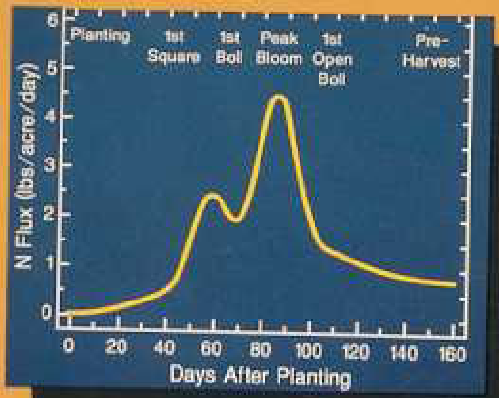
Nitrogen Fertilizer Management in Arizona



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Section I:

The Role of Nitrogen Fertilizer Use in Arizona Agriculture

Introduction

Nitrogen is the essential nutrient element which is required in the greatest quantities by most commercial crops. Most of the nitrogen utilized by crop plants is derived from synthetic nitrogen fertilizers, from soil organic matter derived from plant and animal residues or byproducts, or from the symbiotic association of certain soil microorganisms with various legume plants. From such symbiotic associations, otherwise unavailable nitrogen gas from the atmosphere can be converted into forms which are useable to the host legume plants.

Alfalfa is the only major crop grown in Arizona which depends primarily on symbiotically fixed nitrogen. The remaining cotton, grain, vegetable, fruit and specialty crops, representing 80 to 85% of total crop acreage are dependent on additions of synthetic and naturally produced nitrogen fertilizers to achieve optimum productivity. Crop production in Arizona is particularly dependent on the use of off farm nitrogen sources for two reasons. The first is the limited availability of animal manures. All of the manure produced in Arizona is sufficient to supply nitrogen for only about 10% of the cultivated crop acreage at typical application rates. The second reason is related to the naturally low levels of organic matter in desert soils. The low levels of nitrogen mineralized from soil organic matter each year are not sufficient to fully support the highly productive irrigated cropping systems found in Arizona. Consequently, the increasing availability of inexpensive synthetic nitrogen fertilizers following World War II has made them the source preferred by most Arizona growers to supply nitrogen for their crops. In short, there is no practical substitute for nitrogen fertilizers in commercial agriculture as it is currently practiced in Arizona.

Figure 1 depicts the sharp rise in synthetic nitrogen fertilizer use occurring in Arizona during the past 50 years. This increasing use has been

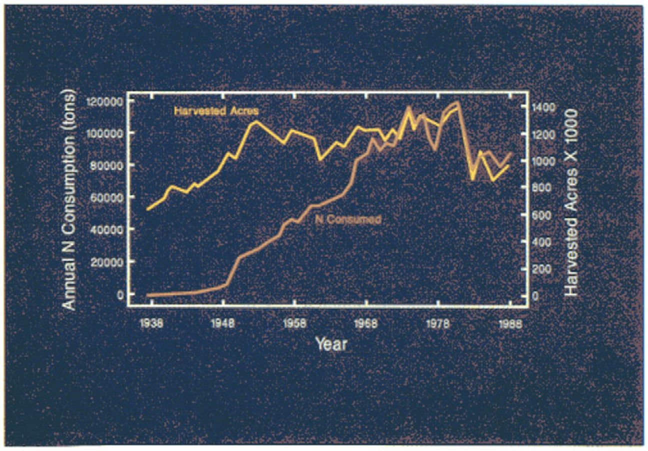

Figure 1.
Annual consumption of nitrogen from commercial fertilizers and number of harvested acres of cropland in Arizona between 1938 and 1988.

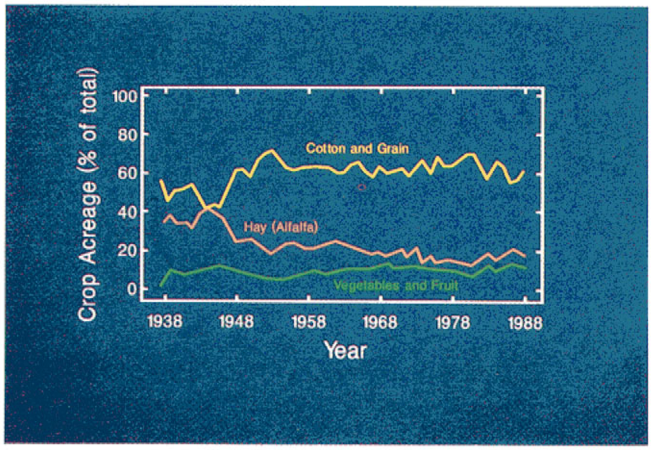

Figure 2.
Annual acreage distribution of major crop types grown in Arizona between 1938 and 1988.

fueled in part by expansion in the harvested acreage during the 1940's and early 1950's (Figure 1) and to some extent by a shift in cropping patterns away from low nitrogen use crops such as alfalfa in favor of cotton, grain and vegetable crops which require much higher nitrogen inputs (Figure 2). In addition, new crop varieties introduced over this period have been bred to produce higher yields which require more nutrients, including nitrogen. This trend of increasing crop yields with time is illustrated in Figure 3 for upland and Pima cotton. The influence of the release of new higher yielding varieties on average crop yields in Arizona is especially evident for Pima cotton where most production is obtained from a very small number of cultivars. Substantial yield increases were observed shortly after the introduction of varieties S-1, S-5 and S-6 in 1951, 1975 and 1983 respectively.

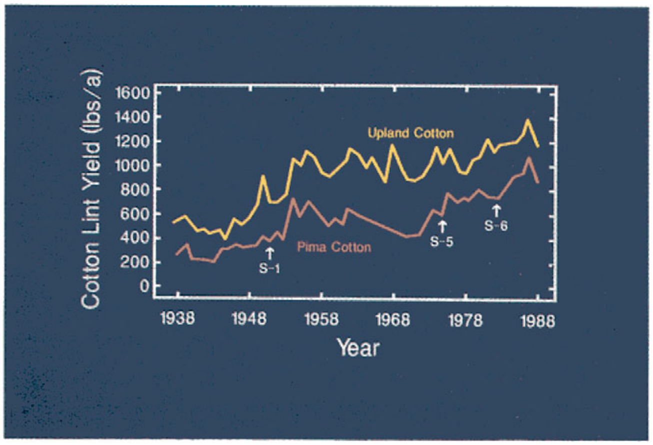

Figure 3.
State-wide average cotton lint yields for Upland and Pima cultivars in Arizona between 1938 and 1988. Arrows indicate the release of new Pima cotton varieties.

An increasing preference for fluid versus dry nitrogen fertilizers is shown in Figure 4. This reflects the greater convenience, flexibility and labor savings of fluid fertilizers over dry materials and in some cases, the lower unit cost of some fluid nitrogen sources. Prior to 1950, sodium + calcium nitrates and ammonium sulfate were preferred while today, urea is the dry nitrogen material most widely used in Arizona (Figure 5). Anhydrous ammonia (NH_3) has long been the most popular fluid nitrogen source primarily because of its low relative cost. However, anhydrous ammonia requires pressurized storage, transport and handling equipment. In addition, anhydrous ammonia is highly caustic and potentially hazardous and in some cases can lead to deterioration of soil and water quality with prolonged use. These factors have greatly curtailed the consumption of anhydrous ammonia since 1980. In its place, nonpressurized urea-ammonium nitrate solution (32% nitrogen) is now the most widely used fluid N material (Figure 6).

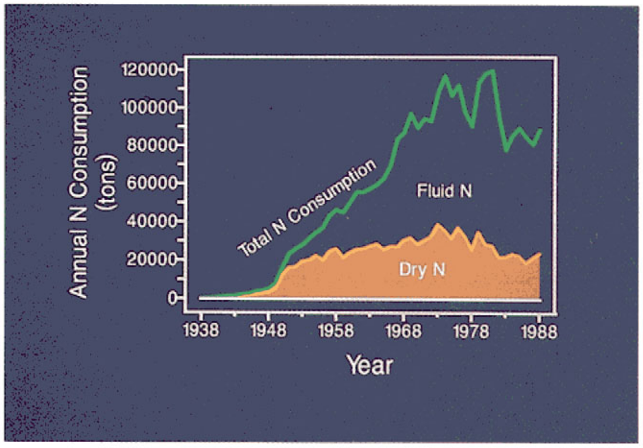

Figure 4.
Average annual consumption of dry and fluid nitrogen from commercial fertilizers in Arizona between 1983 and 1988.

The rise in *total* annual nitrogen fertilizer use in Arizona since 1938 has been accompanied by a similar increase in the *average* amount of nitrogen applied per acre of harvested cropland (Figure 7). This increase may in part reflect subtle changes in cropping patterns and the need for more nitrogen to satisfy the greater nutrient requirements of newer,

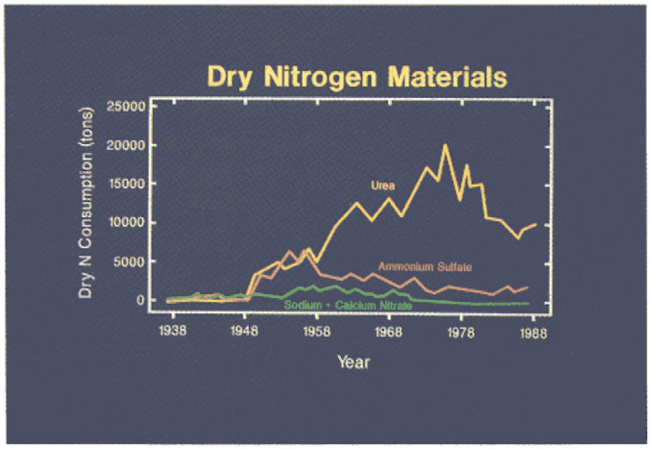

Figure 5.
Average annual consumption of nitrogen from selected dry fertilizer materials in Arizona between 1938 and 1988.

high yielding crop varieties. Arizona leads the nation in the productivity per acre for Upland cotton, spring wheat, barley and alfalfa. Nonetheless, the average nitrogen application rate in Arizona is also one of the highest in the nation, averaging 187 lbs./harvested acre during 1985-1988. Only Florida and California surpass this figure with average nitrogen rates of 418 and 227 lbs./acre respectively (Berry and Hargett, 1988 Fertilizer Summary Data. Tennessee Valley Authority). These two figures may be somewhat inflated due to multiple cropping which occurs each year in fields within these two states.

Nitrogen Fertilizer Use and Environmental Concerns

An approximation of overall nitrogen use efficiency in Arizona can be obtained by dividing the total annual production of harvested materials of the state by the total weight of nitrogen fertilizer applied during that year. This yields a Nitrogen Productivity Index which estimates the amount of harvested agricultural product resulting from each unit of nitrogen applied.

Since 1950 the Nitrogen Productivity Index has not changed dramatically but shows a slight shift downward (Figure 7). This trend plus the perception that much higher nitrogen rates are used in Arizona than in much of the country have fueled speculation that excessive amounts of nitrogen are sometimes being applied. This has caused concern about migration of unutilized nitrogen (usually in the nitrate, or NO_3 form) below the crop root zone and eventually into groundwater supplies. However, little is known about the extent of migration of nitrates into groundwater. Other nonpolluting losses for nitrates in soil also may occur and are discussed in Section II.

Monitoring of groundwater quality by several government agencies has found increasing problems with high nitrate levels in Arizona (personal communication, Carol Russell, Arizona Department of Environmental Quality). A recent compilation of water quality data revealed that 10.2% of the 6864 wells tested in Arizona exceeded

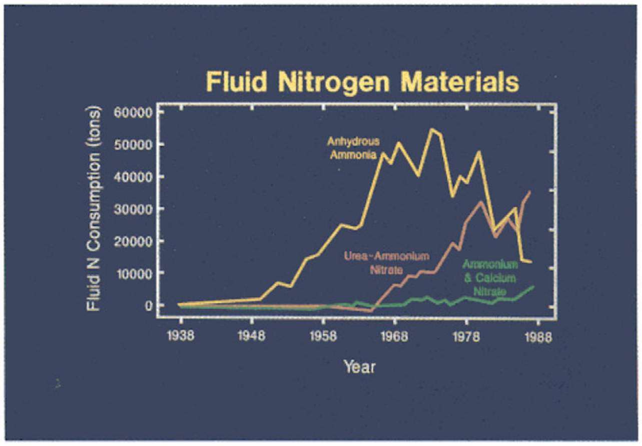

Figure 6.
Average annual consumption of nitrogen from selected fluid fertilizer materials in Arizona between 1938 and 1988.

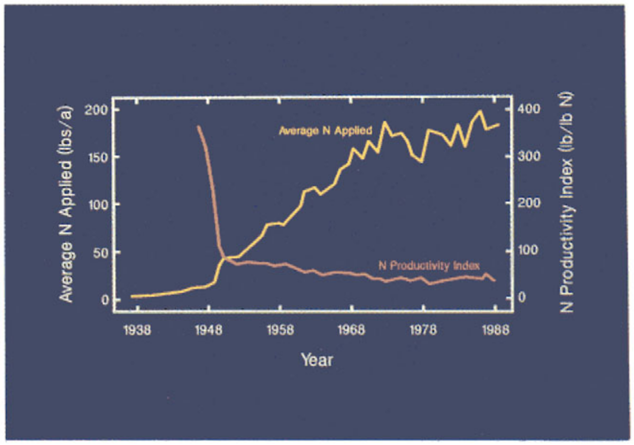

Figure 7.
Average annual application of nitrogen per harvested acre and an estimated Nitrogen Productivity Index in Arizona between 1938 and 1988.

the maximum recommended concentration of 10 milligrams per liter (mg/l) of nitrate-nitrogen (NO_3-N) in drinking water as set by the Environmental Protection Agency. This is equivalent to 45 mg/l of nitrate (NO_3).

The spatial distribution of the wells testing above the 10 mg/l standard does not present any clear association with human activities which may be responsible for these elevated nitrate levels. Intensive agricultural areas as well as locations with no agriculture at all have shown elevated nitrate concentrations in well water. Contributions of nitrates can come from multiple sources, including mineralized soil organic matter, geologic deposits, septic tanks, sewage treatment plants, concentrated animal operations and agricultural applications of nitrogen fertilizer. Elevated levels of nitrate in some Arizona wells prior to 1960 in predominately non-urban areas suggest that geological sources of nitrate can be locally important. It is likely that any nitrate contamination of groundwater that currently exists is related to several sources. The identification of specific contributions from individual sources is presently not possible.

The presence of excessive nitrate in drinking water is most serious for bottle fed infants less than six months old. Their immature digestive systems are not able to properly metabolize nitrate. Bacteria in their stomachs convert nitrate to nitrite which then reacts with hemoglobin to form methemoglobin. This condition is referred to as methemoglobinemia. This methemoglobin molecule, unlike hemoglobin, is unable to carry oxygen. As methemoglobin levels in the blood increase, symptoms of oxygen starvation begin to occur. Because oxygen starvation causes a bluish discoloration of the body, methemoglobinemia is commonly referred to as "blue baby" disease. This condition is potentially fatal but is also very easily treated if diagnosed.

The incidence of methemoglobinemia in Arizona is very difficult to determine. It is not one of the diseases which are routinely reported to public health agencies. To date, no confirmed cases of methemoglobinemia resulting from agricultural contamination have been reported in Arizona (personal communication, Norm Peterson, Epidemiologist, Arizona State Department of Health and Dr. Lynn Tausig, Department of Pediatrics, University Medical Center).

There is additional concern that elevated concentrations of nitrates in drinking water may increase the incidence of stomach cancer in adults. Nitrate can be converted to N-nitrosamines in the digestive system and these compounds have been identified as carcinogens.

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

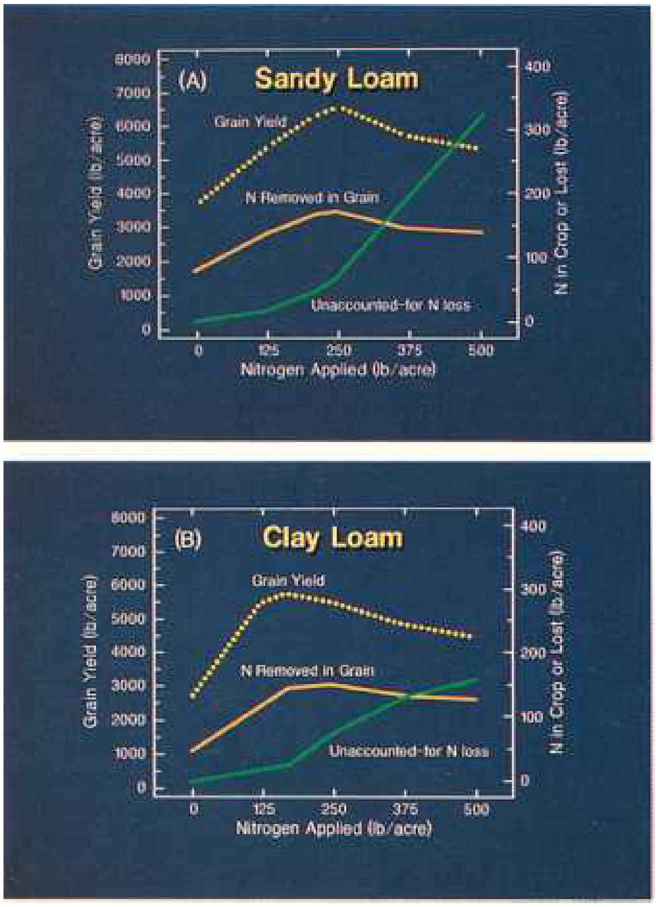

Figure 8.
Grain yields and a partial nitrogen budget for irrigated durum wheat crops receiving varying rates of nitrogen fertilizer when grown on a Casa Grande sandy loam (A) and a Trix clay loam (B).

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

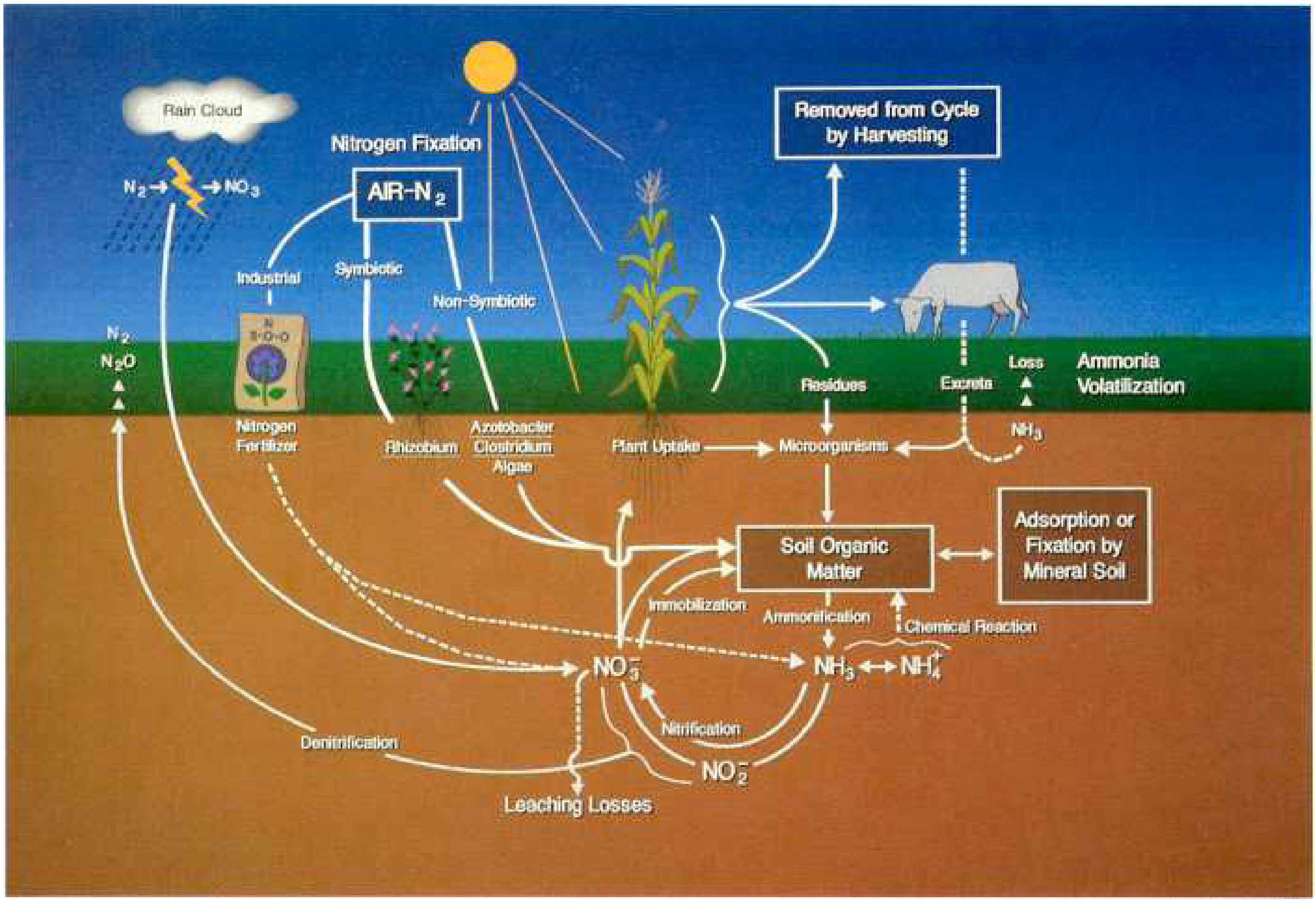

Figure 9. The nitrogen cycle in soils.

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		With water		Mechanical			
		Soil pH		Soil pH			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%.

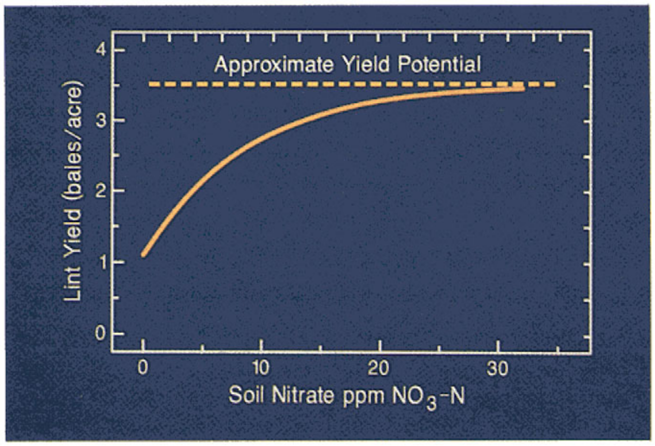

Figure 10.
Relationships between lint yields of unfertilized Acada cotton and NO_3-N content in the soil (dry weight basis) immediately following preplant irrigation (Gardner and Tucker, 1967. Nitrogen Effects on Cotton: II. Soil and Petiole Analysis. Soil Sci. Soc. Amer. Proc. 31:785-791).

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	Nutrient Content* Phosphorus	Nutrient Content* 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:

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

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:

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

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

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

Dry Material	Analysis*	Nitrogen Composition			Nutrient Content	
		NH_3/NH_4	NO_3	Urea	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			Nutrient Content		Density
		NH_3/NH_4	NO_3	Urea	N	P_2O_5	
		%			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:

$$\text{Flow rate (ozs./min.)} \quad \frac{\text{Desired nutrient rate in lbs./acre}}{\text{Nutrient content of fertilizer in lbs./gal.}} \times \frac{\text{No. acres} \times 2.133}{\text{Injection period in hours}} \qquad \text{Eq. 4}$$

OR

$$\text{Flow rate (mls./min.)} \quad \frac{\text{Desired nutrient rate in lbs./acre}}{\text{Nutrient content of fertilizer in lbs./gal.}} \times \frac{\text{No. acres} \times 60.52}{\text{Injection period in hours}} \qquad \text{Eq. 5}$$

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?

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

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:

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

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.

