitrogen they contain will be plant available. Table 7 lists the decay rates of several types of organic materials. In general, nitrogen availability begins within several weeks after the organic material has been applied and extends for a period of up to 2 to 3 years.