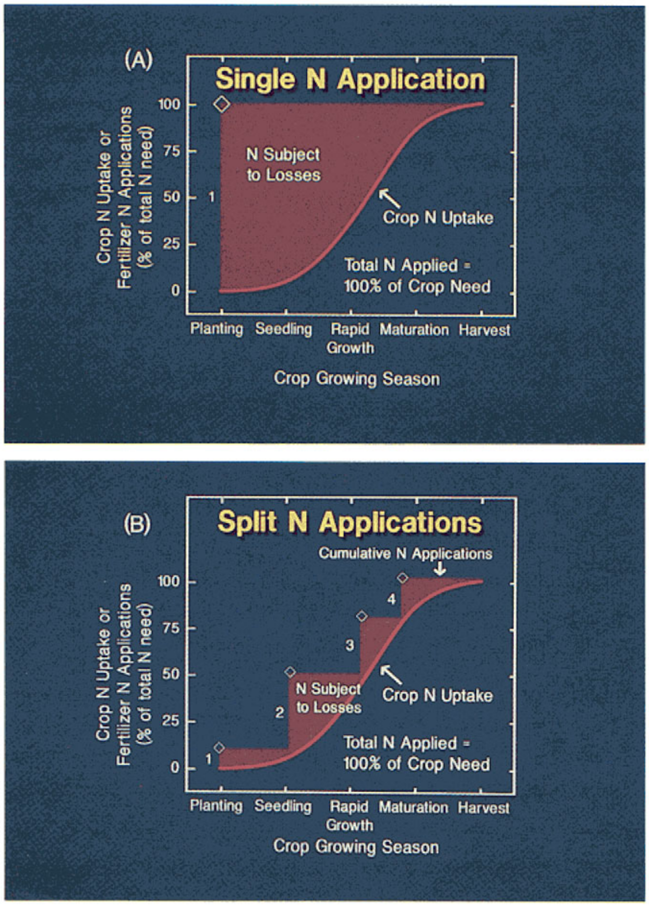

Figure 11.
General estimations of potential soil nitrogen losses occurring when nitrogen fertilizer is applied in a single (A) or in split applications (B).

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*

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.

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.

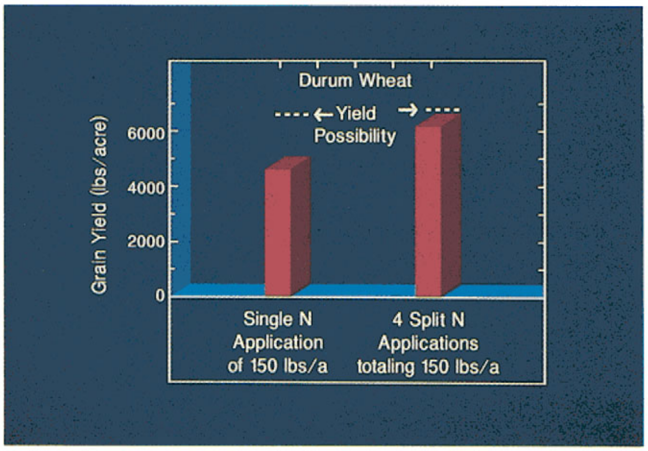

Figure 12.
Grain yields of durum wheat resulting from single and split applications of 150 lbs. nitrogen fertilizer per acre from experiments conducted on a Pima clay loam soil.

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:

Eq. 7

$$\begin{array}{ccccc} NH_4^+ & 2O_2 \xrightarrow{\text{microbes}} & NO_3^- & + 2H^+ & + H_2O \\ \text{ammonium} & \text{oxygen} & \text{nitrate} & \text{hydrogen} & \text{water} \end{array}$$

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.

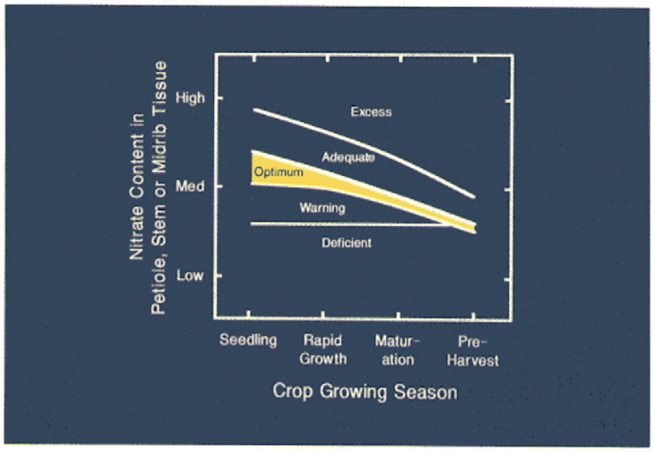

Figure 13.
Generalized interpretation of plant tissue NO_3-N levels in annual crops.

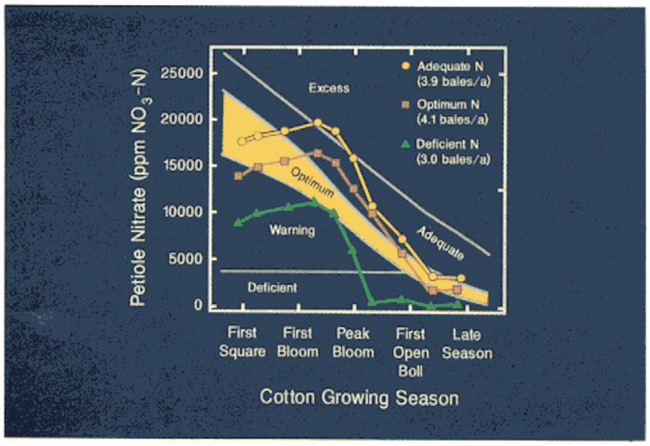

Figure 14.
Graphical interpretation of petiole NO_3-N levels in Upland cotton receiving varying levels of nitrogen fertilizers.

- **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.

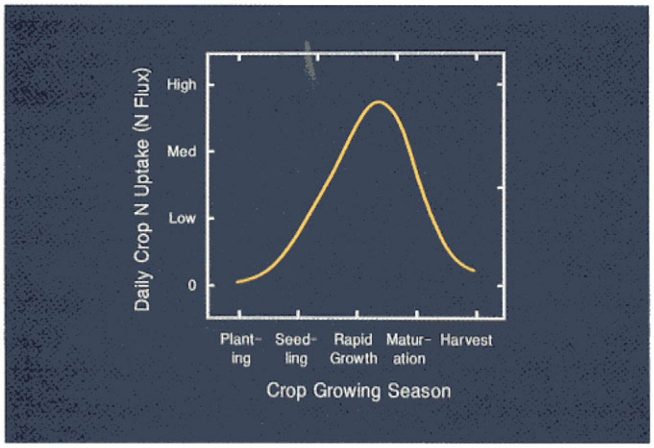

Figure 15.
Generalized pattern of daily nitrogen uptake (N flux) by annual crops.

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.

These materials allow for the least control over the rate and timing of nitrogen release to crops. Cropping systems which rely on organic nitrogen sources for all or most of their nitrogen supply will probably experience accumulations of nitrate in the soil profile during periods of low nitrogen demand by crops. This accumulation of nitrates will be subject to leaching losses any time irrigation water or precipitation is applied in excess of the moisture holding capacity of the root zone. For this reason it might be advisable to supply only a portion of the nitrogen requirement of a crop in organic forms and utilize immediately available nitrogen materials to insure adequate nutrition during periods of peak nitrogen demand.

Commercially prepared slow release nitrogen fertilizers are specifically formulated to release their nitrogen over a specified period of time, usually 6 to 12 weeks. These materials should be carefully chosen to match their nitrogen release characteristics with crop requirements and anticipated climatic conditions. Slow release nitrogen fertilizers are more fully discussed under GP 1.7.

The most effective management strategy will be one that recognizes the pattern of nitrogen demand by the crop and the nitrogen release characteristics of all important nitrogen sources to provide adequate, but not excessive levels of soil nitrogen throughout the growing season. Deficiencies of nitrogen at anytime should be avoided since yield, quality and/or earliness could be adversely affected.

GP 2.1 Coordinate the timing and rate of nitrogen fertilizer applications to supply adequate nitrogen throughout the growing season.

Decisions concerning the *rate(s) of nitrogen* fertilizer to apply during a growing season must include consideration of the expected crop yield and all contributions of soil nitrogen during that period. These criteria are discussed under BMP 1. The *timing of nitrogen* applications must account for differences in nitrogen demand by the crop throughout the growing season and the time lag between application of fertilizers and plant availability of the nitrogen they contain.

Nitrogen uptake studies for individual crops are required to determine the total nitrogen contained in the biomass of a crop and to identify periods of peak nitrogen demand. Specific nitrogen uptake characteristics of durum wheat are shown in Figure 16. This crop contained 230 lbs. of nitrogen per acre in the grain, straw and chaff and yielded 6700 lbs. of grain per acre. Nitrogen uptake proceeded at a very slow rate during the first 40 days after planting. However, between the 3 to 4-leaf stage and jointing the daily nitrogen uptake rate (N flux) increased from 0.3 to a maximum of 2.4 lbs. of nitrogen per acre per day. After anthesis (flowering) nitrogen uptake decreased to only about 0.8 lbs. per acre per day by physiological maturity.

The timing of nitrogen fertilizer must also be compatible with the application equipment available to the grower and with their irrigation management system. With proper equipment, nitrogen can be applied directly to the soil prior to planting or as

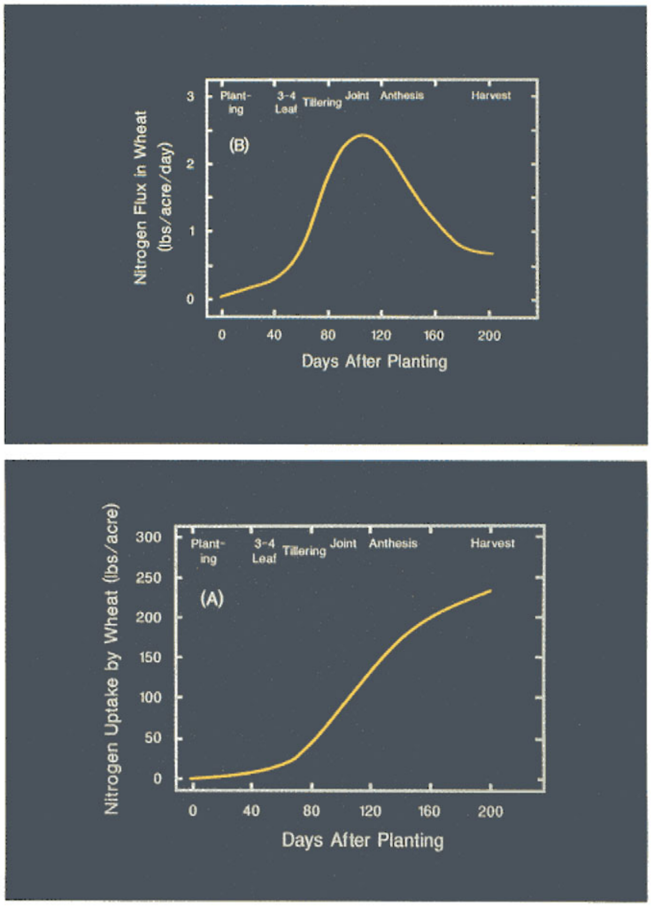

Figure 16.
Cumulative (A) and daily (B) nitrogen uptake patterns for a durum wheat crop yielding 6700 lbs. grain per acre.

a sidedress application after stand establishment. When appropriate, sidedressing and cultivation can be done simultaneously to reduce the number of field operations.

Later in the season nitrogen solutions may be applied in conjunction with irrigation events via fertigation. This may be the only method of applying nitrogen after appreciable crop canopy development. Thus a nitrogen management program must be coordinated with not only crop demands and nitrogen release characteristics of different fertilizer materials but also with the specific irrigation schedule which is followed. This is particularly important in systems where only a small number of irrigation events are needed, such as with basin or furrow irrigation.

Several examples of optimum nitrogen application schedules for durum wheat are listed in Table 15. These schedules were derived from field experiments on sites with varying soil texture, cropping history and residual soil nitrate content. In these experiments the effects of varying nitrogen rates and timing on grain yield and quality were determined. The nitrogen application schedules were determined to be optimum if higher rates of nitrogen did not significantly increase grain yield and if lower rates resulted in lower yields or unacceptable grain protein levels (i.e. below 14%). In general the optimum nitrogen fertilizer rates increased on coarse textured soils and on sites low in residual nitrate content.

Irrigation methods which permit frequent and smaller water applications such as with drip or sprinkler systems allow the greatest flexibility in coordinating the time and rate of nitrogen applications. The greatest nitrogen use efficiency will normally be achieved when numerous, small applications are made rather than a few large applications. This assumes that the total amount of nitrogen used is nearly equal to the actual nitrogen fertilizer requirement of the crop. Too many split applications of nitrogen which greatly exceed the requirement by the crop will result in a very low nitrogen uptake efficiency and a high potential for nitrate leaching losses. Periodic plant tissue nitrogen tests are particularly helpful in fine tuning nitrogen applications under these conditions.

GP 2.2 Add the seasonal nitrogen fertilizer requirement in multiple applications (see GP 1.5).

GP 2.3 Use slow-release nitrogen fertilizers (see GP 1.7).

Table 15.
Optimum nitrogen fertilizer application schedules for durum wheat crops grown on sites with varying soil texture, cropping history and residual soil nitrate content (after Knowles et al. 1991. Improved Nitrogen Management in Irrigated Wheat Using Basal Stem Nitrate Analysis: I. Nitrate Uptake Dynamics. Agronomy Journal Vol. 2; and Doerge and Ottman, unpublished data).

			Optimum N Application Schedule**				
			Times of N Application				
Soil Texture	Preceding Crop*	Preplant Soil Test NO3-N	Preplant	Tillering	Joint	Anthesis	Total
		ppm	*lbs. N/acre*				
sandy loam	sudan grass	3	60	50	75	30	215
clay loam	sudan grass	3	60	30	55	30	175
sandy loam	alfalfa	16	0	40	60	35	135
clay loam	cotton (+ manure)	88	0	0	0	0	0

**sudan grass and alfalfa crops received no nitrogen fertilizer and all plant materials were removed.*

***nitrogen applications made preplant and at the tillering, jointing and anthesis growth stages were in conjunction with the first four irrigation events, respectively.*

BMP 3. Application of nitrogen fertilizer shall be by a method designed to deliver nitrogen to the area of maximum crop plant uptake.

Applications of nitrogen fertilizers can be made either before or after stand establishment. In general, pre-emergence applications will be less efficient due to the time lag between application and crop demand for nitrogen and the potential for nitrogen losses during this time. Low rates of soluble nitrogen fertilizers banded with or near the seed at planting will normally be the most efficient method of pre-emergence nitrogen application with annual crops. Broadcast or water run applications at this time are normally the least efficient, especially on coarse textured soils.

The use of ammonium nitrogen sources at appropriate rates for pre-emergence applications is generally recommended. Mobile forms of nitrogen such as nitrate and urea can be easily leached below the root zone of seedling crops. In contrast, ammonium nitrogen from ammonium sulfate, ammonium phosphates or anhydrous ammonia will temporarily remain adsorbed on the soil at the point of application and will not be subject to leaching losses for up to several weeks.

Post-emergence applications of nitrogen can be physically placed into the root zone by sidedressing or applied to the soil surface as a topdress or water run application, and then be transported into the root zone with downward or lateral movement of irrigation water.

The optimum placement of pre- or post-emergence nitrogen applications therefore depends on two principle factors. The first is the extent and location of the active root system at the time of fertilizer application. The effective rooting depths of several important crops are listed in Table 16. It should be noted that these rooting depths are for crops nearing physiological or harvest maturity. Early in the growing season, all annual crops must be considered as "shallow rooted crops." This is demonstrated in Figure 17 where the root zone development of basin irrigated wheat is depicted. Note that at the 3-leaf stage the effective rooting depth is probably less than one foot. *Fertilizer placement or irrigation practices which result in nitrogen occurrence below the rooting zone at any time during the growing season have the potential for causing nitrate leaching losses.*

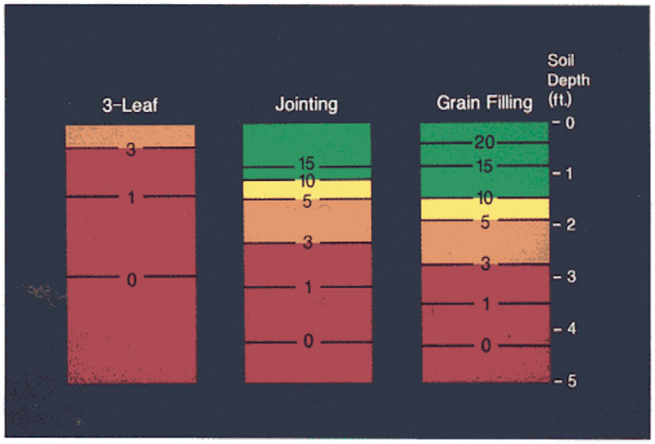

Figure 17.
Measured root densities in basin irrigated durum wheat at three stages of growth. Densities are in number of roots per square inch.

The rooting pattern of drip irrigated crops varies considerably from that observed when basin, furrow or sprinkler systems are used. The rooting patterns of surface and subsurface drip irrigated cotton are shown in Figure 18. Note that the maximum rooting density occurs in the immediate vicinity of water emission and that in both cases the effective rooting depth does not exceed about 18 inches. The rooting patterns characteristic of other drip irrigated crops are similar to cotton.

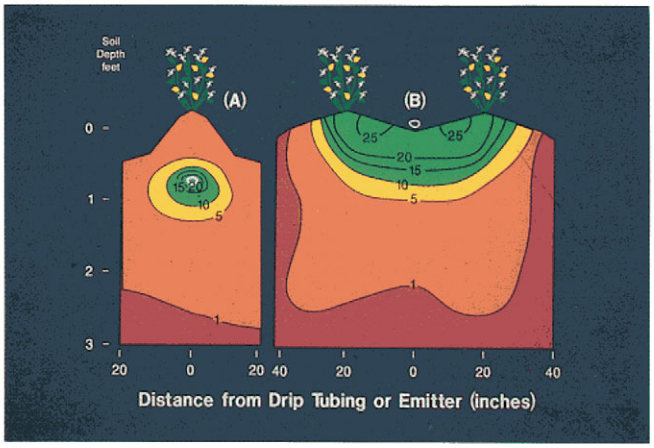

Figure 18.
Measured root densities in subsurface (A) and surface (B) drip irrigated Upland cotton. Densities are in number of roots per square inch measured at the peak bloom stage.

The second factor which regulates the optimum placement of nitrogen fertilizers is the direction of soil water movement in relation to the root and fertilizer placement zones following nitrogen applications. Nitrogen which is not placed directly in the root zone should be delivered to a location such that it will be carried into the most active portion of the rooting zone as irrigation water moves into the soil. Figure 19 illustrates in cross-section the direction of water movement which occurs in basin/sprinkler, furrow and drip irrigated systems.

The optimum placement of nitrogen fertilizer for furrow irrigated crops is somewhat dependent on the time of application(s) during the growing season. Nitrogen applied before or at planting is most efficiently placed several inches below the seed zone. This however, may not be feasible when using manures or other bulky organic fertilizers which should always be broadcast applied and then incorporated into the seedbed prior to planting. Later in the season, but before canopy closure, nitrogen can most effectively be applied as a sidedressing. Fertilizers should be injected 2 to 5 inches below the soil surface at a point about 1/3 to 1/2 of the way up from the bottom of the furrow where root pruning is avoided. After ground equipment can no longer enter the fields the application of fluid nitrogen fertilizers via fertigation is probably the most efficient and practical method available.

Table 16.
Approximate rooting depths for various crop types receiving furrow or basin irrigation (after Rauschkolb et al., 1979. Nitrogen Management Relative to Crop Production Factors. In, Nitrate In Effluents from Irrigated Lands. University of California, Riverside; and Erie et al., 1982. Consumptive Use of Water by Major Crops in the Southwestern United States. USDA-ARS Conservation Research Report No. 29).

Crop	Rooting Depth at Maturity
Field Crops	**Feet**
Alfalfa	3 - 5
Corn	3 - 5
Cotton	5 - 7
Irrigated pasture	1 - 2
Small grains	2 - 4
Sudangrass	4 - 6
Sugarbeets	3 - 5
Vegetable Crops	
Beans	2 - 4
Cucumbers	1.5 - 2.5
Onions	1 - 2
Other vegetables	1 - 2
Peppers	2 - 4
Potatoes	2 - 4
Tomatoes	3 - 5
Watermelons	4 - 6
Tree Fruit and Vine Crops	
Most tree crops	5 - 7
Grapes	3 - 6
Turf	1 - 2

Under some conditions dilute nitrogen solutions sprayed on plant foliage can be effectively utilized by certain crops. Such foliar applications of nitrogen are generally not especially advantageous unless immediate action is needed to avert a serious and imminent nitrogen deficiency. While effective, these treatments are generally more expensive than comparable soil applications and can safely deliver only a few pounds of nitrogen per acre per treatment. Higher application rates will increase the risk of foliar burning. Foliar applications should be viewed as a means of supplementing soil N applications.

Foliar applications can be safely made using low biuret urea (<2% biuret) at the rate of 1 to 5 lbs. of nitrogen per acre. It is always wise to carefully adhere to recommendations of the manufacturer when using any commercial product for foliar applications. Greatest absorption of foliar applied nutrients will occur at moderate temperatures, high humidity and low wind speed. In cases where low rates of nitrogen are needed and fertigation is not feasible, then foliar applications may be the most efficient method available especially when they can be combined with the application of other spray materials.

GP 3.1 Apply nitrogen fertilizers where they can be most efficiently used by crop plants.

Table 17 lists the general efficiencies of various nitrogen application techniques which may be used in conjunction with the irrigation systems most commonly used in Arizona. In addition, diagrams of the most efficient nitrogen fertilizer placement(s) recommended for use with these systems are shown in Figure 20.

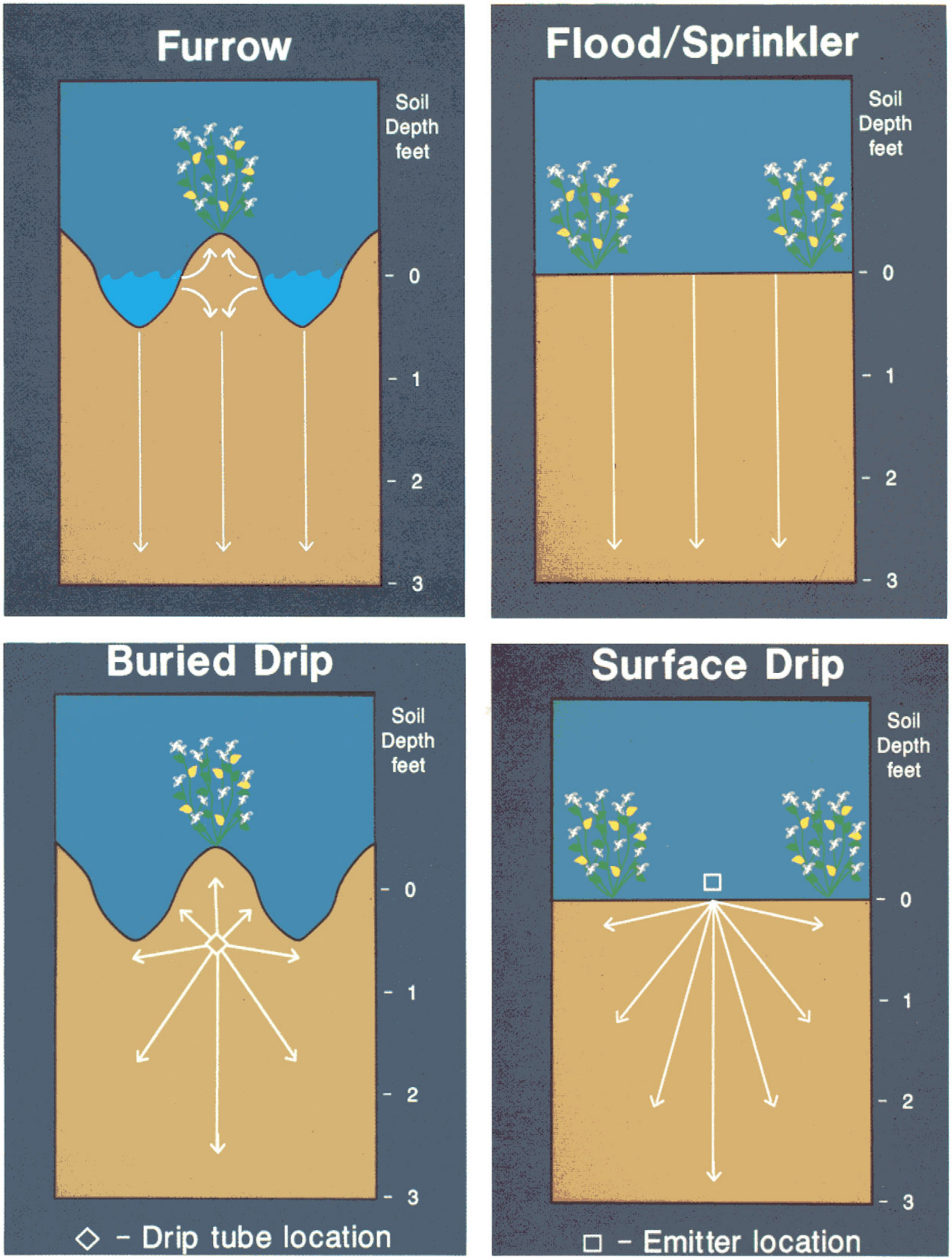

Figure 19.
Soil profile diagrams showing the direction of irrigation water movement into the soil for the irrigation methods commonly used in Arizona.

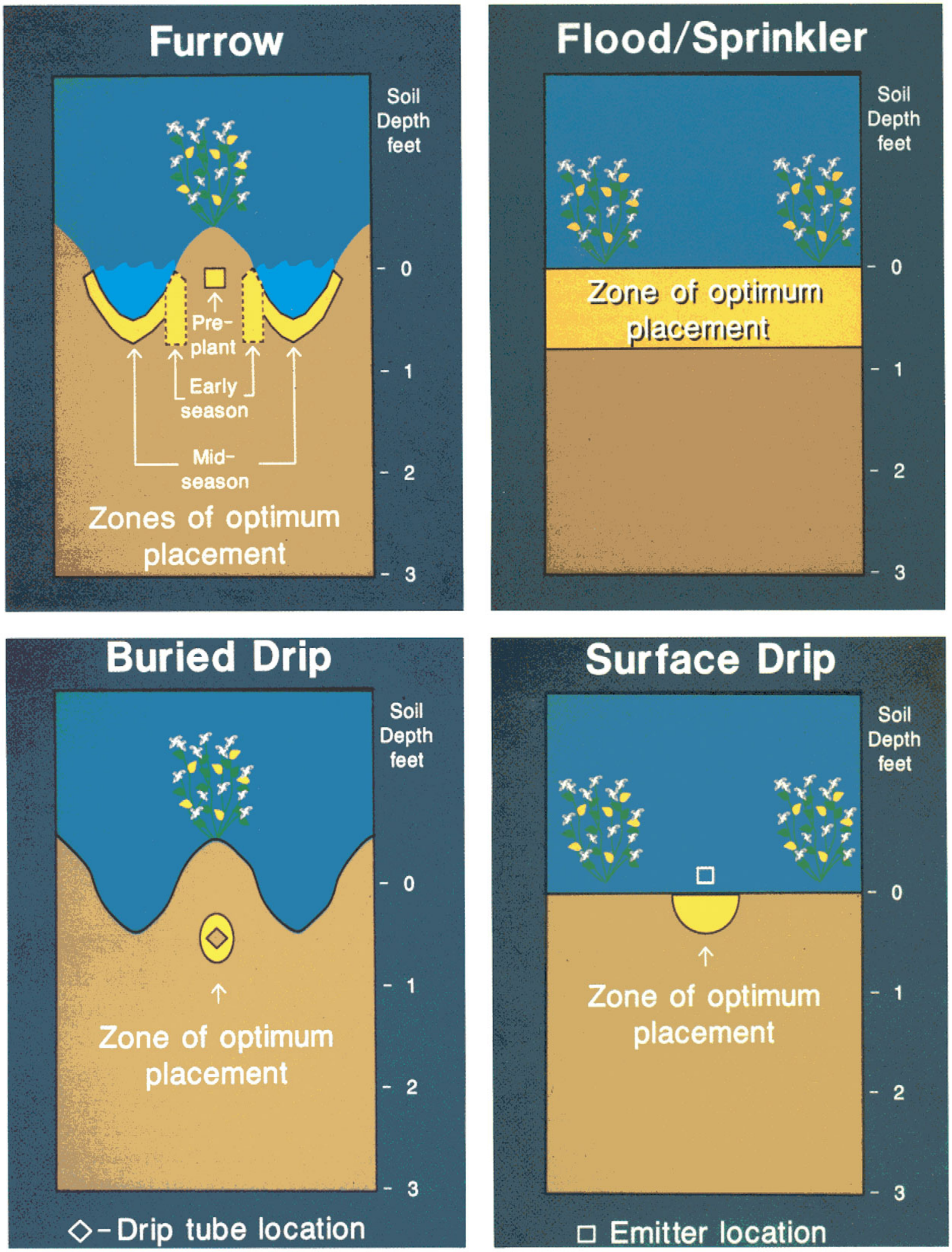

Figure 20.
Soil profile diagrams showing the zone(s) of optimum nitrogen fertilizer placement in conjunction with the irrigation methods commonly used in Arizona.

Table 17.
Relative nitrogen uptake efficiencies achieved using different fertilizer placement methods in conjunction with typical irrigation systems. These estimates assume that nitrogen is supplied from soluble fertilizer materials and at rates which are not excessive.

Irrigation Method	Nitrogen Uptake Efficiency Low (<25%)	Moderate (25-50%)	High (>50%)
Furrow	• water run before midseason • preplant broadcast and incorporated on sandy soils	• water run after midseason • preplant injection banding • Preplant broadcast and incorporate on heavier soils • sidedressing at seeding stage	• sidedressing at midseason
Basin/Sprinkler	• preplant broadcast and incorporated on sandy soils • fertigation preplant or at seedling stages	• fertigation or broadcast application followed by irrigation before midseason • preplant broadcast and incorporated on heavier soils	• preplant injection banding • fertigation or broadcast application followed by irrigation after midseason
Drip	• all other application methods		• injection through drip system • placement directly below emitters

GP 3.2 Incorporate nitrogen fertilizers which are applied to the soil surface.

All nitrogen fertilizers applied to the soil surface should be incorporated as soon after application as possible to reduce losses by volatilization and/or runoff. A discussion of ammonia volatilization is found on p. 6 with a listing of estimated nitrogen losses from surface broadcast applications for different fertilizer materials and application methods presented in Table 3.

GP 3.3 Apply nitrification inhibitors in combination with ammoniacal (NH^+_4) fertilizer formulations (See GP 1.6).

BMP 4. Application of irrigation water to meet crop needs shall be managed to minimize nitrogen loss by leaching and runoff.

Providing adequate irrigation water for the evaporative use of the crop, leaching of excess salts, promotion of seed germination and/or crop protection must all be considered in achieving this BMP. Nine Guidance Practices are included under this BMP to either improve the ability of an operator to know how much irrigation water to apply or facilitate more precise and/or uniform application of water to croplands.

The amount of irrigation water needed annually to leach excess salts is referred to as the "leaching requirement" (LR). The LR is defined as the fraction of irrigation water applied which passes below the root zone in order to maintain the salt content in the root zone within the tolerance of the crop being grown.

$$LR = \frac{EC_w}{5(EC_e) - EC_w} \qquad \text{Eq. 8}$$

where: LR = leaching requirement expressed as a fraction

EC_w = salinity of the irrigation water in mmhos/cm or dS/m

EC_e = soil salinity level tolerated by the crop in mmhos/cm or dS/m in a saturated paste extract

(after Ayers and Westcot, 1985. *Water Quality for Agriculture,* FAO, United Nations)

Nitrate present in the soil at the time of leaching irrigations will be subject to loss to the same extent as other soluble salts which are present. For this reason it is best to conduct leaching events when soil nitrate levels are low and when further nitrate depletion will not restrict crop growth.

The salinity tolerance levels (EC_e) for most of the important crops grown in Arizona are listed in Table 18.

Furthermore, the total annual depth of water needed to supply for both crop demand and the LR can be estimated as follows:

$$AW = \frac{ET}{1\text{-}LR} + SE + CP \qquad \text{Eq. 9}$$

where: AW = total annual water requirement (inches)

ET = annual crop water demand (inches)

Table 18.
Estimated salinity tolerance of selected crops expressed as electrical conductivity in a saturated paste extract (EC_e). (after Ayers and Westcot, 1985. Water Quality for Agriculture, FAO, United Nations).

Crop	Soil Salinity Threshold Above Which Yield Loss Will Occur	
	mmhos/cm or dS/m	ppm
Field Crops		
Barley	8.0	5120
Corn	1.7	1090
Cotton	7.7	4930
Sorghum	6.8	4350
Wheat, bread	6.0	3840
Wheat, durum	5.9	3780
Forage Crops		
Alfalfa	2.0	1280
Bermudagrass	6.9	4420
Sudan grass	2.8	1790
Fruits and Vegetables		
Apple	1.5	960
Asparagus	8.0	5120
Broccoli	2.8	1790
Cabbage	2.8	1790
Cantaloupe	2.2	1410
Cauliflower	1.8	1150
Citrus	1.7	1090
Corn, sweet	1.7	1090
Grape	1.5	960
Lettuce	1.3	830
Pecan	1.7	1090
Pistachio	1.7	1090
Potato	1.7	1090
Watermelon	2.2	1410

LR = leaching requirement expressed as a fraction

SE = water needed for stand establishment (inches)

CP = water needed for crop protection (inches)

In many cases the inherent inefficiencies in most irrigation systems are sufficient to satisfy the LR without the application of additional "leaching" water. The amounts of water needed for stand establishment and crop protection will depend on many factors and ultimately on the judgement of the grower.

GP 4.1 Apply the amount of irrigation water required to meet crop needs.

Following this GP requires that growers be able to accurately estimate crop water use. This may be done directly by taking plant measurements or soil measurements, and indirectly by estimation from weather data. Then, the grower must have the ability to precisely apply predetermined amounts of irrigation water to individual farm fields. The amount of soil water depletion that can be tolerated by crops varies considerably (Table 19). Any irrigation scheduling technique must recognize crop specific soil moisture depletion requirements.

Table 19.
Generalized maximum allowable soil depletion and available soil moistures for different soil types when crop use is 0.20-0.25 in./day (after Doorenbos and Pruitt. 1977. Guidelines for Predicting Crop Water Requirements. AO Irrigation and Drainage Paper No. 24).

Crop	Maximum Allowable Depletion*	Available Soil Moisture for Different Soil Types Fine	 Medium	 Coarse
		in./ft.		
Alfalfa	0.55	1.43	1.10	0.55
Barley	0.55	1.43	1.10	0.55
Broccoli	0.45	1.17	0.90	0.45
Cabbage	0.45	1.17	0.90	0.45
Carrots	0.35	0.91	0.70	0.35
Cauliflower	0.45	1.17	0.90	0.45
Citrus	0.50	1.30	1.00	0.50
Corn	0.60	1.56	1.20	0.60
Cotton	0.65	1.69	1.30	0.65
Decidious Orchards	0.50	1.30	1.00	0.50
Grapes	0.35	0.91	0.70	0.35
Grass	0.50	1.30	1.00	0.50
Lettuce	0.30	0.78	0.60	0.30
Melons	0.35	0.91	0.70	0.35
Onions	0.25	0.65	0.50	0.25
Peppers	0.25	0.65	0.50	0.25
Potatoes	0.25	0.65	0.50	0.25
Sorghum	0.55	1.43	1.10	0.55
Spinach	0.20	0.52	0.40	0.20
Wheat	0.55	1.43	1.10	0.55
Ripening	0.90	2.34	1.80	0.90
TOTAL AVAILABLE SOIL WATER		2.6	2.0	1.0

When plant use is 0.10 in./day or less increase values by 30% or when plant use is 0.30 in./day or more reduce values by 30%.

Soil moisture deficits can be measured *directly* using devices or techniques such as neutron probes, tensiometers, resistance blocks and gravimetric sampling. Even determining the moisture content of soil by hand using the “feel” method can be helpful in determining how much irrigation water is needed (Table 20). Other methods such as infrared thermometry or crop canopy reflectance measurements

Table 20.
Indicators of soil moisture content based on appearance, feel, and consistence for varying soil textures, The “Feel” Method (after Hohn, C.M. The Feel Test Tells When to Irrigate. New Mexico State University).

Degree of Moisture	Percent Useful Soil Moisture Remaining	Soil Texture*			
		Coarse	Light	Medium	Heavy to Very Heavy
Dry	0	Dry, loose, single-grained, flows through fingers.	Dry, loose, flows through fingers.	Powdery, dry, sometimes slightly crusted but easily breaks down into powdery conditions.	Hard, baked, cracked, sometimes has loose crumbs on surface.
Low	50 or less	Still appears to be dry; will not form a ball with pressure.	Still appears to be dry; will not form a ball.	Somewhat crumbly, but will hold together from pressure.	Somewhat pliable; will ball under pressure.
Fair	50 to 75	Same as course tecture under 50 or less.	Tends to ball under pressure but seldom will hold together.	Forms a ball and is very pliable; slicks readily if relatively high in clay.	Easily ribbons out between fingers, has a slick feeling.
Excellent	75 to field capacity	Tends to stick together slightly; sometimes forms a very weak ball under pressure.	Forms weak ball breaks easily, will not stick.	Forms a ball and is very pliable; slicks readily if relatively high in clay.	Easily ribbons out between fingers, has a slick feeling.
Ideal	At field capacity	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand.	Same as coarse.	Same as coarse.	Same as coarse.
Too wet	Above field capacity	Free water appears when soil is bounced in hand.	Free water will be released with kneading.	Can squeeze out free water.	Puddles and free water forms on surface.

**Coarse refers to sand and loamy sand, Light: sandy loam and loam; Medium: silt, silt loam and sandy clay loam; Heavy to Very Heavy: clay, sandy clay, silty clay, clay loam and silty clay loam.*

can be used to estimate plant water stress. Regardless of the method used, some on-site calibration is required for specific soils and plants.

Estimates of crop water use can also be approximated *indirectly* from historical evapotranspiration data (Erie et al., 1982. Consumptive Use of Water by Major Crops in the Southwestern United States. USDA-ARS Conservation Research Report No. 29.) or from near real-time weather data obtained through the Arizona Meteorological Network (AZMET) at the University of Arizona.

Irrigation water can be accurately measured onto a field using flumes, weirs, orifice plates or flow meters. The actual device used will depend on the type of irrigation delivery system and other site specific factors.

GP 4.2 Install trickle irrigation systems to improve water application efficiency and uniformity.

Trickle or drip irrigation is a water delivery system which utilizes a series of low pressure, low volume plastic pipes, tubing, emitters, sprayers, sprinklers or bubblers. Conveyance and emission of water can occur either above or below the soil surface.

The primary advantage of trickle systems with respect to nitrogen management is that precise amounts of nitrogen and irrigation water can be applied very uniformly over an entire field. Thus with careful operation, trickle systems can greatly reduce the potential for deep percolation or runoff from croplands, especially on soils that are very permeable or cannot be leveled.

To reduce the hazard of emitters plugging, only completely water soluble and compatible nitrogen solutions should be used. Clear solutions containing urea, ammonium nitrate and/or calcium nitrate are usually highly compatible with properly designed trickle systems. In contrast, fertilizer suspensions or materials which form colloids when added to water should not be used with trickle systems. Fertilizers should be injected near the end of the irrigation cycle with enough time included to flush all lines and emitters prior to turning off the system.

There are many agronomic, financial and logistical factors which will determine whether installation of a trickle irrigation system is advisable. It is advisable to obtain professional assistance when information on selecting, designing and maintaining a trickle irrigation system is needed.

GP 4.3 Apply furrow irrigations using surge flow techniques.

Surge flow irrigation is the application of irrigation water to a given furrow in a series of pulses rather than a single, uninterrupted irrigation set. This technique advances the flow of water to the end of a field with less surface storage and with reduced runoff. Thus, when properly applied, surge flow irrigation can increase water distribution uniformity and reduce deep percolation losses. Surge irrigation is best suited on fields with coarse textured soils and a slope greater than 1%. It can also work well on fine textured (clay) soils with severe cracking problems. Surge irrigation does not work well on noncracking fine textured soils or with level basins. This technique will require greater inputs of labor, capital equipment and maintenance in comparison with conventional furrow irrigation systems.

GP 4.4 Adjust irrigation application rate and set time for sprinkler irrigation systems, depending on soil and slope characteristics.

Soils vary greatly in the rate at which water infiltration will occur; from about 2.0 inches/hour on a coarse sandy soil to 0.05 inches/hour on a clay soil (Table 21). Efficient sprinkler irrigation systems match water application rates with infiltration properties of the soil. High application of water can result in either surface runoff which could transport soluble nitrogen into receiving surface water, or in ponding and subsequent deep percolation of water and leaching losses of nitrogen. Conversely, low application rates or short set times can reduce application efficiency by increasing water losses due to evaporation.

Adjusting sprinkler application rates to correspond to specific soil and crop conditions can increase irrigation efficiency, lower water costs as well as reduce the potential for the contamination of surface and/or groundwater supplies. Soil survey reports for most of the irrigated soils in Arizona are available through the Soil Conservation Service.

GP 4.5 Angle irrigation furrows to reduce the furrow slope.

The orientation of irrigation furrows at angles other than 90° from the irrigation delivery ditch can reduce the slope for a furrow. Angling of furrows will be most effective when the slope in the field is perpendicular to the delivery ditch. This practice can increase irrigation efficiency while reducing tail end ponding and runoff. However, for optimum irrigation efficiency, both the rate and amount of water application must be properly designed. Angle furrowing can achieve many of the goals of land leveling but without the large capital cost.

Angle furrowing may result in some increased labor and machinery costs due to variable row length. The alignment of irrigation furrows may require preseason evaluation of slope values and slope direction in individual fields.

GP 4.6 Install irrigation runs on the contour in fields with excessive slope.

In fields where excessive slopes result in rapid runoff and severe erosion, land leveling or angled irrigation runs may not be feasible management alternatives. In these cases irrigation runs (i.e. furrows) can be arranged to conform with the surface contours of the field. When properly installed, this practice of contour furrowing can significantly reduce the potential for runoff and soil erosion from fields with variable or excessive slope. Reduced tail water ponding can also lower the potential for downward movement of soluble nutrients due to leaching.

The arrangement of contoured irrigation runs requires preseason planning and familiarity with the conditions in individual fields. This practice is most appropriate in narrow mountain valleys as opposed to the broad alluvial areas in southern Arizona.

GP 4.7 Use land leveling to adjust field gradients.

Land leveling can be used to physically adjust the gradients or slopes in farm fields. This practice is used to minimize or eliminate runoff while maximizing irrigation uniformity and efficiency. Leveling should be considered for fields where existing gradients either contribute to excessive runoff and deep percolation or are not uniform. The advisability of using land leveling will depend on such factors as soil depth, soil texture, water quality and quantity, topography, and crop selection. Suitable characteristics of the subsoil are necessary if deep cuts are to be made.

The economics of land leveling will depend on the existing gradients in the field and the amount of soil to be moved, the availability of suitable equipment and whether the farm operator owns the land. The USDA-Soil Conservation Service estimates that the payback period for land leveling costs is about five years for most areas in Arizona.

Those unfamiliar with land leveling practices should consult with a qualified professional to have specific fields evaluated for the applicability of this guidance practice.

Table 21.
Representative soil physical properties including infiltration rate and available moisture content (after Israelson and Hansen. 1965. Irrigation Principles and Practices. John Wiley and Sons, Inc. N.Y.)

Soil Texture	Infiltration Rate*		Total Available Moisture	
	Average	Normal Range	Average	Normal Range
	inches/hour		*inches/foot of soil*	
Sand	2	1 - 10	1.0	0.8 - 1.2
Sandy loam	1	0.5 - 3	1.4	1.1 - 1.8
Loam	0.5	0.3 - 0.8	2.0	1.7 - 2.3
Clay loam	0.3	0.1 - 0.6	2.3	2.0 - 2.6
Silty clay	0.1	0.01 - 0.2	2.5	2.2 - 2.8
Clay	0.2	0.05 - 0.4	2.7	2.4 - 3.0

**intake rates can vary greatly with soil structure and structural stability, even beyond the normal ranges shown.*

GP 4.8 Adjust irrigation run distance to maximize irrigation efficiency.

The selection of the proper furrow length must account for actual water infiltration rates. These rates are determined by soil texture and condition, slope and the rate that water is applied to the furrow. Greater water application uniformity combined with decreased percolation and runoff will all be achieved when suitable irrigation run lengths are selected.

Shortening irrigation run length should be considered when field gradients contribute to excessive runoff, when coarse textured soils result in high infiltration rates and when land leveling is not an acceptable alternative. A reduction in field length can be achieved by either using gated irrigation pipe or by the construction of new irrigation ditches. These options involve varying installation, maintenance and labor costs.

GP 4.9 Adjust basin size or distance between border dikes to maximize irrigation efficiency.

Basin size and irrigation water delivery rates should be matched with the infiltration characteristics of specific soils used in graded border basin and dead level basin irrigation systems. In general, smaller basins and/or higher water delivery rates are required on increasingly permeable soils. The length of a basin also has a controlling influence on irrigation efficiency. Short, wide basins are more efficient than long, narrow ones. Some on-site calibration of the effect of basin size and water application rate on irrigation uniformity and efficiency will be required.

BMP 5. The application of irrigation water shall be timed to minimize nitrogen loss by leaching and runoff.

Irrigation water is applied to crop lands to replenish soil moisture reserves, leach excess salts, promote seed germination and stabilize soil against wind erosion. Therefore, after stand establishment and leaching, irrigation water applications should be timed to coincide with soil moisture depletion and crop need. Both over and under application of water can result in reduced or unproductive crop growth, lower yields and ultimately in smaller profits. Over application of irrigation water and excessive nitrogen fertilizer rates are the two most critical factors which result in leaching of nitrates below the crop root zone and subsequent contamination of groundwater (RANN Report. 1979. Nitrate in Effluents from Irrigated Lands. University of California, Riverside).

Applications of irrigation water should be timed to avoid excessive soil moisture depletion. Allowable depletions vary from about 20% for some vegetables to over 60% for cotton (Table 19).

GP 5.1. Schedule irrigation applications based on crop need.

Timely measurement or estimation of soil moisture content and/or crop water stress are needed to effectively schedule when irrigation is needed. Various devices and techniques are available to assist in determining when, and in some cases, how much irrigation water is required (Table 22). Regardless of the irrigation scheduling method that is used, some on-site calibration will be required for specific soils.

BMP 6. The operator shall use tillage practices that maximize water and nitrogen uptake by crop plants.

Various tillage and soil management practices can be used to improve water delivery into the root zone or allow for efficient and uniform distribution of irrigation water to a farm field. Four guidance practices which improve irrigation efficiency are discussed under BMP 4. Four additional practices are presented here which can be used to facilitate water movement into the crop rooting zone.

Increased permeability of soils to the downward movement of irrigation water has the potential to result in accelerated leaching of solutes, including nitrates, if the amount and/or frequency of irrigation events is excessive. Conversely, if irrigations are scheduled correctly, appropriate tillage practices will tend to promote optimum growing conditions for crop plants. Under these conditions the uptake of nutrients and water will be maximized and the potential for nitrate leaching losses will be minimized.

GP 6.1 . Use land leveling to adjust field gradients (see GP 4.7).

Table 22.
Irrigation scheduling techniques and devices available to facilitate measurement or estimation of soil moisture, crop canopy stress and crop water use.

Irrigation Scheduling Tools	Information Supplied	
	When to irrigate	How much to irrigate
Soil Moisture Measurement		
Feel and appearance	X	X
Soil tensiometers	X	X
Neutron probe moisture tester	X	X
Resistance moisture tester (e.g. gypsum block)	X	X
Gravimetric moisture testing	X	X
Check Book Methods		
Computer models	X	X
Crop Canopy Stress*		
Crop Water Stress Index (CWSI) using infrared thermometry	X	
Leaf water potential using a pressure bomb	X	
Visual crop appearance	X	
Evaporative Loss Estimation*		
Reference evapotranspiration (ETo)	X	
AZMET**	X	
Evaporation pan	X	
Historical comsumptive use	X	

**These methods primarily determine when to irrigate. By periodic calibration to actual soil moisture content, how much water to apply may also be calculated.*

***Refers to the Arizona Meteorological Network of the University of Arizona.*

GP 6.2. Adjust irrigation run distance to maximize irrigation efficiency (see GP 4.8).

GP 6.3. Angle irrigation furrows to reduce furrow slope (see GP 4.5).

GP 6.4. Install irrigation runs on the contour in fields with excessive slope (see GP 4.6).

GP 6.5. Rip soil in wheel row furrows.

Repeated equipment traffic through farm fields can result in serious compaction in wheel row furrows later in the season. This leads to reduced permeability in these areas and unequal water infiltration in traffic versus nontraffic rows. All soil types are subject to compaction, but particularly those soils which are high in silt and/or clay content. Wheel pressure on moist but not saturated soils will usually result in the greatest severity of compaction.

Mechanical disruption of soil compaction can be accomplished by inrow ripping. This involves inserting ripper shanks to the depth of the compacted soil and moving the shank horizontally along the length of the affected wheelrow. Inrow ripping is normally done in conjunction with other field operations such as cultivation or side dressing.

Care should be taken to avoid ripping to excessive depths. This practice may require excess energy and can impede the flow of irrigation water, damage root systems or cause excessive infiltration. In some crops, compaction of the furrow bottoms for the first several irrigations will actually improve irrigation efficiency. Under these conditions this practice is not recommended.

GP 6.6. Rip soils during land preparation to depths sufficient to disperse identified compaction zones.

Mechanical disruption of compacted surface and sub-soil horizons may be necessary for proper water infiltration and crop root development. Ripping, chiseling or deeper subsoiling can be used to disperse compaction resulting from previous equipment traffic. If uncorrected, soil compaction will result in poor water infiltration, inefficient water use and reduced crop productivity. Greater runoff from compacted soils can directly lead to an increased potential for groundwater contamination by nitrates if tailwater is not reused.

All soil types are subject to compaction, but particularly those soils which are high in silt and/or clay and low in organic matter content. Equipment traffic on moist but not saturated soils will usually result in the most severe compaction.

Preseason ripping should be done prior to furrowing and at right angles or diagonally to equipment traffic patterns in the previous season. The level of soil moisture is critical if subsoil ripping is to be effective. The soil should be moist enough to be workable but also dry enough to fracture and disperse compacted soil layers. *The need for soil ripping should be established by identifying compacted layers in the soil before performing the operation.* Unnecessary deep ripping will increase production costs for the expense of the tillage itself and for excessive amounts of water required for preplant irrigation. The application of soluble N fertilizers prior to deep ripping should be avoided if subsequent preplant irrigation will leach N below the expected depth of the root zone.

GP 6.7. Cultivate furrow irrigated crops.

The application of water to furrow irrigated fields will invariably lead to a slaking of soil aggregates and the formation of a surface crust within the furrow. This crusting forms a beneficial layer which helps reduce evaporation losses initially, but which also can dramatically reduce water infiltration rates in later irrigation events.

Cultivation is traditionally used for weed control. Cultivation just prior to an irrigation also mechanically mixes and aerates compacted or crusted soils in furrow irrigated fields. This practice will improve water infiltration and increase irrigation efficiency thereby reducing the potential for runoff and the associated leaching hazards of unused tailwater.

GP 6.8. Use preseason deep plowing.

The practice of mechanically inverting the surface 12 to 24 inches of soil can have several beneficial effects. First, it can redistribute nutrients which have been leached below the root zone of shallow rooted crops. Second, it can be used in place of shallow ripping or chiseling to disperse soil compaction occurring above the plow depth. Third, it can redistribute harmful concentrations of soluble salts or weed seeds which may have been present at the soil surface. And fourth, it could aid water movement by mixing stratified soil layers. Deep plowing can also stimulate early season microbial activity and the release of nutrients contained in organic residues previously incorporated.

Deep plowing of furrowed fields should be done after the furrows are disced down and when the soil contains enough moisture to be workable. Plow at right angles to previous equipment traffic patterns and at an angle to ripping patterns if the field was ripped prior to plowing.

Tractors with relatively high horsepower ratings are required for deep versus shallow plowing. The use of custom operators should be considered by growers who do not have equipment suitable for deep plowing.

Other Methods 7. Other methods to minimize nitrogen loss from leaching, runoff or backflow into irrigation wells.

Nine Guidance Practices are listed under Other Methods. Three are designed to limit seepage losses of irrigation waters, two protect well casings from contamination, one specifies cropping sequences to enhance recovery of soil nitrogen and two outline techniques for enhancing root zone aeration and crop uptake of water and nitrogen.

GP 7.1. Divert and confine irrigation runoff water into reuse systems.

Irrigation of farm fields with appreciable slope often leads to the accumulation of ponded tailwater at the bottom end of the field. The collection, storage and reuse of this runoff water can greatly decrease the potential for uncontrolled leaching of nitrates (or other soluble chemicals) which could occur beneath ponded tailwater.

The entire reuse system will include a storage reservoir or sump, a suitable pump, and a pipe and ditch system capable of delivering captured tailwater onto adjacent croplands. Heavy duty earth moving equipment and engineering assistance may be required for the proper design and construction of a tailwater reuse system. This includes an assessment of whether a sump at a particular site should be lined or sealed to minimize seepage losses.

Appreciable capital costs are often associated with the construction, operation and maintenance of an onfarm reuse system. For this reason this practice may not be applicable when the farm operator is not the land owner.

GP. 7.2 Line irrigation delivery ditches to reduce water losses.

Seepage and weed growth along unlined earthen irrigation ditches can result in significant water loss. In addition, seepage can directly contribute to the potential for dissolved nitrates to enter and pollute groundwater supplies. Lining ditches with concrete, plastic or other impermeable materials can significantly increase irrigation efficiency and reduce seepage losses.

The decision to line irrigation ditches will incur considerable capital costs particularly if concrete is used. The practice of lining ditches is most effective on loamy to sandy textured soils and is most feasible when the operator is the land owner. The applicability of other water conveyance structures such as pipelines should also be considered (see GP 7.3). Water run applications of nitrogen fertilizers should be avoided in unlined irrigation ditches.

GP 7.3 Install pipelines to convey irrigation water.

The installation of pipelines to carry irrigation water instead of using open canals can improve irrigation water utilization by decreasing water losses from seepage and evaporation. Reducing seepage losses can significantly lower the potential for leaching of nitrates and other pollutants into groundwater sources.

Proper equipment, construction materials, design and layout, and engineering assistance are all essential for the installation of an effective and low maintenance pipeline distribution system. The implementation of this management practice should be considered when the farm operator owns the cropland, when excessive seepage losses will or do occur from unlined water delivery systems, and when other types of surface conveyance are inefficient or unsuitable.

GP 7.4 Upgrade well design or condition.

Wells can act as direct conduits for pollutants into the groundwater when they are not properly completed or maintained or when they contain perforated and/or damaged casing segments. Pollution can occur when cascading flows from areas of upper casing damage and/or perforation or preferential flow down the casings of uncompleted wells carry pollutants into lower portions of the aquifer.

All wells should be properly completed prior to operation and then inspected periodically for evidence of damage or cascading flows. Inspections and needed repairs should be scheduled during off-season periods when possible. If cascading flows from upper level perforations occur, water tests for nitrate or other possible pollutants should be made to determine the potential for groundwater contamination and the necessity for implementing this management practice.

Onsite visual or audio well inspections can identify most problems which are associated with unacceptable well design or condition. Contact a suitable pump and well maintenance company for assistance in determining the condition of existing well casings and whether additional improvements are needed.

GP 7.5 Equip closed irrigation systems having chemical injection capabilities with appropriate antisiphon check valves.

Closed or pressurized irrigation systems such as trickle or sprinkler systems are routinely equipped with chemical injectors to apply soluble fertilizer solutions or other agricultural chemicals in the irrigation water; a practice known as chemigation. However, if unprotected by a suitable antisiphon system including check and relief valves, chemical injectors can also provide a means for backflow of pumped irrigation water when the pump is shut down. This flow of water passes down through the well casing and ultimately can reenter and pollute groundwater supplies.

A properly designed system should include the following components (Figure 21):

1) a check valve, to prevent reverse flow, and a vacuum relief valve in the irrigation line;
2) an inspection port or other device which permits monitoring of the performance of the check valve in the irrigation line;
3) an automatic low pressure drain, located between the main check valve and the irrigation pump such that water will drain away from the well casing or the water source being used;
4) a check valve in the chemical injection line; and
5) an interlocking device between the power supply for the chemical injector(s) and that of the irrigation pumping plant to insure that both units will shut off simultaneously.

GP 7.6 Equip transfer hoses on fertilizer nurse rigs with valves to prevent spillage.

The delivery end of all fertilizer nurse rig transfer hoses should be fitted with a suitable ball valve. The proper use of this valve will prevent spillage losses of about 3 to 5 gallons of fertilizer solution per transfer. In addition, a second in line ball valve should be installed on the nurse rig itself, between the tank and the point where the transfer hose is at-

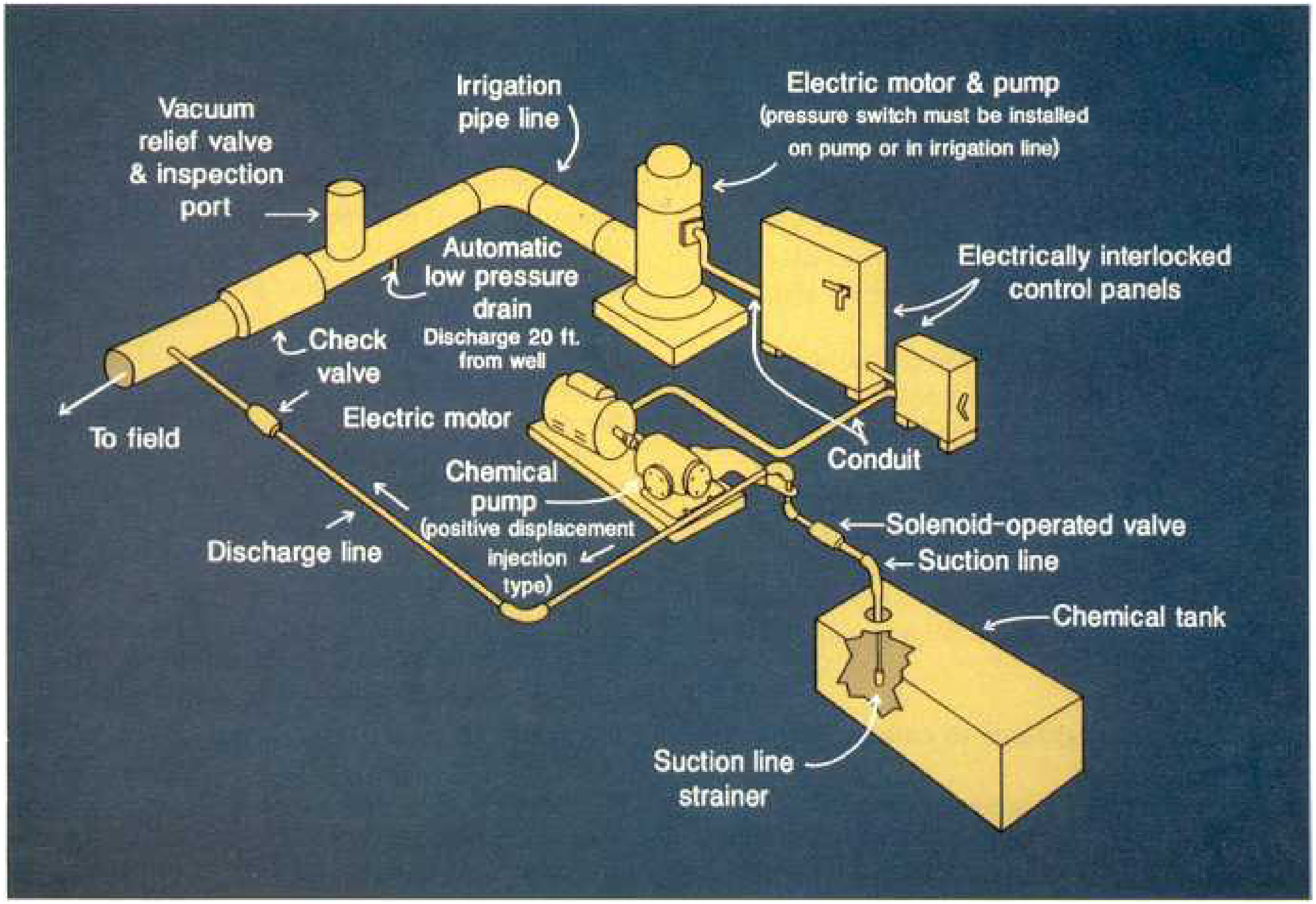

Figure 21.
An example of EPA-required antipollution devices and equipment arrangement for chemigation using a motor driven system (after: Doane's Agricultural Report. 1988. Chemigation Safety Requirements. Vol. 51, No. 19-6).

tached. Valves should be periodically checked for proper operation and/or leakage.

Contact your fertilizer or farm equipment dealer for assistance in obtaining suitable corrosion resistant ball valves for use with your fertilizer nurse rig. Fertilizer dealers who supply nurse rigs should equip them with the appropriate valves.

GP 7.7 Follow shallow rooted crops with deep rooted crops in crop rotation.

Many shallow rooted crops are high value vegetable and specialty crops which receive high rates of nitrogen fertilizer. Some of this nitrogen may be leached below their effective rooting zone but could still be utilized by succeeding crops with deeper root systems (see Table 16). The use of deep rooted crops following shallow rooted crops can increase nitrogen fertilizer use efficiency and reduce the potential for nitrate contamination of groundwater via leaching.

Rooting depth and nitrogen recovery are not the only factors affecting the choice of a cropping sequence or rotation. Other considerations including herbicide use restrictions, market demand and the availability of labor and farm equipment must also be evaluated.

GP 7.8 Practice soil aeration in turf areas.

Aeration is an indispensable turf management technique which can improve turf growth in many ways. Aeration reduces compaction in the surface soil layer thereby increasing oxygen availability to roots and improving water infiltration. Some aeration techniques can also mechanically reduce thatch accumulation. By improving the growing environment for turf, aeration can improve nitrogen fertilizer use efficiency and reduce the potential for ponding of irrigation water and subsequent leaching into groundwater supplies.

Various techniques are available to mechanically improve soil aeration in permanent turf plantings where more conventional tillage or cultivation is not possible. In general, soil aeration is accomplished by either slitting the soil surface or removing soil cores. Other management techniques such as topdressing with sand or soil amendments, mowing and dragging - together or separately, can be used in conjunction with aeration to further improve physical properties of the soil or to restore an aesthetically pleasing appearance to the turf surface. Aeration can be performed at any time during the year but greatest benefits are obtained in the spring and summer growing season.

GP 7.9 Apply amendments which contribute soluble calcium to sodic soils and irrigation water.

Soils in arid and semiarid regions commonly contain high concentrations of adsorbed sodium (Na). This results in poor soil structure, sealing of the soil surface when wetted, low water infiltration rates and low crop productivity. In addition, soils irrigated with high sodium water will also become increasingly sodic over time. A number of chemical and organic soil amendments can be used to remove unwanted sodium from sodic soils. Likewise, the application of various soluble chemicals to irrigation water can offset the adverse effects of high sodium levels they may contain. The proper use of soil and water amendments can significantly increase water infiltration and irrigation efficiency while lowering water costs and runoff from croplands. Improved conditions for crop growth and reduced runoff can increase nitrogen uptake efficiency and reduce the potential for nitrate contamination of groundwater by leaching.

- **Reclaiming Sodic Soils**

The first step in reclaiming a sodic soil is to measure the extent of sodium saturation using a soil test for exchangeable sodium percentage, or ESP. The recommended procedure is to measure the sodium, calcium and magnesium concentrations in a saturated paste extract and then calculate ESP using the following two equations (from Richards, 1954. Diagnosis and Improvement of Saline and Alkali Soils, USDA Agriculture Handbook 60):

Eq. 10

$$\text{Sodium Adsorption Ratio (SAR)} = [Na^{+}] / \sqrt{([Ca^{+2}] + [Mg^{+2}])/2}$$

NOTE: Na, Ca and Mg are expressed as milliequivalents per liter (meq/L).

$$\text{ESP} = \frac{100\,(-0.0126 + 0.01475\ \text{SAR})}{1 + (-0.0126 + 0.01475\ \text{SAR})} \qquad \text{Eq. 11}$$

The interpretation of ESP values depends on the soil texture and is summarized in Table 23.

Table 23.
Interpretation of exchangeable sodium percentage (ESP) values in soils of varying texture.

Soil Texture	Sodium Hazard in Soil		
	None	Moderate	Severe
		ESP (%)	
Sandy loam	0 - 12	13 - 20	>20
Silt loam	0 - 10	11 - 15	>15
Clay loam	0 - 7	8 - 12	>12

When a moderate to severe sodium hazard exists and water penetration is poor then an application of a soil amendment should be considered. Organic amendments such as animal manures or plant residues are helpful in improving the physical condition of soil for absorbing irrigation waters. Repeat applications of these materials over several years may be required to fully reclaim a sodic soil. However, these organic amendments are not effective if the soil is continually irrigated with high sodium water. The use of organic soil amendments is discussed under GP 1.3

In most cases, sodic soils are reclaimed by using chemical amendments which displace sodium from the surfaces of soil particles. The amendments most commonly used in Arizona are listed in Table 24. Soluble sodium compounds are then leached below the root zone with applications of supplemental irrigation water. The amendment used most in Arizona is gypsum ($CaSO_4 \bullet 2H_2O$). Gypsum directly supplies the soluble calcium which takes part in the sodium displacement reaction. Gypsum reacts with sodic soils as follows:

Eq. 12

$$\text{gypsum + sodic soil} > \text{calcium soil} + \underset{\substack{\text{sodium sulfate}\\ \text{(leachable)}}}{Na_2SO_4}$$

Other commonly used amendments contain acidifying compounds which react with naturally occurring calcite ($CaCO_3$) or "free lime" in the soil to release soluble calcium. The most common such materials are elemental sulfur, sulfuric acid, ammonium polysulfide and calcium polysulfide (lime-sulfur). These compounds are effective only on sodic soils which contain calcite and react as follows:

- **Oxidation of sulfur**

Eq. 13

$$\underset{\text{sulfur}}{S} + \underset{\text{oxygen}}{\frac{3}{2}O_2} + \underset{\text{water}}{H_2O} \xrightarrow[\text{microbes}]{} \underset{\text{sulfuric acid}}{H_2SO_4}$$

- **Neutralization of sulfuric acid**

Eq. 14

$$\underset{\text{sulfuric acid}}{H_2SO_4} + \underset{\text{calcite}}{CaCO_3} \rightarrow \underset{\text{gypsum}}{CaSO_4} + \underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O}$$

Table 24.
Commonly used soil amendments and their chemically equivalent values.

Amendment	Chemical Formula	Rate Equivalent to 1 Ton of Pure Gypsum
Gypsum	$CaSO_4 \bullet 2H_2O$	2000 lbs.
Ammonium polysulfide	NH_4S_x	950 lbs.* 98 gal.*
Sulfuric acid	H_2SO_4	1220 lbs.
Sulfur	S	380 lbs.
Lime sulfur (22% S)	CaS_x	1360 lbs.

**reflects S content only*

Sulfuric acid reacts with the soil immediately while the microbial oxidation of sulfur takes several weeks or even months to occur. The fineness of soil applied sulfur materials is critical and products with individual particle sizes of <100 mesh are recommended. Materials with coarser particles will react much more slowly with the soil. Finally, the gypsum formed when sulfuric acid reacts with calcite reclaims a sodic soil in the same manner shown in Equation 12.

The rate of material needed depends on the specific amendment that is used, the degree of sodium saturation in the soil and the purity of the amendment. A typical application rate is 1 to 2 tons of gypsum per acre or equivalent amounts of the

Table 25.
Expected restriction in the rate of irrigation water infiltration based on salinity and the sodium adsorption ratio of various water sources. (after Ayers and Westcot, 1985. Water Quality for Agriculture, FAO, United Nations).

Irrigation Water Quality		Degree of Infiltration Restriction		
Salinity	(EC$_{w}^{*}$	None	Moderate	Severe
dS/m*	ppm	SAR		
0 - 0.5	0 - 320	—**	0 - 6	> 6
0.5 - 1	320 - 640	0 - 3	3 - 12	> 12
1 - 2	640 - 1280	0 - 7	7 - 17	> 17
> 2	> 1280	0 - 15	15 - 25	> 25

**electrical conductivity of the water.*

***very low electrolyte water may cause reduced infiltration in soils as a result of removing beneficial calcium and magnesium salts from the surface and causing dispersal of surface soil particles and crusting.*

other amendments listed in Table 24. Greater rates for highly sodic soils and lower maintenance application rates under marginally sodic conditions may also be warranted.

- **Treating Sodic Water**

Irrigation water which is high in sodium or very low in total salt content may exhibit low infiltration rates into cultivated soils. The expected restriction in water infiltration is related to the salinity level and SAR of the water as summarized in Table 25.

The addition of soluble calcium compounds to sodic or very low salinity water can effectively increase water infiltration rates, particularly on heavier textured soils. Gypsum, calcium nitrate and calcium chloride are all effective materials when properly applied. The rate of material to apply will depend on the quality of the water. An initial water test for salinity, calcium, magnesium and sodium is required to calculate the proper rate of water amendment to use. Typical rates are about 100 to 300 lbs. of pure gypsum per acre-foot of water.

In most cases specialized equipment is required to accurately inject or meter soluble calcium solutions into irrigation water. Contact your Cooperative Extension agent, soils specialist, agricultural fieldman/consultant or amendment distributor for assistance in selecting appropriate amendments, rates and methods of application for your specific soil and water conditions. A computer program entitled *WATERTST* interprets water analysis data for many water quality properties including gypsum requirement. The program is available from The University of Arizona, Cooperative Extension.

Section III:

Nitrogen Management Guides for Individual Crops

Alfalfa

Nitrogen applications are rarely needed in alfalfa production in Arizona. Alfalfa is a legume which normally derives most of its nitrogen requirement from Rhizobia bacteria located in nodules on the roots. These bacteria convert atmospheric nitrogen into forms of organic nitrogen, a process known as fixation. The primary problems with nitrogen applications to alfalfa are stimulation of weed growth, reduced nodulation, and reduced effectiveness of nodules in "fixing" of nitrogen.

- **New seedings**

All alfalfa seed can be inoculated immediately before seeding to insure an adequate population of nitrogen-fixing bacteria. A fresh, effective, live culture of Rhizobia should be used. Carefully observe the expiration date marked on the culture as well as all label directions. The most effective way to inoculate seed involves the use of sticking compounds which hold the bacteria culture on the surface of the seed and protect it from desiccation. Hard seed coats may require scarification to enhance the effectiveness of the sticker materials. Preinoculated seed may also be used but can produce poor results depending on seed storage conditions and the length of time between treatment and planting.

There may be enough effective bacteria remaining in the soil of fields where alfalfa has recently been grown for successful inoculation of new seedlings. However, the total cost of inoculation is small and can be viewed as cheap insurance against poor crop performance.

If a soil test for NO_3-N taken prior to planting is below 15 ppm then an application of up to 15 to 25 lbs. N per acre may be beneficial. Nitrogen should be broadcast and incorporated into the seedbed or applied in the irrigation water immediately after planting.

- **Established stands**

Nitrogen applications to established alfalfa stands in Arizona under experimental conditions have not increased yields when less than 20 tons of dried hay per acre are harvested per year. Applications exceeding 20 to 30 lbs. N per acre may reduce the effectiveness of existing root nodules and increase the dependence of the plant on mineral (fertilizer) nitrogen forms. Application of irrigation water as soon as possible after cutting is probably the most critical factor in achieving rapid regrowth of alfalfa.

- **Plant tissue analysis**

The total nitrogen content in the whole above-ground plant, sampled at 1/10th bloom should exceed 2.5 and preferably 3.0%.

- **Nutrient removal**

A harvest of 10 tons of dry alfalfa hay per acre per year will contain about 500 lbs. nitrogen.

Apples

- **Young trees**

Adequate supplies of nitrogen are needed to promote rapid growth and development of young nonbearing trees. Optimum terminal growth should be 20 to 36 inches annually. One and two-year old trees may be injured if N is banded around the tree. Use Table 26 as a guide to N applications to young apple trees.

Table 26.
Suggested nitrogen application rates for apple trees in the first seven years after orchard establishment.

Tree Age	N Application Rate
	lbs./acre
1	None to 25
2	25 - 50
3 - 5	25 - 75
6 - 7	40 - 100

Nitrogen should be applied in late winter to early spring but not after June 1. Nitrogen should be applied directly in the irrigation water or else placed such that water movement will carry soluble N into the root zone.

- **Mature orchards**

The overall vigor of the tree and appearance of the leaves are the best indication of nitrogen status. Annual terminal growth should be 10 to 14 inches.

Determination of the N concentration in leaves from current season growth can also be useful in estimating tree N status. Samples should be collected between July 1 and August 1 from leaves which are free of insect, disease or mechanical damage. Collect leaves from several sides of the main tree but avoid sampling from suckers or water sprouts. Do not collect more than two leaves per shoot and select leaves from the middle of the current season growth (Figure 22). Sample so that the petiole remains attached to the leaf blade. Collect about 100 leaves from randomly selected trees within the block to be tested.

Tree vigor and leaf N value must be considered together to make a meaningful assessment. Above normal vigor and high leaf N indicate over fertilization with N. Below normal leaf N and poor vigor indicate a nitrogen deficiency. Above normal leaf N and low vigor suggest that another factor is limiting tree growth. Low leaf N and high vigor can occur on trees with poor fruit set.

Table 27.
Interpretation of nitrogen levels in apple leaf tissue samples. Somewhat higher leaf N levels may be needed for Granny Smith trees.

Leaf Tissue Nitrogen Content	Nitrogen Status
%	
Below 2	Deficient
2 - 2.5	Adequate
Above 2.5	Excess

Excess N can result in poor quality, increased incidence of bitter pit and late-coloring in nonspur reds. Reduce N rates where trees are crowding and pruning is required to restrict tree size.

The annual nitrogen requirement for mature, low density orchards ranges from none to about 2 lbs. N per tree. Higher density plantings require less N per tree but have similar requirements per acre.

Use caution when applying all-ammonium (NH_4^+) N sources such as anhydrous ammonia, aqua ammonia and ammonium sulfate to spur-type Red Delicious apples grown on noncalcareous, or acidic soils. These N forms can accentuate manganese (Mn) uptake resulting in Mn toxicity, also referred to as apple measles.

Foliar applications of low (<2%) biuret urea may be used to supplement soil applications of N. To reduce the potential for tree injury do not use rates over 3 to 5 lbs. of urea per 100 gallons of water, or more than 10 to 20 lbs. urea per acre.

The timing and method of N applications which are best for mature trees are the same as presented above for young trees.

- **Nutrient removal**

A harvest of 800, forty-pound boxes of apples per acre will contain about 25 lbs. N.

Figure 22.
Collect leaf tissue samples for nutrient analysis during the month of July. Sample whole leaves from the middle of the current season growth as shown above.

Asparagus

The level of nitrogen fertility has more influence on the growth and yield of asparagus than any other single plant nutrient because it is the nutrient most often deficient in Arizona soils. With good management, a total of about 300 to 350 lbs. N per acre is usually needed for optimum production on established fields. Fern tissue analysis during the season can be very useful in monitoring the nitrogen status of the crop. Deficiencies of nitrogen at any time in the season are to be avoided, as yields will usually be reduced. Water and nitrogen must be managed carefully, as excessive applications of irrigation water have been shown to reduce the efficiency of nitrogen fertilizers due to leaching of nitrogen below the rooting zone. Adequate nitrogen fertility also contributes to higher spear production early in the harvest season when market prices are often the most favorable.

Fertilizer recommendations given below apply to all adapted varieties grown in Arizona and are based on an initial crown population of 20,000 per acre and a yield potential of 8,000 to 12,000 lbs. per acre. Rates may need to be adjusted for significantly different plant populations or yield goals or if stands are established by direct seeding or using containerized transplants.

- **New plantings**

New asparagus crowns are normally planted in the spring with no harvest taken in the first year and limited cutting in the second season. A total of about 200 to 300 lbs. N per acre is recommended during each of the first two growing seasons. Nitrogen should be applied in four or more equal applications beginning at planting time in the first year or at the end of the harvest period in the second year.

- **Established fields**

Nitrogen should be applied in four or more roughly equal amounts beginning at the end of the harvest period. Analysis of the total nitrogen content of recently mature fern tissue sampled between mid-May through mid-September is a good indicator of the nitrogen status of the crop. The recently matured fern tissue in the top 12 inches of new fern growth should be sampled. This can be accomplished by harvesting the top 12 inches of fern and then removing and discarding the uppermost 4 inches of immature growth (Figure 23). The tissue analyzed consists of the leaflets or "needles" only. These can be easily separated from the stems by drying the sample at 150° F (65°C) for 24 to 48 hours and then shaking or stripping the needles. Samples should be refrigerated if immediate oven-drying is not possible.

The fern sample should then be submitted to a laboratory for total Kjeldahl nitrogen analysis. Do not sample ferns which are diseased, damaged or unrepresentative. About 25 to 50 ferns per sample are adequate for analysis. The number of samples tested from each field depends on the uniformity of the field. Samples should be collected from randomly selected plants within uniform areas representing portions of a field that can be fertilized separately. Samples should be taken at one month intervals throughout the fern growing season. Applications of nitrogen should be stopped about 4 to 6 weeks before dormancy is induced by termination of irrigation in the fall.

- **Interpretation of fern nitrogen levels**

The nitrogen content of the fern tissue is normally high (with adequate soil fertility) early in the season during the initial flush of vegetative growth. Levels will drop during mid-summer when fruiting and seed production take place. Subsequent flushes of fern growth in the early fall will normally result in a corresponding increase in fern nitrogen content. Desirable levels of total nitrogen in fern tissue are shown in Table 28 and Figure 24.

Table 28.
Desirable levels of total Kjeldahl nitrogen in asparagus fern tissue at various times during the growing season.

Date	Desirable Levels of Fern Total N
	%
May 20	3.5
June 20	3.6
July 20	2.7
August 20	2.6
September 20	3.0

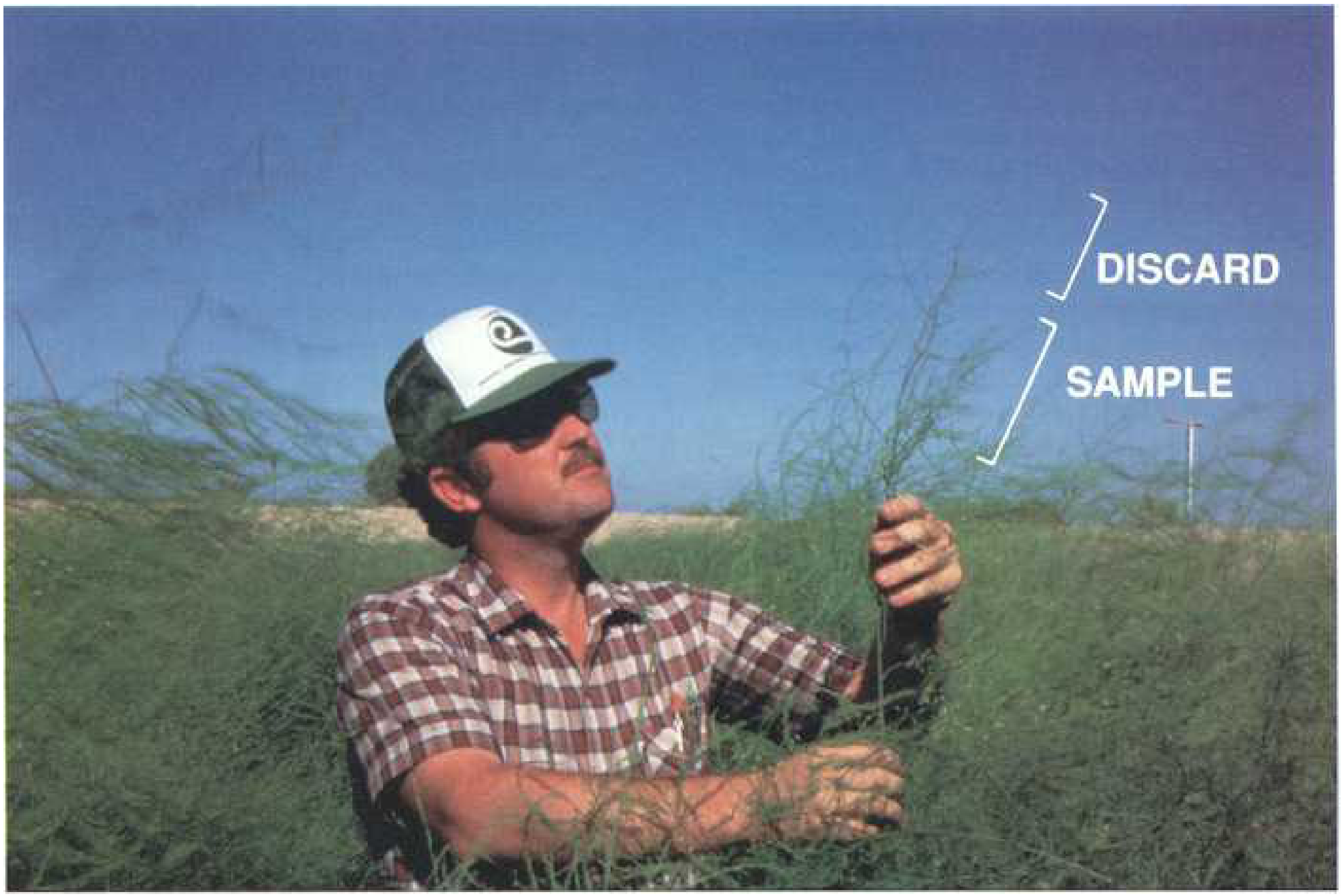

Figure 23.
Sample recently mature fern tissue throughout the fern growing season from the top 12 inches of new fern growth. Then discard the uppermost four inches of immature growth.

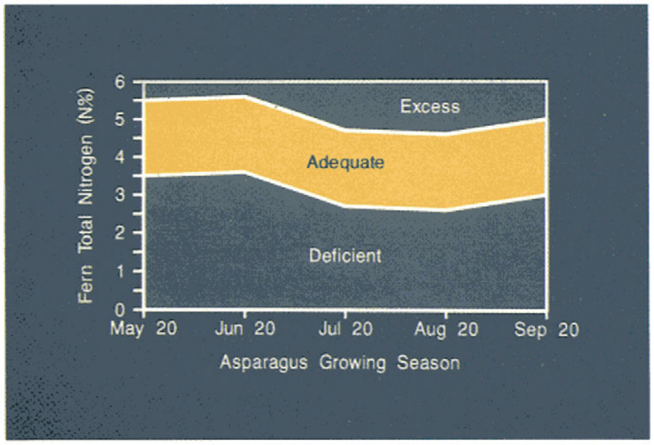

Figure 24.
Interpretation of total nitrogen in asparagus fern tissue at different times during the growing season.

Applications of nitrogen fertilizer should be made to maintain fern nitrogen levels in the "Adequate" portion of the graph. The form of nitrogen fertilizer applied is generally not of great importance as long as a consistent and adequate supply of nitrogen is maintained throughout the growing season. Caution should be used when applying ammonium (NH_4) sources of nitrogen such as anhydrous or aqua ammonia in order to avoid plant injury from ammonia toxicity, especially on very sandy soils.

- **Nutrient removal**

A harvest of 8000 lbs. of asparagus spears per acre will contain about 40 lbs. N.

Broccoli

The level of nitrogen fertility has more influence on the growth and yield of broccoli than any other single plant nutrient because it is the nutrient most often deficient in Arizona soils. With good management, a total of about 175 to 225 lbs. N per acre is usually needed for optimum production. Preplant soil analysis and leaf midrib analysis during the season can be very useful in monitoring the nitrogen status of the crop. Deficiencies of nitrogen at any time in the season are to be avoided, as yields will usually be reduced. Deficiencies after the initiation of bud formation are especially serious, as nitrogen applications after this stage may not completely correct the problem.

Fertilizer recommendations in this guide apply to all broccoli varieties grown in Arizona and are based on a plant population of 30,000 to 35,000 plants per acre and a yield potential of 5 to 7 tons per acre. Rates may need to be adjusted for significantly different plant populations or yield goals.

- **Early season nitrogen**

Preplant applications of 40 to 60 lbs. N per acre on fine-textured soils (clay loams and silty clay loams) and 0 to 40 lbs. N per acre on coarse-textured soils (sands and sandy loams) are generally required. Preplant applications of nitrogen on very sandy soils are usually inefficient because nitrogen is easily leached below the root zone of young plants. Use the lower rates if there is a high residual nitrogen level in the plow layer of soil (i.e. above 15 ppm NO_3-N). About one-half of the total nitrogen applied to the crop should be applied during the first five to seven weeks after stand establishment.

- **Mid-season nitrogen**

At the four- to six-leaf stage of growth (45 to 50 days after seeding) collection of leaf midrib samples for nitrate (NO_3-N) analysis should begin. The thick midrib from the center of the youngest full-sized leaves should be separated from the leaf blade (Figure 25). Be sure to include the stem connecting the leaf blade to the main stalk with the midrib sample. Do not sample midribs from diseased, damaged or unrepresentative leaves. On older plants, sample midribs from the youngest full-sized leaves. These are typically the "easiest" leaves to sample. About 25 to 50 midribs per sample are adequate for analysis, depending upon the size of the leaves at the time of collection. The number of samples tested from each field depends on the uniformity of the field. Samples should be collected from randomly selected plants within uniform areas representing portions of a field that can be fertilized separately. Samples should be taken at one- to two-week intervals throughout the season. Samples should be placed in a paper bag and dried at about 150°F (65°C) or refrigerated as soon as possible and submitted to a laboratory for NO_3-N analysis.

- **Interpretation of midrib nitrate levels**

The midrib nitrogen level is normally high (with adequate soil fertility) early in the season during vegetative growth and declines as the season progresses. Desirable levels of nitrate-N are shown in Table 29 and Figure 26.

A timely application of nitrogen fertilizer can prevent or slow the decline of midrib nitrate. If the nitrate-N level is below 5,000 ppm NO_3-N prior to the "first bud" stage, then application of a nitrate or urea source is recommended. These forms of N move readily in soil solution and are immediately available to the plant roots with the first irrigation after the fertilizer has been applied. This decreases the time necessary for recovery from a nitrogen deficiency. At higher levels of midrib nitrogen, the nitrogen source is of less importance because nitrification of ammonium (NH_4) sources can take

Figure 25.
Begin sampling broccoli midribs at the 4- to 6-leaf stage. Collect the midribs from the youngest full-sized leaves are shown above.

Table 29.
Desirable levels of nitrate-nitrogen in broccoli midribs at various stages of growth.

Stage of Broccoli Growth	Approximate Days After Planting	Desirable Levels of Midrib NO_3-N
		ppm
4 to 6 Leaves	45 - 50	10,000
10 to 12 Leaves	60 - 65	9,000
First Bud	70 - 80	6,000
Head Development	80 - 90	3,500
Pre-harvest	100 - 105	2,000

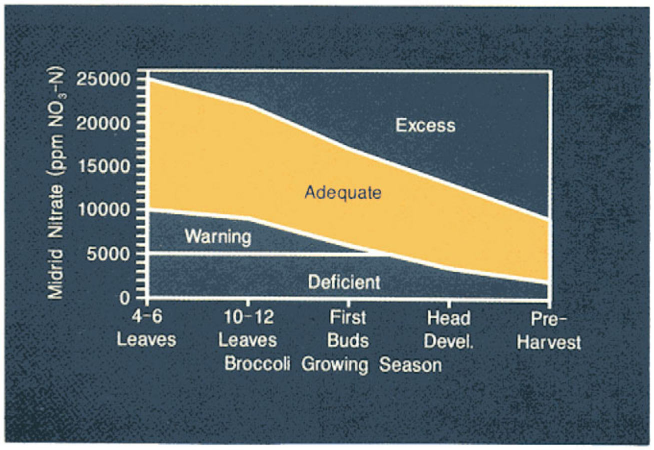

Figure 26.
Interpretation of nitrate-nitrogen levels in broccoli midribs at different stages of growth.

place rapidly enough to permit the resulting NO_3 to be moved into the root zone to supply the needs of the plants. Caution should be used when applying ammonium sources of nitrogen such as anhydrous or aqua ammonia in order to avoid plant injury from ammonia toxicity, especially on very sandy soils.

- **Nutrient removal**

  A harvest of 5 tons of broccoli spears per acre will contain about 90 lbs. N. The entire crop will contain between 250 to 300 lbs. N per acre.

- **Nitrogen uptake patterns**

  Uptake of nitrogen by broccoli is very low prior to the 4- to 6-leaf stage. Nitrogen flux increases to a maximum at the first buds stage, exceeding 8 lbs./acre/day for high yielding sites. Then, because broccoli is harvested prior to entering its reproductive growth stages, nitrogen uptake remains high until harvest.

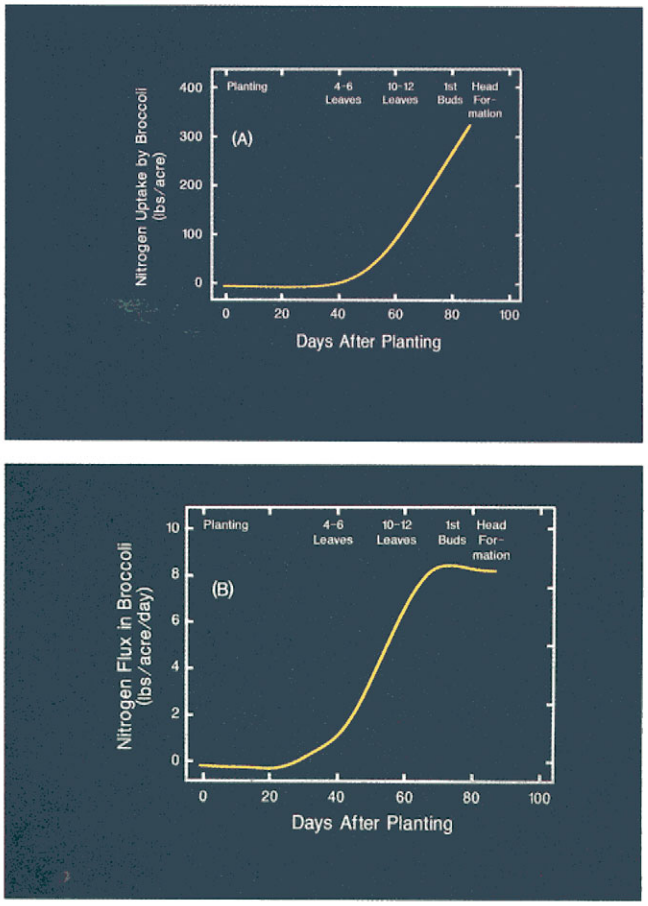

Figure 27.
Cumulative seasonal nitrogen uptake (A) and daily nitrogen flux (B) patterns for Excaliber broccoli at a yield level of 6.8 tons per acre.

Cabbage

The level of nitrogen fertility has more influence on the growth and yield of cabbage than any other single plant nutrient because it is the nutrient most often deficient in Arizona soils. With good management, a total of about 175 to 225 lbs. N per acre is usually needed for optimum production. Preplant soil analysis and leaf midrib analysis during the season can be very useful in monitoring the nitrogen status of the crop. Deficiencies of nitrogen at any time in the season are to be avoided, as yields will usually be reduced. Deficiencies after the initiation of head formation, called "folding," are especially serious, as nitrogen applications after this stage may not completely correct the problem.

Fertilizer recommendations in this guide apply to all regular cabbage varieties grown for either fresh market or processing, and are based on a plant population of 25,000 to 30,000 plants per acre and a yield potential of 35 to 40 tons per acre. Rates may need to be adjusted for significantly different plant populations or yield goals. Somewhat different fertilizer rates may be needed for other varieties, such as Chinese cabbage and red cabbage.

- **Early season nitrogen**

Preplant applications of 40 to 60 lbs. N per acre on fine-textured soils (clay loams and silty clay loams) and 0 to 40 lbs. N per acre on coarse-textured soils (sands and sandy loams) are generally required. Preplant applications of nitrogen on very sandy soils are usually inefficient because nitrogen is easily leached below the root zone of young plants. Use the lower rates if there is a high residual nitrogen level in the plow layer of soil (i.e. above 15 ppm NO_3-N). About one-half of the total nitrogen applied to the crop should be applied during the first five to seven weeks after stand establishment.

- **Mid-season nitrogen**

At the four- to six-leaf stage of growth (45 to 50 days after seeding), collection of leaf midrib samples for nitrate (NO_3-N) analysis should begin. The thick midrib from the center of the youngest full-sized leaves should be separated from the leaf blade (Figure 28). Do not sample midribs from diseased, damaged or unrepresentative leaves. On older plants, sample midribs from the youngest full-sized wrapper leaves. These are typically the "easiest" to sample. About 25 to 50 midribs per sample are adequate for analysis, depending upon the size of the leaves at the time of collection. The number of samples tested from each field depends on the uniformity of the field. Samples should be collected from uniform areas representing portions of a field that can be fertilized separately. Samples should be taken at one- to two-week intervals through heading. Samples should be placed in a paper bag and dried at about 150°F (65°C) or refrigerated as soon as possible and submitted to a laboratory for NO_3-N analysis.

Figure 28.
Begin sampling cabbage midribs at the 4- to 6-leaf stage. Collect the midribs from the youngest full-sized leaves as indicated above.

- **Interpretation of midrib nitrate levels**

The midrib nitrogen level is normally high (with adequate soil fertility) early in the season during vegetative growth and declines as the season progresses. Desirable levels of nitrate-N are shown in Table 30 and Figure 29.

A timely application of nitrogen fertilizer can prevent or slow the decline of midrib nitrate. If the nitrate-N level is below 5,000 ppm prior to the "folding" stage, then application of a nitrate or urea source is recommended. These forms of N move readily in soil solution and are immediately available to the plant roots with the first irrigation after the fertilizer has been applied. This decreases the time necessary for recovery from a nitrogen deficiency. At higher levels of midrib nitrogen, the nitrogen source is of less importance because nitrification of

Table 30.
Desirable levels of nitrate-nitrogen in cabbage midribs at various stages of growth.

Stage of Cabbage Growth	Approximate Days After Planting	Desirable Levels of Midrib NO_3-N
		ppm
4 to 6 Leaves	45 - 50	11,000
10 to 12 Leaves	60 - 65	8,000
Folding	75 - 80	6,000
Early Heading	90 - 95	4,000
Pre-harvest	100 - 105	3,000

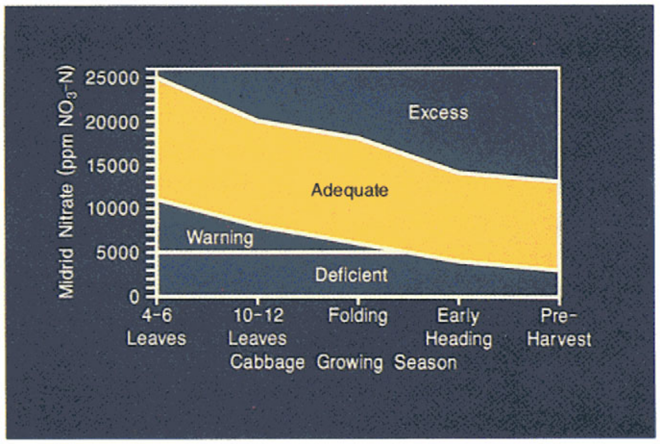

Figure 29.
Interpretation of nitrate-nitrogen in cabbage midribs at different stages of growth.

ammonium (NH_4) sources can take place rapidly enough to permit the resulting NO_3 to be moved into the root zone to supply the needs of the plants. Caution should be used when applying ammonium sources of nitrogen such as anhydrous or aqua ammonia in order to avoid plant injury from ammonia toxicity, especially on very sandy soils.

- **Nutrient removal**

  A harvest of 20 tons of cabbage heads per acre will contain about 185 lbs. N. The entire crop will contain about 220 lbs. N per acre.

- **Nitrogen uptake patterns**

  Nitrogen uptake is very low prior to the 10 to 12 leaf stage. By the folding stage, nitrogen flux increases to a maximum of almost 6 lbs. per acre per day. Then because cabbage is harvested before the crop enters reproductive growth, nitrogen uptake remains moderately high until harvest time.

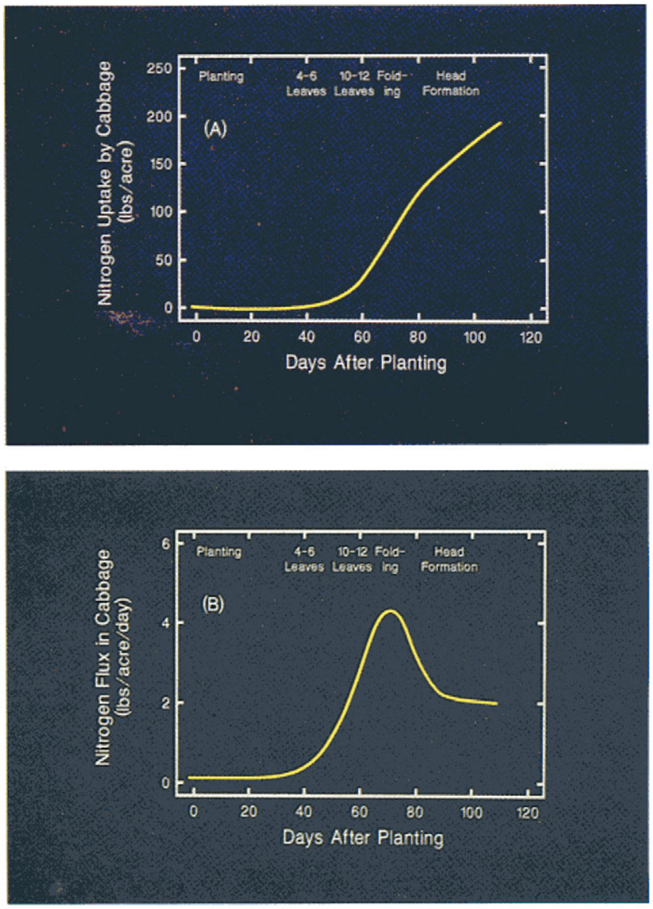

Figure 30.
Cumulative seasonal nitrogen uptake (A) and daily nitrogen flux (B) patterns for Moran Hybrid cabbage at a yield level of 35 tons per acre.

Cantaloupe

The level of nitrogen fertility has more influence on the growth and yield of cantaloupe than any other single plant nutrient because it is the nutrient most often deficient in Arizona soils. With good management a total of about 70 to 150 lbs. N per acre is usually needed for optimum production.

Preplant soil analysis and leaf petiole analysis during the season can be useful in monitoring the nitrogen status of the crop. Deficiencies of nitrogen at any time of the season are to be avoided, as marketable yield, melon netting and general plant vigor and appearance will usually suffer. Deficiencies after fruits are 2 to 4 inches in diameter are especially serious, as nitrogen applications after this stage may not completely correct the problem.

Fertilizer recommendations in this guide apply to all cantaloupe varieties grown in Arizona and are based on a plant population of 5000 to 7000 plants per acre and a yield potential of 20 to 30 tons per acre. Rates may need to be adjusted for significantly different plant populations or yield goals.

- **Early season nitrogen**

Preplant applications of nitrogen are not often required since early season uptake of N prior to the early runner stage is very low. If the soil test value for NO_3-N taken before planting is below 10 ppm then apply 50 lbs. N per acre. Nitrogen should be broadcast on the soil surface just prior to listing and shaping of the melon beds.

- **Mid-season nitrogen**

At the 3- to 4-leaf stage of growth, collection of leaf petioles for nitrate analysis should begin. The petiole (leaf stem) from the youngest full-sized leaves should be sampled. This is normally the third or fourth leaf from the end of a vine (Figure 31). Do not sample petioles from diseased, damaged or unrepresentative leaves. About 25 to 50 petioles per sample are adequate for analysis. The number of samples tested from each field depends on the uniformity of the field. Samples should be collected from randomly selected plants within uniform areas representing portions of a field that can be fertilized separately. Samples should be placed in paper bags and dried at about 150° F (65°C) or refrigerated as soon as possible and submitted to a laboratory for NO_3-N analysis. Petioles should be collected at the 3- to 4-leaf, early runner, 2-inch melon and full-size melon stages.

- **Interpretation of petiole nitrate levels**

The petiole nitrate level is normally high (with adequate soil fertility) early in the season during vegetative growth and declines as the season progresses. The interpretation of petiole nitrate values and corresponding midseason fertilizer applications are shown in Table 31 and Figure 32.

Petiole nitrate concentrations should be maintained above 4000 ppm NO_3-N throughout the season. Visual symptoms of N deficiency such as pale green foliage or reduced vine growth appear when the petiole nitrate concentration falls below about 2000 ppm NO_3-N. This should be avoided as some reduction in yield will probably occur even if the deficiency is corrected. No losses of yield or quality have been observed when high rates of N fertilization have resulted in excessive levels of petiole NO_3-N.

Applications of N after melons have reached full size but before harvest will be of little or no help in correcting a nitrogen deficiency late in the season. This is because N uptake falls very rapidly once melons have reached their full size. In addition, ammonium forms of N applied at this time will be adsorbed on soil particles at the point of application and will remain positionally unavailable to plant roots.

If the nitrate-N level is below 4,000 ppm NO_3-N then application of a nitrate or urea source is recommended. These forms of N move readily in soil solution and are immediately available to the plant roots with the first irrigation after the fertilizer has been applied. This decreases the time necessary for recovery from a nitrogen deficiency. At higher levels of petiole N, the nitrogen source is of less importance because nitrification of ammonium (NH_4) sources can take place rapidly enough to permit the resulting NO_3 to be moved into the root zone to supply the needs of the plants. Caution should be used when applying ammonium sources of nitrogen such as anhydrous or aqua ammonia in order to avoid plant injury from ammonia toxicity, especially on very sandy soils.

Figure 31.
Begin collecting cantaloupe petioles at the 3- to 4-leaf stage, sampling the youngest full-sized leaf. Once runners begin to form, this is usually the third or fourth leaf from the end of the vine as shown above.

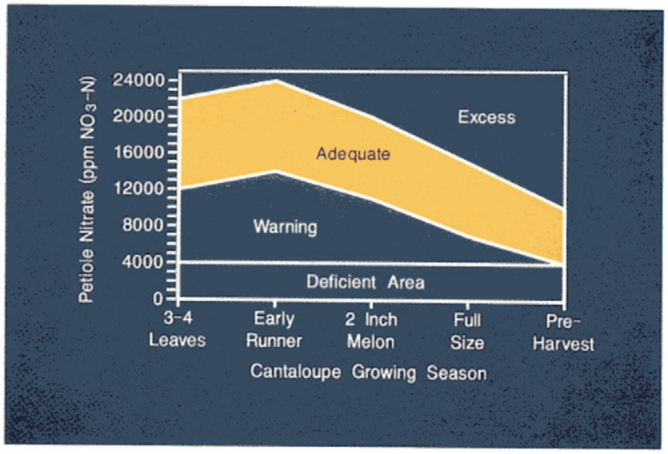

Figure 32.
Interpretation of nitrate-nitrogen in cantaloupe petioles at different stages of growth.

- **Nutrient removal**

  A harvest of 20 tons of cantaloupes per acre contains about 50 to 60 lbs. N. The entire crop will contain about 90 lbs. N per acre.

- **Nitrogen uptake patterns**

  Nitrogen uptake in cantaloupes is very slow prior to the early runner stage. Nitrogen flux increases rapidly as melons begin to form and reaches a maximum as fruits approach full-size. Very little N is taken up after this point.

Table 31.
Interpretation of NO_3-N levels in cantaloupe petioles and corresponding nitrogen fertilizer recommendations at various growth stages.

Stage of Cantaloupe Growth	Petiole NO_3-N Ranges	Apply this Amount of Fertilizer N
	ppm	lbs./acre
3- to 4-leaves	>12,000	none
	4,000 to 12,000	25 to 50
	<4,000	50 to 75
Early runner	>14,000	none
	4,000 to 14,000	25 to 50
	<4,000	50 to 75
2-inch melon	>9,000	none
	4,000 to 9,000	0 to 25
	<4,000	25 to 50
Full size	>6,000	none
	4,000 to 6,000	0 to 20
	<4,000	20 to 30

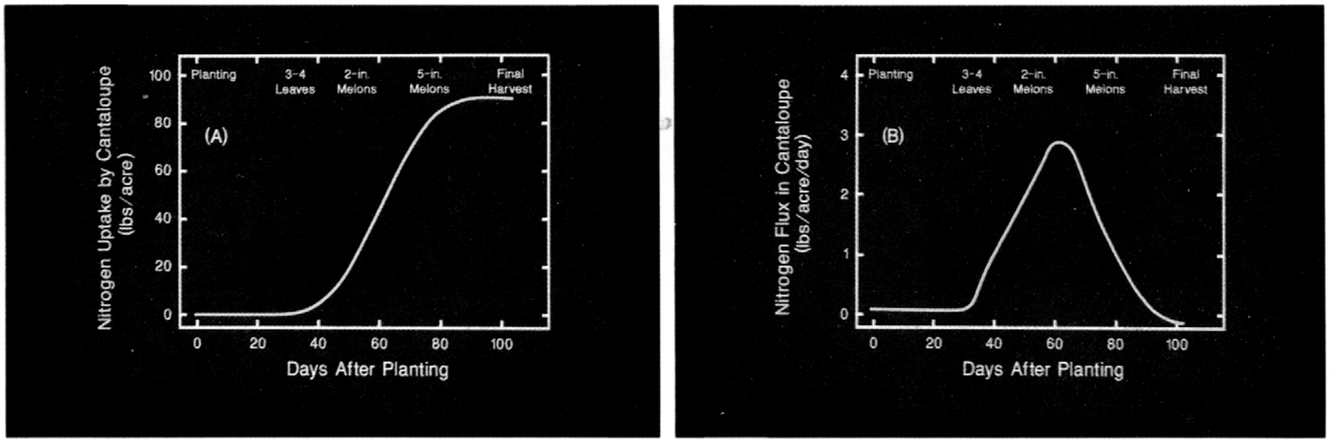

Figure 33.
Cumulative seasonal nitrogen uptake (A) and daily nitrogen flux (B) patterns for Laguna cantaloupe at a yield level of 20 tons per acre.

Cauliflower

The level of nitrogen fertility has more influence on the growth and yield of cauliflower than any other single plant nutrient because it is the nutrient most often deficient in Arizona soils. With good management, a total of about 200 to 250 lbs. N per acre is usually needed for optimum production. Preplant soil analysis and leaf midrib analysis during the season can be very useful in monitoring the nitrogen status of the crop. Deficiencies of nitrogen at any time in the season are to be avoided, as yields will usually be reduced. Deficiencies after the initiation of curd formation, called "buttoning," are especially serious, as nitrogen applications after this stage may not completely correct the problem.

Fertilizer recommendations in this guide apply to all cauliflower varieties grown in Arizona and are based on a plant population of 25,000 plants per acre and a yield potential of 10 to 15 tons per acre. Rates may need to be adjusted for significantly different plant populations or yield goals.

- **Early season nitrogen**

Preplant application of 40 to 60 lbs. N per acre on fine-textured soils (clay loams and silty clay loams) and 0 to 40 lbs. N per acre on coarse-textured soils (sands and sandy loams) are generally required. Preplant applications of nitrogen on very sandy soils are usually inefficient because nitrogen is easily leached below the root zone of young plants. Use the lower rates if there is a high residual nitrogen level in the plow layer of soil (i.e. above 15 ppm NO_3-N). About one-half of the total nitrogen applied to the crop should be applied during the first five to seven weeks after stand establishment.

- **Mid-season nitrogen**

At the four- to six-leaf stage of growth (45 to 50 days after seeding), collection of leaf midrib samples for nitrate (NO_3-N) analysis should begin. The thickened midribs from the center of the youngest full-sized leaves should be separated from the leaf blades. Be sure to include the stem connecting the leaf blade to the main stalk with the midrib sample (Figure 34). Do not sample midribs from diseased, damaged, or unrepresentative leaves. On older plants, sample midribs from the youngest full-sized leaves. These are typically the "easiest" leaves to sample. About 25 to 50 midribs per sample are adequate for analysis, depending upon the size of the leaves at the time of collection. The number of samples tested from each field depends on the uniformity of the field. Samples should be collected from uniform areas representing portions of a field that can be fertilized separately. Samples should be taken at one- to two-week intervals throughout the season. Samples should be placed in a paper bag and dried at about 150°F (65°C) or refrigerated as soon as possible and submitted to a laboratory for NO_3-N analysis.

Figure 34.
Begin sampling cauliflower midribs at the 4- to 6-leaf stage. Collect the midribs from the youngest full-sized leaves as shown above.

- **Interpretation of midrib nitrate levels**

The midrib nitrogen level is normally high (with adequate soil fertility) early in the season during vegetative growth and declines as the season progresses. Desirable levels of nitrate-nitrogen are shown in Table 32 and Figure 35.

A timely application of nitrogen fertilizer can prevent or slow the decline of midrib nitrate. If the nitrate-N level is below 5,000 ppm NO_3-N prior to the "buttoning" stage, then application of a nitrate or urea source is recommended. These forms of N move readily in soil solution and are immediately available to the plant roots with the first irrigation after the fertilizer has been applied. This decreases the time necessary for recovery from a nitrogen deficiency. At higher levels of midrib N, the nitrogen source is of less importance because nitrification of ammonium (NH_4) sources can take

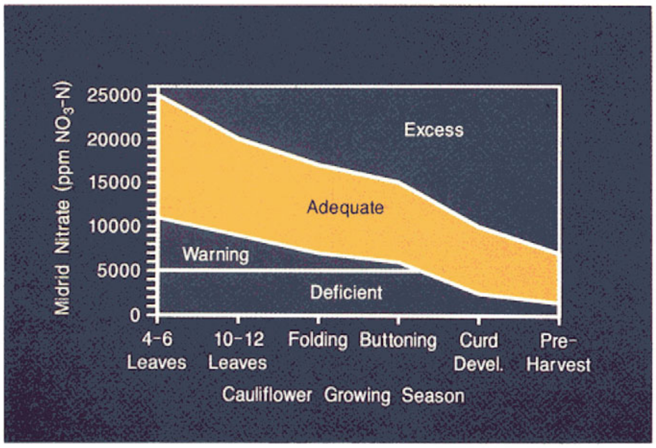

Figure 35.
Interpretation of nitrate-nitrogen in cauliflower midribs at different stages of growth.

place rapidly enough to permit the resulting NO_3 to be moved into the root zone to supply the needs of the plants. Caution should be used when applying ammonium sources of nitrogen such as anhydrous or aqua ammonia in order to avoid plant injury from ammonia toxicity, especially on very sandy soils.

Table 32.
Desirable levels of nitrate-nitrogen in cauliflower midribs at various stages of growth.

Stage of Cauliflower Growth	Approximate Days After Planting	Desirable Levels of Midrib NO_3-N
		ppm
4 to 6 Leaves	45 - 50	11,000
10 to 12 Leaves	60 - 65	9,000
Folding	75 - 80	7,000
Buttoning	85 - 90	6,000
Curd Development	100 - 105	2,500
Pre-harvest	115 - 120	1,500

- **Nutrient removal**

A harvest of 10 tons of cauliflower curds per acre contains about 125 lbs. N. The entire crop will contain about 250 lbs. N/acre.

- **Nitrogen uptake patterns**

Nitrogen uptake by cauliflower is very low prior to the 4- to 6-leaf stage. By the buttoning stage, N flux has increased to about 6 to 8 lbs. per acre per day. Nitrogen uptake temporarily slows as the curd begins to form and then increases again. Then, because cauliflower is harvested prior to entering reproductive growth, nitrogen uptake remains high until harvest.

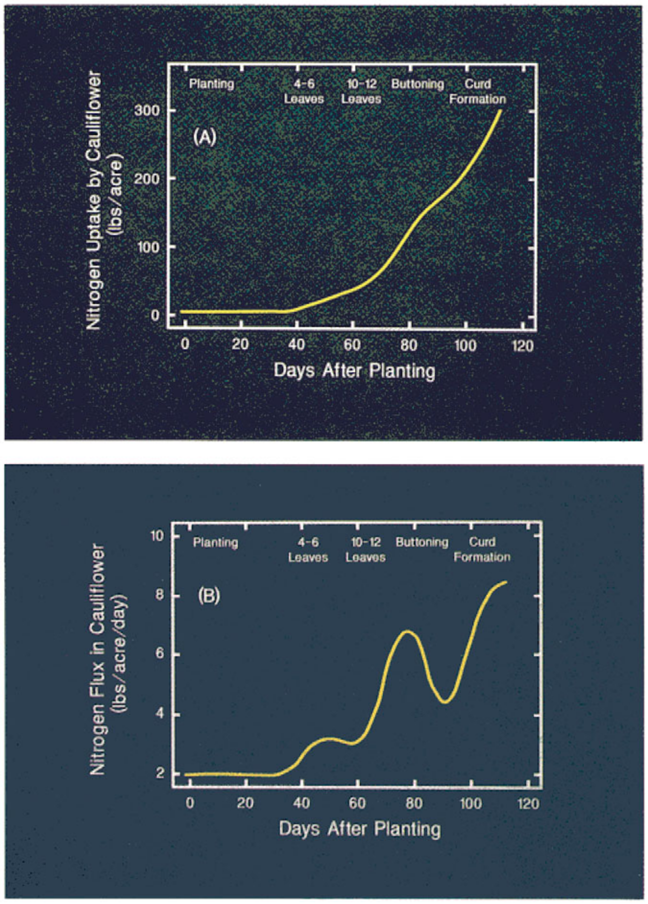

Figure 36.
Cumulative seasonal nitrogen uptake (A) and daily nitrogen flux (B) patterns for Snowball-123 cauliflower at a yield level of 11.7 tons per acre.

Citrus

The level of nitrogen fertility has more influence on the growth, yield and quality of citrus than any other single plant nutrient because it is the nutrient most often deficient in Arizona soils. Observations of annual shoot growth and size and color of leaves and fruit are helpful in determining the nitrogen needs of citrus trees. Leaf tissue analysis from mature trees can also be used to monitor the nitrogen status of an orchard. Soil analysis before orchard establishment can be useful in determining the suitability of a particular site for citrus production, as well as indicate the need for nitrogen during the first years after planting (Table 33).

- **Young trees**

Adequate supplies of nitrogen are needed to promote rapid growth and development of young nonbearing trees. Supplying the N needs of new orchards should be based on a soil test for NO_3-N and subsequent tree vigor.

- **Mature orchards**

The following are typical ranges of application for established citrus orchards over five years old:

- 1 to 2 lbs. N per mature tree
- 2 to 3 lbs. N per mature tree on very sandy soils

Use lower rates for grapefruit and the higher rates for high vigor varieties such as lemons.

Excessive applications of N can have several adverse effects, including increased rind thickness and toughness, a decreased solids:acid ratio and an increased susceptibility of new foliage to winter injury. In addition excessive foliar applied N can cause leaf burn.

Use August leaf samples to guide N applications on mature trees (over five years old). Sample 5- to 7-month-old, bloom-cycle leaves from non-fruiting terminals on healthy trees (Figure 37). Use Table 34 to guide N applications to mature citrus trees.

Table 34.
Suggested nitrogen application rates for mature citrus trees based on August leaf N concentrations.

Total N in Leaves	Apply this amount of N per tree*
%	lbs.
<2.2	3 - 4
2.2 - 2.3	2 - 3
2.4 - 2.6	1 - 2
2.7 - 2.8	1/2 - 1
>2.8	0 - 1/2

**use the higher rates for lemon trees*

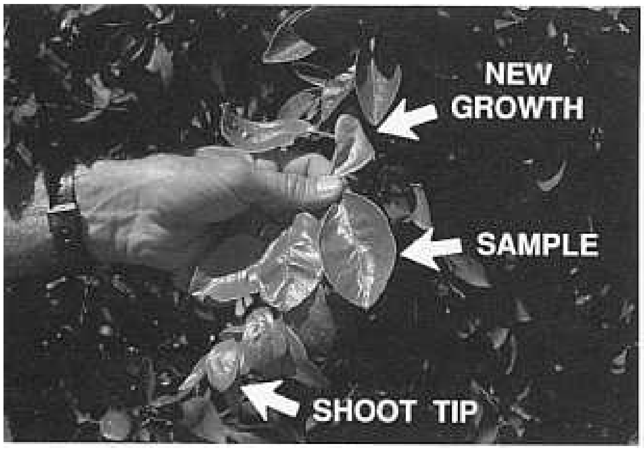

Figure 37.
Collect leaf tissue samples in August for nutrient analysis. Sample 5- to 7-month old, bloom-cycle leaves from the middle of non-fruiting terminals as shown above.

Table 33.
Suggested nitrogen fertilizer rates for citrus trees during their first five years based on preplant soil nitrate-nitrogen levels.

NO_3-N Soil Test	Apply This Amount of N (lbs./tree)		
ppm	1st yr.	2nd - 3rd yr.	4th - 5th yr.
0 - 10*	0 - 0.5	0.75	1.0
10 - 20	0.25	0 - 0.5	0.5 - 0.75
above 20	0	0.25	0.25 - 0.5

**Rates up to 1/2 lb. N on trees before the fourth year and 1 1/2 lbs. N on trees in the fourth and fifth years may be required on very sandy soils such as on the Yuma Mesa.*

- **Timing of N applications**

  Apply 1/2 of the required N in late winter with the remainder applied in 3 to 6 applications through mid-summer. Continue applications through August for lemons and other early maturing varieties. More frequent, lighter applications are recommended on sandy soils such as the Superstition sand, which is found on the Yuma Mesa.

- **Importance of forms of N**

  Ammonium (NH_4) forms of N such as anhydrous and aqua ammonia and ammonium sulfate will become available for plant uptake with the second irrigation following application. Nitrate (NO_3) and urea forms of N are available after the first irrigation. Caution should be used when applying anhydrous and aqua ammonia to avoid plant injury from ammonia toxicity, especially on very sandy soils.

- **Methods of application**

  Inject N into irrigation water or place dry N fertilizers in the basin around each tree and follow immediately with irrigation. The uniformity of N applied with irrigation water will only be as good as the uniformity of water application.

  For foliar applications use 10 lbs. low biuret (<2%) urea per 100 gallons. Allow one month between foliar applications.

- **Nutrient removal**

  A harvest of 10 to 15 tons of citrus per acre will contain about 35 to 60 lbs. N.

Field Corn

The level of nitrogen fertility has more influence on the growth and yield of field corn than any other single plant nutrient because it is the nutrient most often deficient in Arizona soils. The amount of fertilizer N required will vary depending on the yield potential of the crop and the amount of residual N in the soil prior to planting. Preplant soil analysis and plant tissue analysis during the season can be very useful in monitoring the nitrogen needs of the crop.

Fertilizer recommendations in this guide apply to all field corn varieties grown in Arizona and are based on a plant population of 30,000 plants per acre and yield potentials of 8500 to 11,000 lbs. (150 to 200 bushels) of grain per acre or 20 to 30 tons of silage per acre. Rates may need to be adjusted for significantly different yield goals.

- **Estimating crop N requirement**

Prior to planting a composite soil sample should be analyzed for NO_3-N content. Estimate the total amount of N fertilizer that is required from Table 35. Adjust this N rate as needed depending on crop appearance, mid-season plant tissue test results and previous experience.

Table 35.
Estimated seasonal nitrogen fertilizer rates for field corn based on preplant soil nitrate-nitrogen levels. These guidelines have not been verified for field corn grown in Arizona.

Soil Test NO_3-N	Approximate N Fertilizer Rate*
ppm	lbs./acre
0 - 10	200 - 300
10 - 20	120 - 200
20 - 50	50 - 120
above 50	0 - 50

**decrease this N rate by 60 lbs./acre if corn follows alfalfa.*

- **Early season nitrogen**

Up to 60 lbs. N per acre should be applied before or at planting particularly if the NO_3-N soil test value is below 20 ppm. Nitrogen can be broadcast on the soil surface and incorporated or placed in a band two inches below and to the side of the seed. Band applications of N above 60 lbs. per acre increase the risk of salt damage to young seedlings, especially on sandy textured soils.

- **Mid-season nitrogen**

All remaining nitrogen should be sidedressed or applied in the irrigation water between the 3- to 4-leaf stage and tasseling. Applications of N at the silking stage and beyond should only be made if N deficiency has been identified by plant tissue analysis or visual symptoms.

Periodic sampling of plant tissue during the growing season can be very useful in monitoring the nitrogen status of the crop (Table 36).

About 10 to 25 plants or plant parts should be sampled from each area being tested. The number of samples tested from each field depends on the uniformity of the field. Samples should be collected from randomly selected plants in uniform areas representing portions of a field that can be fertilized separately. Samples should be placed in a paper bag and dried at about 150°F (65°C) or refrigerated as soon as possible and submitted to a laboratory for total N or NO_3-N analysis as needed.

If a nitrogen deficiency is detected at any time up through the silking stage, then application of a nitrate or urea source is recommended. These forms of N move readily in soil solution and are immediately available to the plant roots with the first irrigation after the fertilizer has been applied. This decreases the time necessary for recovery from the nitrogen deficiency. Otherwise, the nitrogen source is of less importance because nitrification of ammonium (NH_4) sources can take place rapidly enough to permit the resulting NO_3 to be moved into the root zone to supply the needs of the crop. Caution should be used when applying ammonium sources of nitrogen such as anhydrous or aqua ammonia in order to avoid plant injury from ammonia toxicity, especially on very sandy soils.

- **Nutrient removal**

A grain yield of 11,200 lbs. per acre will contain about 150 lbs. of N. The entire crop of grain plus stover will contain about 270 lbs. N per acre.

- **Nitrogen uptake patterns**

The uptake of nitrogen by field corn consists of three distinct phases. The first is characterized by a

Table 36.
Interpretation of nitrogen levels in different plant parts of field corn throughout the growing season.

Plant Part*	N Test, Units	Growth Stage				
		3-4 Leaf	8 Leaf	12 Leaf	Tassel	Silk
		Adequate nitrogen level in plant tissue				
Whole plant	Total N%	4.0	3.5			
Youngest mature leaf	Total N%	4.0	3.5	3.2	3.2	
Ear leaf	Total N%	—	—			2.9
Basal stalk	NO_3-N ppm	12,000	14,000	12,000	10,000	8,000

**The "ear leaf" is the leaf immediately below and opposite the primary ear. Stalk samples consist of the four inches of main stalk tissue immediately above the ground level. These guidelines have not been verified for field corn grown in Arizona.*

low but increasing N flux between the seedling through the 8-leaf stage. Nitrogen flux rises dramatically to a maximum, approaching 10 lbs. N per acre per day at the 12-leaf stage, followed by an equally rapid decline until silking. Nitrogen flux during the grain filling period which follows is moderately low, generally averaging 1 to 2 lbs. N per acre per day.

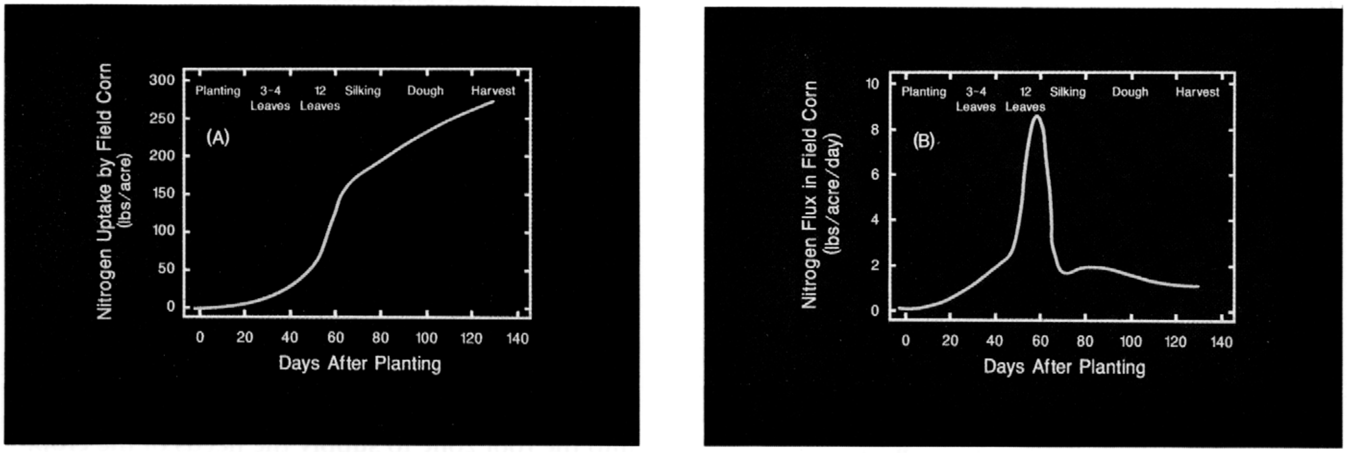

Figure 38.
Cumulative seasonal nitrogen uptake (A) and daily nitrogen flux (B) patterns for field corn at a yield level of 11,200 lbs. grain per acre (after Ritchie et al. 1986. How a Corn Plant Develops. Special Report No. 48. Iowa State University).

Sweet Corn

The level of nitrogen fertility has more influence on the growth and yield of sweet corn than any other single plant nutrient because it is the nutrient most often deficient in Arizona soils. With good management, a total of about 175 to 225 lbs. N per acre is usually needed for optimum production. Preplant soil analysis and lower stalk and ear leaf tissue analysis during the season can be very useful in monitoring the nitrogen status of the crop.

Fertilizer recommendations in this guide apply to all sweet corn varieties grown in Arizona and are based on a plant population of 20,000 plants per acre and a yield potential of 7 to 8 tons per acre. Rates may need to be adjusted for significantly different plant populations or yield goals.

- **Early season nitrogen**

A preplant application of 40 to 60 lbs. N per acre on fine-textured soils (clay loams and silty clay loams) and 0 to 40 lbs. N per acre on coarse-textured soils (sands and sandy loams) are generally required. Preplant applications of nitrogen on very sandy soils are usually inefficient because nitrogen is easily leached below the root zone of young plants. Use the lower rates if there is a high residual nitrogen level in the plow layer of soil (i.e. above 15 ppm NO_3-N). Nitrogen can be broadcast on the soil surface and folded into the bed at listing or incorporated by discing prior to listing. With proper equipment N can also be placed in a band two inches below and to the side of the seed. Band applications of N above 60 lbs. per acre increase the risk of salt damage to young seedlings, especially on sandy textured soils.

- **Mid-season nitrogen**

All remaining N should be side dressed or applied in the irrigation water between the 3- to 4-leaf stage and tasseling. Applications of N at the silking stage and beyond should only be made if a N deficiency has been identified by plant tissue analysis or visual symptoms.

Figure 39.
Sample the lower four inches of main stalk tissue as shown above.

At the 3- to 4-leaf stage, collection of lower stalk samples for nitrate (NO_3-N) analysis should begin. The stalk samples consist of the four inches of main stalk tissue immediately above ground level (Figure 39). Do not sample stalks from diseased, damaged, or unrepresentative plants. About 10 to 25 stalks per sample are adequate for analysis, depending upon the size of the plants at the time of collection. The number of samples tested from each field depends on the uniformity of the field. Samples should be collected from randomly selected plants within uniform areas representing portions of a field that can be fertilized separately. Samples should be taken at the 3-leaf, 6-leaf, 9-leaf, 12-leaf, tassel and silking stages of growth. Samples should be place in a paper bag and dried at about 150°F (65°C) or refrigerated as soon as possible and submitted to a laboratory for NO_3-N analysis.

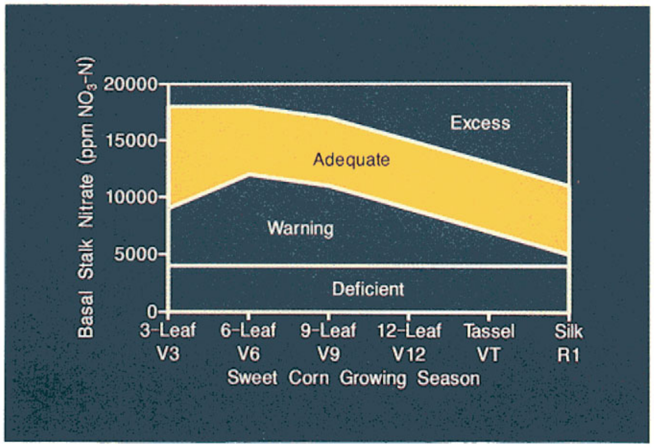

Figure 40.
Interpretation of nitrate-nitrogen levels in sweet corn stalk tissue at different stages of growth.

Table 37.
Desirable levels of nitrate-nitrogen in sweet corn stalk tissue at various stages of growth.

Stage of Sweet Corn Growth	Approximate Days After Planting*	Desirable Levels of Stalk NO_3-N
		ppm
3 Leaves	30 - 35	9,000
6 Leaves	45 - 50	12,000
9 Leaves	55 - 60	11,000
12 Leaves	65 - 70	9,000
Tassel	70 - 75	7,000
Silking	75 - 80	5,000
Pre-Harvest	95 - 100	4,000

**for spring planted crops only*

- **Interpretation of stalk nitrate levels**

The stalk NO_3-N level is normally high (with adequate soil fertility) early in the season during vegetative growth and declines as the season progresses. Desirable levels of nitrate-nitrogen are shown in Table 37 and Figure 40.

A timely application of nitrogen fertilizer can prevent or slow the decline of stalk nitrate. If the nitrate-N level is below 5,000 ppm NO_3-N prior to the tasseling stage, then application of a nitrate or urea source is recommended. These forms of N move readily in soil solution and are immediately available to the plant roots with the first irrigation after the fertilizer has been applied. This decreases the time necessary for recovery from a nitrogen deficiency. At higher levels of stalk N, the nitrogen source is of less importance because nitrification of ammonium (NH_4) sources can take place rapidly enough to permit the resulting NO_3 to be moved into the root zone to supply the needs of the plants. Caution should be used when applying ammonium sources of nitrogen such as anhydrous or aqua ammonia in order to avoid plant injury from ammonia toxicity, especially on very sandy soils.

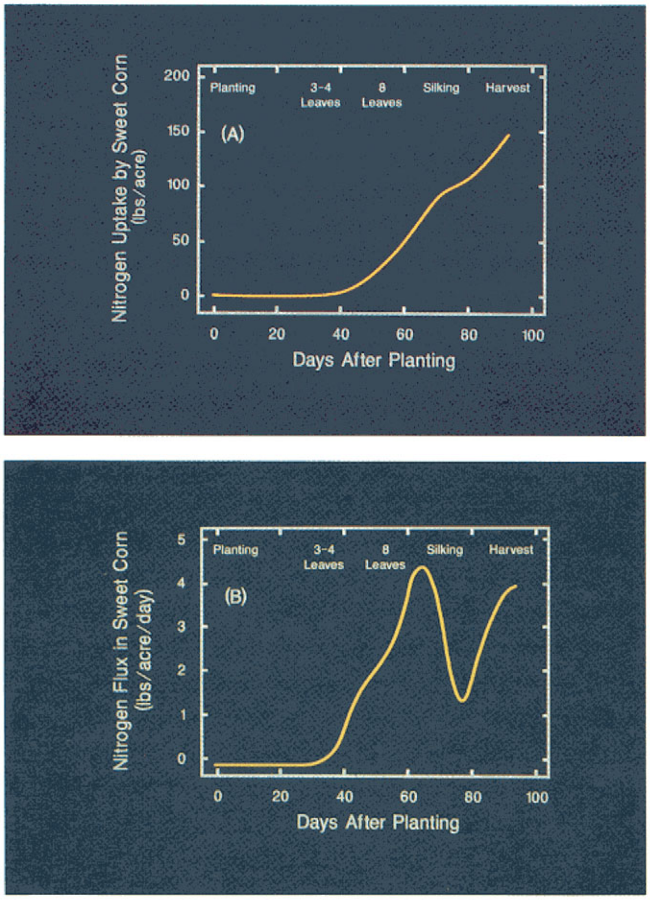

Figure 41.
Cumulative seasonal nitrogen uptake (A) and daily nitrogen flux (B) patterns for Sweetie '82 sweet corn at a yield level of 7.0 tons per acre.

Ear leaf samples can also be taken at the early silking stage to evaluate the nitrogen status of the crop. Follow the same sampling and handling criteria listed above for stalks. The leaf blade to be collected is from the leaf immediately below and opposite the primary ear. A total N concentration between 2.5 and 2.7% in the ear leaves at silking indicates that N supply is adequate for optimum ear yield.

- **Nutrient removal**

A harvest of 8 tons of marketable sweet corn ears per acre will contain about 60 lbs. N. The entire crop will contain about 150 to 170 lbs. N per acre.

- **Nitrogen uptake patterns**

The seasonal uptake of nitrogen by sweet corn includes three distinct phases. The first is characterized by a low but increasing N flux between the seedling through the 6 leaf stage. Nitrogen flux rises rapidly to a maximum, approaching 5 lbs. N per acre per day at the 12 leaf stage, followed by an equally sharp decline until silking. Nitrogen flux during the formation of the corn ear is moderately low at first but can exceed 3 lbs. per acre per day by harvest.

Cotton, Upland and Pima

Nitrogen is the nutrient that is required most often and in larger amounts than other nutrients for cotton production. Common rates of fertilizer N applied to cotton range from 50 to 300 lbs. N per acre. The management of fertilizer N is critical, both for insuring optimum lint yield and quality and in minimizing the potential for environmental contamination. Preplant soil analysis and leaf petiole analysis during the season can be very useful in monitoring the nitrogen status of the crop.

- **Early season nitrogen**

Applications of N at or before planting are seldom recommended unless the residual N content in the soil is very low. This is because young stands of cotton have a very low N requirement and soluble nitrates can be easily leached when irrigation water is applied during germination and early season growth. Use Table 38 to estimate preplant N fertilizer requirements.

Table 38.
Estimated preplant nitrogen fertilizer rates for Upland and Pima cotton based on preplant soil nitrate-nitrogen levels.

Preplant Soil Test Level	Apply this Amount of N
ppm NO_3-N	lbs. N/acre
0 - 5	30 - 50
5 - 10	20 - 30
10 - 15	0 - 20
> 15	0

When N is required, an ammonium (NH_4) form such as anhydrous ammonia (82-0-0), monoammonium phosphate (11-53-0), ammonium phosphate-sulfate (16-20-0), solution ammonium polyphosphate (10-34-0) or ammonium sulfate (21-0-0) should be used to minimize leaching losses early in the season. Nitrogen can be broadcast and incorporated into the soil prior to listing or it can be banded near or below the seed placement zone. Two to three inches of soil should separate the fertilizer and the seed. Anhydrous or aqua ammonia should be injected 6 to 9 inches below the soil surface prior to planting and should never be placed near the seed zone in order to avoid seedling injury from ammonia toxicity.

- **Mid-season nitrogen**

At the pin head square stage, collection of leaf petiole samples for nitrate (NO_3-N) analysis should begin. The petiole is the leaf stem which connects the leaf blade to the main stalk. The petiole is selected from the most recently fully expanded leaves, usually the petiole of the third to the fifth leaf from the terminal (Figure 42). Selection of the correct petioles can substantially influence test results. Petioles from leaves which are younger than the first fully expanded mature leaf will have NO_3-N values lower than those from the mature leaves. The NO_3-N levels of petioles from the second and third fully expanded mature leaves are the same as those from the first mature leaf. In general, if any doubt exists about which petioles to use, collecting petioles slightly older than the first mature fully expanded leaf is better than collecting younger petioles.

About 25 to 30 petioles per sample are adequate for analysis. The number of samples tested from each field depends on the uniformity of the field. Samples should be collected from randomly selected plants within uniform areas representing the largest part of a field that can be treated separately. Samplings are made at one- to two-week intervals through July.

Figure 42.
Begin sampling cotton petioles when squares first start to appear. Collect petioles from the youngest mature leaves as shown above.

- **Interpretation of petiole nitrate levels**

The petiole nitrogen level is normally high (with adequate soil fertility) early in the season during vegetative growth and declines as the season progresses and fruit develops. The rate and extent of decline is one key to interpretation of petiole nitrate-nitrogen values. Nitrogen shortages or boll load can cause a reduction in petiole nitrate. Therefore, for the interpretation of a particular petiole nitrate value, the stage of growth and boll load should be considered.

Desirable levels of nitrate-nitrogen are shown in Table 39 and Figure 43. These levels are conservative in that slightly lower levels are not deficient at any particular period. An unusually heavy boll load often causes a rapid decline in petiole nitrate, but this may not be indicative of an actual nitrogen deficiency in the soil. In this case one must choose between making a fertilizer application and waiting for another petiole analysis.

Table 39.
Desirable levels of nitrate-nitrogen in Upland and Pima cotton at various stages of growth.

Stages of Cotton Growth	Desirable Petiole Nitrate Levels	
	Pima	Upland
	ppm NO_3-N	
Early Squaring	10,000+	18,000+
Early Bloom	8,000+	14,000+
First Bolls	4,000+	8,000+
First Open Bolls	2,000+	4,000+

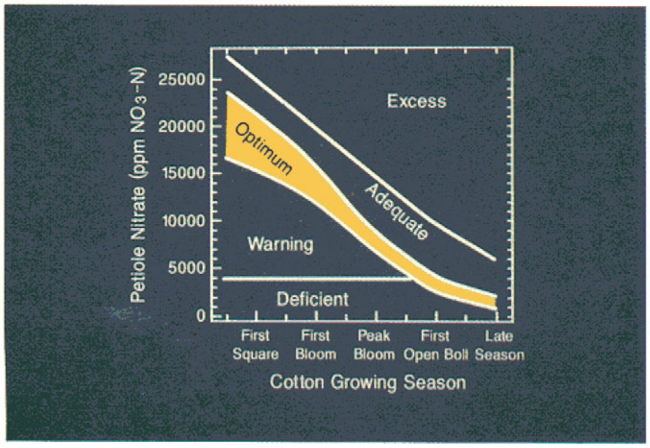

Figure 43.
Interpretation of nitrate-nitrogen levels in Upland cotton petioles at different stages of growth.

A timely application of nitrogen can prevent or slow the decline of petiole nitrate. If the nitrate-N level is about 4000 ppm or below (prior to the first open bolls), application of a nitrate or urea source is recommended. These forms of N move readily in soil solution and are rapidly absorbed by the cotton plant, thus decreasing the time necessary for recovery from a deficiency. At higher levels of petiole nitrate, the nitrogen source is of less importance because nitrification of ammonium (NH_4) sources can take place rapidly enough to permit the resulting NO_3 to be moved into the root zone to supply the needs of the plants. Caution should be used when applying ammonium sources of nitrogen such as anhydrous or aqua ammonia in order to avoid plant injury from ammonia toxicity, especially on very sandy soils.

The effect of kind and amount of fertilizer, time of application, cropping history, and soil texture must also be considered when interpreting petiole nitrate results. For example, when petiole nitrate is approaching a deficient level, and nitrogen in an ammonium form was applied a short time before sampling, petiole analysis would not reflect this application, yet additional fertilizer would not be needed. Cases of low petiole nitrate have been observed when appreciable nitrogen had been applied but frequent heavy irrigations had leached it below the plant root zone. Also, when cotton follows alfalfa or applications of manure, the petiole nitrate value may appear low without an actual need for additional nitrogen because of the continual supply of nitrogen from decomposing organic matter in the soil.

- **Defoliation and N management**

At the end of the season, Upland cotton plants lend themselves best to chemical defoliation when petiole NO_3-N levels have declined below 2,000 ppm. It is important to manage N nutrition to lower petiole NO_3-N levels late in the season without driving the plant into a N deficiency that will diminish yield. This can be done by reducing or eliminating N inputs to the crop after the peak bloom period.

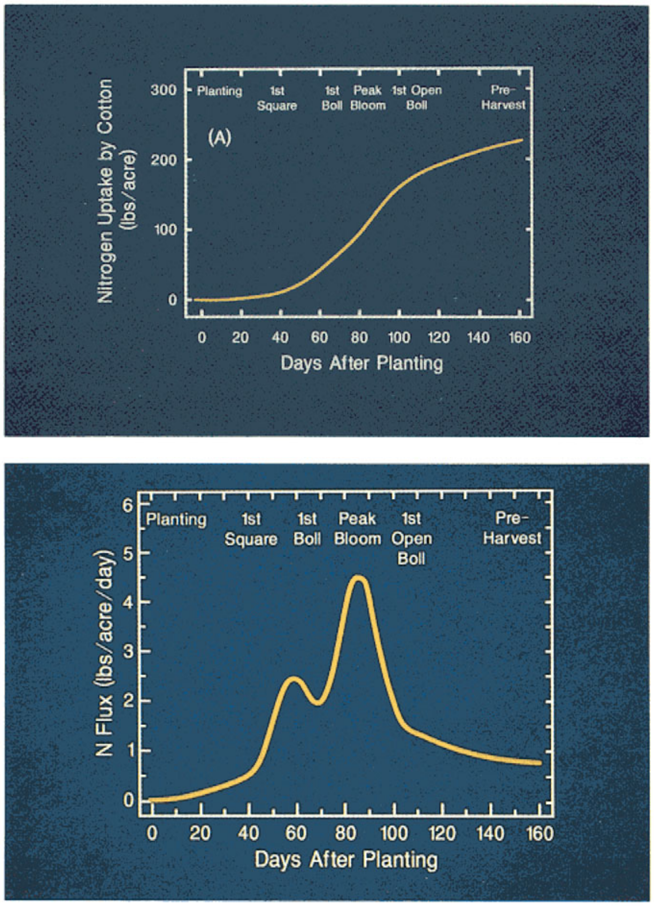

Figure 44.
Cumulative seasonal nitrogen uptake (A) and daily nitrogen flux (B) patterns for DPL-62 Upland cotton at a yield level of 4.0 bales lint per acre.

- **Nutrient removal**

  A harvest of 1920 lbs. lint (4 bales) per acre will contain about 120 lbs. of N in the cotton seed removed during the ginning process. The entire crop will contain about 225 lbs. N per acre. About 60 lbs. of N is required for each bale of cotton lint yield.

- **Nitrogen uptake patterns**

  Nitrogen uptake by cotton is very low early in the season prior to the pin head square stage. As the plant rapidly grows in size and begins producing bolls, N flux increases sharply. Maximum N flux occurs during the peak bloom stage, exceeding 4 lbs. N per acre per day on high yielding sites. After the first open boll appears, N flux decreases rapidly to less than 1 lb. per acre per day by defoliation time.

Grapes

Nitrogen is the nutrient most often limiting grape production in Arizona; yet the N requirement per acre is much lower than most other horticultural and field crops. Deficiency symptoms are difficult to identify in the field unless the deficiency is severe. In these cases, symptoms would include a uniform, pale green to yellow-green color of the foliage and reduced shoot growth. A moderate N deficiency is most common, and is characterized merely by reduced vigor.

Observations of annual vine growth and the size and color of leaves are helpful in determining the N needs of vines. Petiole analysis from mature vines can also be used to monitor the nitrogen status of a vineyard. Soil analysis before vineyard establishment can be useful in determining the suitability of a particular site for grape production, as well as indicate the need for nitrogen in the first years after planting.

- **New vineyards**

Adequate supplies of nitrogen are needed to promote rapid growth and development of young nonbearing vines. Use Table 40 as a guide to N applications in young vineyards.

Table 40.
Nitrogen fertilizer requirements of grape vines for the first and second growing seasons depending on soil and vineyard conditions.

Soil and vineyard conditions	Annual N Rate*
	lbs./acre
Sandy loam to loam soils or following well-fertilized crops	0 - 20
Loamy sand soils	25 - 30
Coarse sandy soils	40 - 50

**Use the higher rates if a preplant soil test for NO_3-N is below 4 ppm N, and use the lower rates if the NO_3-N level is above 20 ppm N. Nitrogen applications in excess of these rates may result in late-season vine growth that may be susceptible to frost injury, particularly in cooler locations.*

- **Mature vineyards**

The overall vigor of vines and the appearance of the leaves are the best indicators of N status. Determination of the nitrate-nitrogen (NO_3-N) concentration in selected petiole samples can also be useful in monitoring the N status of grapes. Obtain samples at the 'full-bloom' stage. The petioles (leaf stems) from the leaves opposite the clusters toward the base of the shoots should be collected (Figure 45). A sample should contain 40 to 50 petioles taken at random from any uniform area within the vineyard. Samples should be placed in a paper bag and dried at about 150°F (65°C) or refrigerated as soon as possible and submitted to a laboratory for NO_3-N analysis.

Use Table 41 to guide N application rates for mature vineyards.

Table 41.
Suggested nitrogen application rates for mature grape vineyards based on soil and vineyard conditions.

Soil and vineyard conditions	Annual N Rate*
	lbs./acre
Deep, sandy loam to loam soils or high-vigor varieties.	0 - 40
Sandy loam soils or medium vigor vines	50 - 60
Sands and loamy sand soils or marginal vineyards. Split application best.	60 - 100

**These rates should only serve as a guide to N applications and should be adjusted depending on laboratory petiole results, vine performance, and grower judgement.*

Excess N can result in lush, dark green foliage and excessive vine growth, an abundance of immature canes with less desirable fruiting wood characteristics, reduced fruit set at the bloom stage, white salt-like deposits or burning at the margins of older leaves, and increased susceptibility to winter injury. Similar symptoms can also result from other nutritional or weather-related problems. Use analysis of leaf petiole nitrate to confirm an excessive N level in the plant (Table 42).

- **Timing of N applications**

Nitrogen should be applied during the late winter to early spring to ensure an adequate supply during vine growth. Late-season applications should only be used with caution to avoid excessive late-season growth which may be more susceptible to winter in-

Table 42.
Interpretation of grape petiole NO_3-N values obtained at the full bloom stage of growth.

Petiole NO_3-N	N Status*
ppm	
below 350	Deficient
600 - 1200	Adequate
above 2000	Excessive

**Desirable levels may vary among different varieties. Some table grape growers perfer somewhat higher levels of petiole N when greater vine vigor is needed.*

Figure 45.
Collect grape petiole samples at the full-bloom stage from leaves opposite clusters toward the base of the shoots (above).

jury. Nitrogen can be applied in one or more applications. Split applications are recommended on sandy soils where leaching of nitrogen below the root zone is a problem.

- **Using different forms of N**

Ammonium (NH_4) forms of N such as ammonium phosphate, anhydrous and aqua ammonia, or ammonium sulfate will become available for plant uptake with the second irrigation following application. Nitrate and urea forms of N are available after the first irrigation. Caution should be used when applying anhydrous and aqua ammonia to avoid plant injury from ammonia toxicity, especially on very sandy soils.

- **Methods of application**

Nitrogen should be applied directly in the irrigation water or else placed such that water movement will carry soluble N into the root zone. Solutions of ammonium sulfate, ammonium nitrate, calcium nitrate, and urea can be injected into both surface and pressurized irrigation systems. Anhydrous ammonia or aqua ammonia should be used with non-pressurized, surface irrigation systems only. The uniformity of N applied with irrigation water will only be as good as the uniformity of water applications.

Dry N fertilizers should be applied in spots or bands 1 to 3 feet from the vines and incorporated below the soil surface either mechanically or with a surface irrigation. Incorporation is especially important to reduce volatilization of ammonium forms of N.

Spot treatment of weaker vines, or vines in especially sandy areas may be required to maintain the desired level of vigor within an entire vineyard.

- **Nutrient removal**

A harvest of 10 tons of grapes per acre will contain about 20 lbs. N.

Lettuce

The level of nitrogen fertility probably has more influence on the growth and yield of lettuce than other plant nutrients because it is the nutrient most often deficient in Arizona soils. With good management, a total of about 175 to 200 lbs. N per acre is needed for optimum production using normal furrow irrigation practices. Leaf midrib analysis during the season can be very useful in monitoring the nitrogen status of the crop. Deficiencies of nitrogen at any time in the season are to be avoided, as yields will usually be reduced or maturity delayed. Deficiencies after the initiation of head formation, called "folding", are especially serious because the size of lettuce heads will be reduced. Applications of nitrogen after the heads have attained full size may result in greener plants but will not affect head size or yields, except perhaps on very sandy soils.

Fertilizer recommendations in this guide apply to all adapted head lettuce varieties and are based on plant populations ranging from 20,000 to 26,000 plants per acre (typically, two rows per 40 inch bed and 12 inch spacing). Significantly different plant populations or non-heading cultivars may require somewhat different fertilizer rates.

- **Early season nitrogen**

Preplant applications of nitrogen are normally very inefficient due to leaching of soluble nitrates that will occur when irrigation water is applied during germination and stand establishment. In addition, preplant applications exceeding 50 to 60 lbs. of ammonium-N per acre have been shown to result in stand loss and stunting of newly germinated seedlings in directly-seeded fields. Nitrogen utilization can be improved by making the first application as a side-dressing or injecting solution fertilizers into the prethinning irrigation. A total of 50 lbs. N per acre can be applied between stand establishment and thinning to provide adequate N nutrition.

- **Mid-season nitrogen**

At the four- to six-leaf stage of growth, collection of leaf midrib samples for nitrate (NO_3-N) analysis should begin. The thick midrib from the center of the youngest full-sized leaves should be separated from the leaf blade (Figure 46). Do not sample midribs from diseased, damaged or unrepresentative leaves. On older plants, sample midribs from the youngest full-sized wrapper leaves. These are typically the "easiest" leaves to sample. About 25 to 50 midribs per sample are adequate for analysis, depending upon the size of the leaves at the time of collection. The number of samples tested from each field depends on the uniformity of the field. Samples should be collected from randomly selected plants within uniform areas representing portions of a field that can be fertilized separately. Samples should be taken at one- to two-week intervals through heading. Samples should be placed in a paper bag and dried at about 150° F or refrigerated as soon as possible and submitted to a laboratory for NO_3-N analysis.

Figure 46.
Begin sampling lettuce midribs at the 4- to 6-leaf stage. Collect the midribs from the youngest full-sized leaves as shown above.

- **Interpretation of midrib nitrate levels**

The midrib nitrate levels should be maintained at a level about 8,000 to 10,000 ppm NO_3-N throughout the growing season (Figure 47). The higher levels are recommended for crops that will form heads during cold periods when the average weekly air temperatures drop below 55° F.

Most N is sidedressed just prior to an irrigation or injected into the irrigation water. For this reason it is suggested that midrib samples be obtained well before an irrigation event so that laboratory results will be available to guide individual mid-season N applications as shown in the Table 43.

A timely application of N fertilizer can prevent or slow the decline of midrib nitrate. If the nitrate-N level is below 6,000 ppm prior to the "folding"

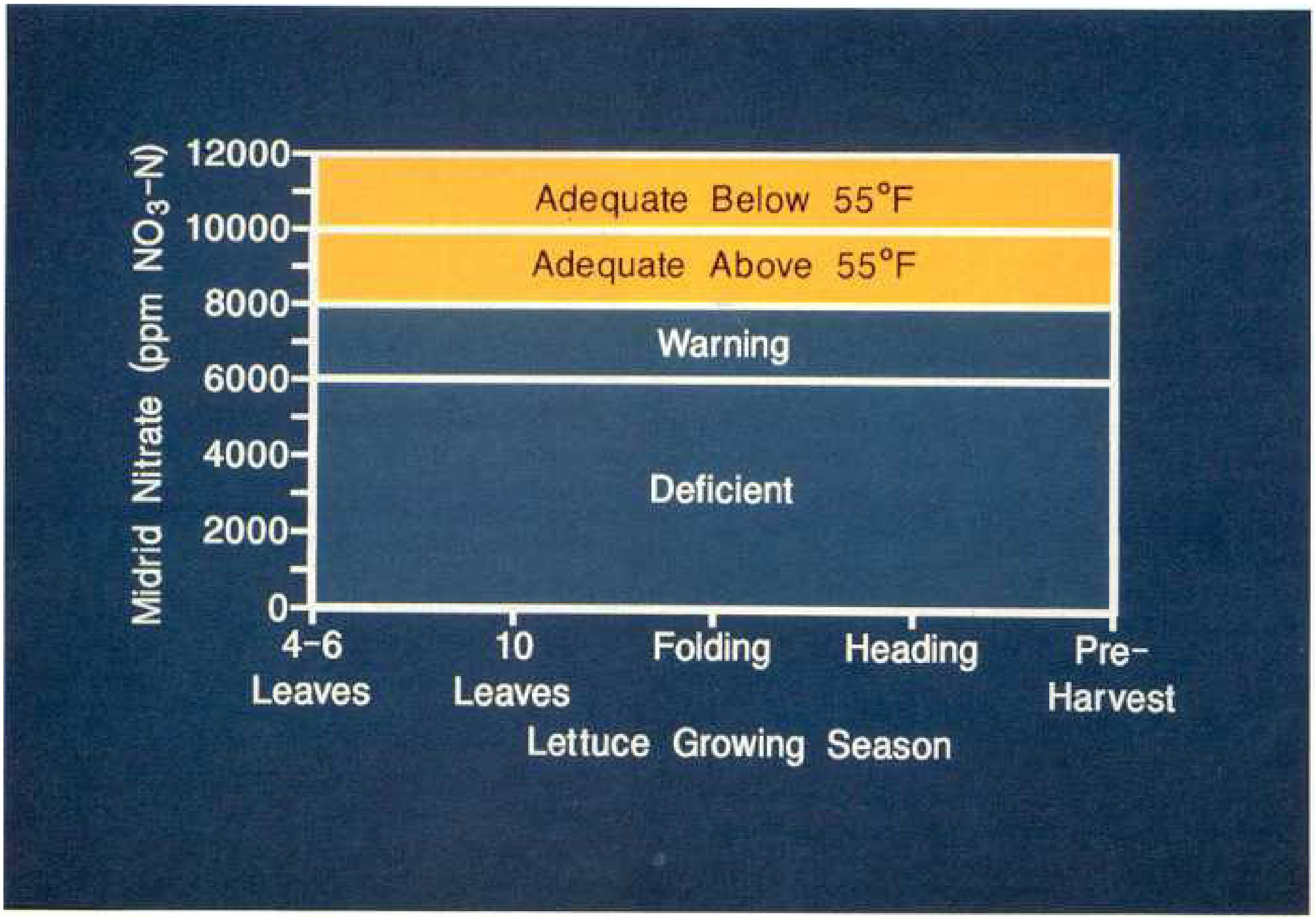

Figure 47.
Interpretation of lettuce midrib NO_3-N levels at different stages of growth and average weekly air temperatures.

Table 43.
Recommended nitrogen fertilizer application rates based on midrib NO_3-N levels. These N rates are for individual N applications made from the 4 to 6 leaf stage through heading.

Midrib NO_3-N	Apply this amount of N*
ppm	lbs/acre
above 10,000	None
6,000 to 10,000	30 to 60
3,000 to 6,000	60 to 80
below 3,000	80 to 100

**Use the higher recommendations if heading occurs during periods of below 55° F average weekly air temperature.*

stage, then application of a nitrate or urea source is recommended. These forms of N move readily in soil solution and are immediately available to the plant roots with the first irrigation after the fertilizer has been applied. This decreases the time necessary for recovery from a nitrogen deficiency. At higher levels of midrib nitrate, the nitrogen source is of less importance because nitrification of ammonium (NH_4) sources can take place rapidly enough to permit the resulting NO_3 to be moved into the root zone to supply the needs of the plants. Caution should be used when applying ammonium sources of nitrogen such as anhydrous or aqua ammonia in order to avoid plant injury from ammonia toxicity, especially on very sandy soils.

NOTE: Nutrient uptake and plant growth almost stop when the soil temperature at 6 inches deep is below 45° F or the average weekly air temperature is below 55° F. Applications of water and/or nitrogen in any form cannot compensate for temperatures below these levels. In fact, unnecessary irrigations can further reduce soil temperatures and decrease oxygen content in the root zone to harmfully low levels. Local weather information can be obtained from the National Weather Service or through Cooperative Extension's Arizona Meteorological Network (AZMET). The local County Extension agent can provide further details on how to access AZMET.

- **Nutrient removal**

A harvest of 800, twenty-four count cartons of head lettuce per acre contains about 50 lbs. N. The entire crop will contain between 100 to 125 lbs. N per acre.

- **Nitrogen uptake patterns**

Nitrogen uptake proceeds very slowly in lettuce until the crop enters the folding stage. Then N flux increases to about 3 lbs. per acre per day during heading for winter-grown crops. Higher N fluxes of shorter duration would be expected for fall- or spring-grown crops which mature more rapidly. Head lettuce generally takes up about 80% of its total N during the last four weeks prior to harvest.

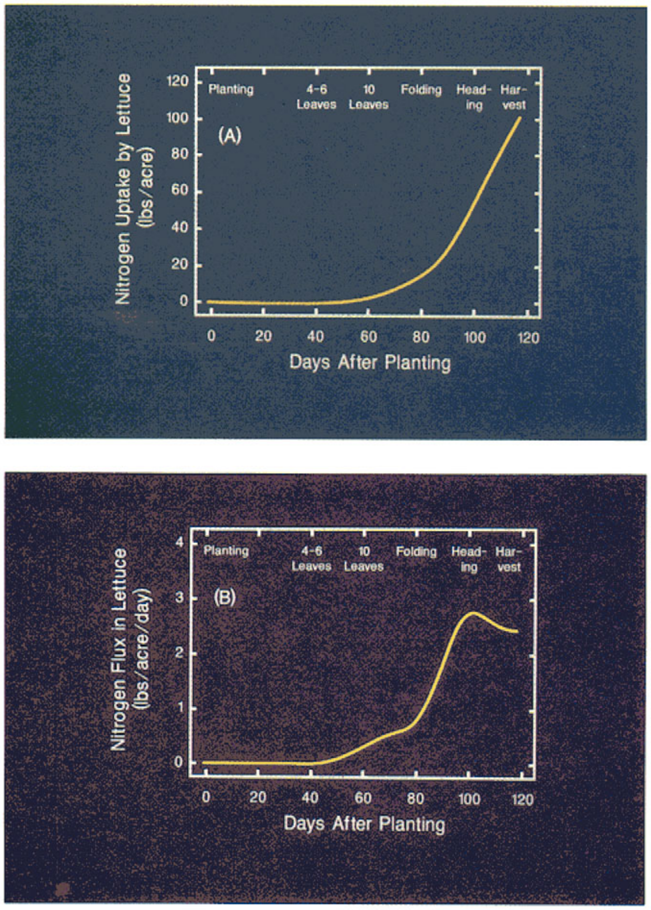

Figure 48.
Cumulative seasonal nitrogen uptake (A) and daily nitrogen flux (B) patterns for winter-planted Climax head lettuce at a yield level of 690 cartons per acre.

Pecans

Mature pecan trees are heavy users of nitrogen. Under most Arizona conditions 150 to 200 lbs. N per acre are required annually for optimum nut production.

Observations of annual shoot growth, size and color of leaves and nut set are helpful in monitoring the N needs of an orchard. Soil analysis before orchard establishment can be useful in determining the suitability of a particular site for pecan production, as well as indicate the need for nitrogen in the first years after planting.

- **Young trees**

Adequate supplies of N are needed to promote rapid growth and development of young nonbearing trees. Supplying the N needs of new orchards should be based on a soil test for NO_3-N and on subsequent tree vigor (Table 44). Excessive applications of N to younger trees can delay the initiation of nut production.

- **Mature orchards**

Pecan trees require a constant supply of N throughout the growing season. Approximately 10 lbs. N is required for each 100 lbs. of expected nut yield. For example, 200 lbs. N would be required for an expected yield of one ton of nuts per acre.

In orchards with pronounced alternate bearing cycles, reduce N applications in years with low nut yields if excessive shoot growth is a problem. Higher rates of N may be required in high yielding years to promote adequate shoot growth. Mature pecan trees should put on three to four feet of top growth each year and about one foot of annual growth on the side branches.

Table 45.
Interpretation of pecan leaf tissue samples for varying total nitrogen concentrations.

Leaf Tissue Nitrogen	Nitrogen Status
%	
below 2.5	Deficient
2.5 - 3.5	Adequate
above 3.5	Excessive

Determination of the N concentration in leaves from the current season growth can also be useful in estimating tree N status (Table 45). Samples should be collected in August from leaves which are free of insect, disease or mechanical damage. Collect the middle pair of leaflets from leaves from the middle of the current season growth (Figure 49). Sample about 100 pairs of leaflets from randomly selected trees within the block to be tested. Samples should be placed in a paper bag and dried at about 150°F (65°C) or refrigerated as soon as possible and submitted to a laboratory for total N analysis.

- **Timing of N applications**

Apply N in 4 to 6 roughly equal amounts beginning in the spring when shoot growth resumes. Make the last application on about August 1 when the nuts begin to fill. More frequent, lighter applications are recommended on very sandy soils.

- **Importance of forms of N**

Ammonium (NH_4) forms of N such as anhydrous and aqua ammonia, or ammonium sulfate will be-

Table 44.
Suggested nitrogen fertilizer rates for pecan trees in the first five years after planting based on soil nitrate-nitrogen levels.

NO_3-N Soil Test	Apply This Amount of N (lbs./acre)*		
ppm	1st yr.	2nd - 3rd yr.	4th - 5th yr.
0 - 4	0 - 40	25 - 50	50 - 100
4 - 20	0	0 - 25	30 - 60
above 20	0	0	20 - 30

**somewhat higher rates may be required on very sandy soils.*

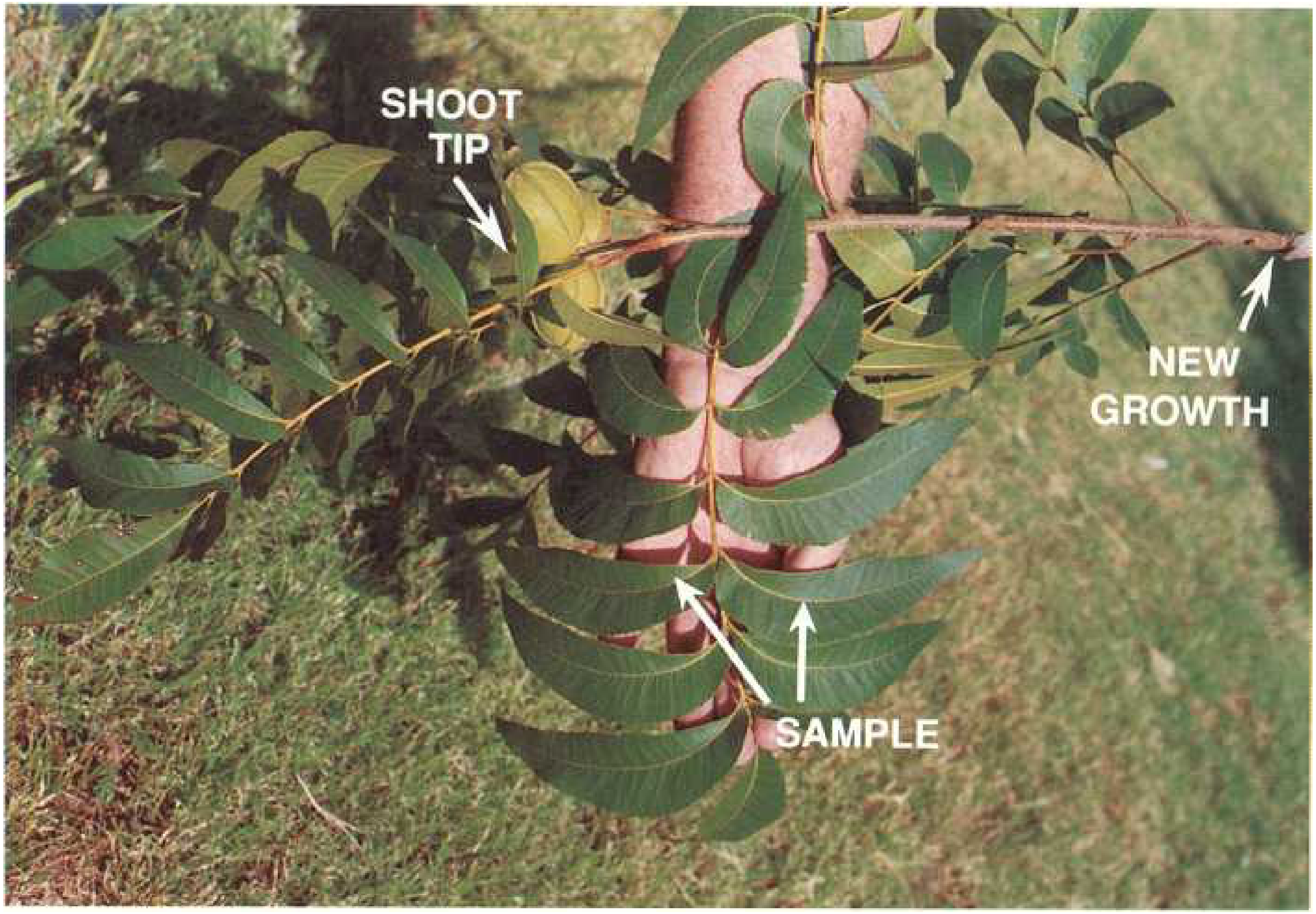

Figure 49.
Collect leaf tissue samples in August for nutrient analysis. Sample the middle pair of leaflets from leaves from the middle of the current season growth (above).

come available for plant uptake with the second irrigation following application. Nitrate and urea forms of N are available after the first irrigation. Caution should be used when applying anhydrous and aqua ammonia to avoid plant injury from ammonia toxicity, especially on very sandy soils.

- **Methods of application**

Nitrogen should be applied directly in the irrigation water or else placed such that water movement will carry soluble N into the root zone. Solutions of ammonium sulfate, ammonium nitrate, calcium nitrate, and urea can be injected into both surface and pressurized irrigation systems. Anhydrous ammonia or aqua ammonia should be used with non-pressurized, surface irrigation systems only. The uniformity of N applied in the irrigation water will only be as good as the uniformity of water applications.

Dry N fertilizers can be applied in spots or bands at the drip line of the trees and incorporated below the soil surface either mechanically or with a surface irrigation. Incorporation is especially important to reduce volatilization of ammonium forms of N.

- **Nutrient removal**

A harvest of 2000 lbs. of pecan nuts per acre will contain about 50 lbs. N.

Pistachios

Mature pistachio trees are moderately heavy users of nitrogen. Under most Arizona conditions 125 to 150 lbs. N per acre are required in heavy fruiting years and about 50 to 75 lbs. N per acre in the off years.

The pronounced alternate bearing cycles observed in pistachios have the greatest influence on the optimum N fertilizer rate to use. Observations of nut set, annual shoot growth and the size and color of leaves are helpful in monitoring the N needs of an orchard.

- **Young trees**

Adequate supplies of N are needed to promote rapid growth and development of young nonbearing trees. Generally one-third of a pound of actual N should be applied annually per inch of trunk diameter. Excessive applications of N to younger trees can delay the initiation of nut production.

- **Mature orchards**

Pistachio trees require a constant supply of N throughout the growing season. Approximately 10 lbs. N is required for each 100 lbs. of expected nut yield. For example, 150 lbs. N would be required for an expected yield of 1500 lbs. of nuts per acre. Mature pistachio trees should put on 18 to 24 inches of shoot growth in "off" years and 8 to 12 inches in "on" years.

Determination of the N concentration in leaves from the current season growth can also be useful in estimating tree N status. Samples should be collected between July 15 and August 15 from leaves which are free of insect, disease or mechanical damage. Collect the middle pair of leaflets from leaves from the middle of the current season growth (Figure 50). Sample about 100 pairs of leaflets from randomly selected trees within the block to be tested. Samples should be placed in a paper bag and dried at about 150°F (65°C) or refrigerated as soon as possible and submitted to a laboratory for total N analysis.

The total N content in pistachio leaflets should be maintained between 2.3 and 2.7% if possible, but above the critical level of 2.1%.

- **Timing of N applications**

Apply N in 4 to 6 roughly equal amounts beginning in the spring when shoot growth resumes. Make the last application on about August 1. More frequent, lighter applications are recommended on very sandy soils.

Figure 50.
Collect leaf tissue samples between July 15 and August 15 for nutrient analysis. Sample the middle pair of leaflets from leaves from the middle of the current season growth (above).

- **Importance of forms of N**

Ammonium (NH_4) forms of N such as anhydrous and aqua ammonia or ammonium sulfate will become available for plant uptake with the second irrigation following application. Nitrate and urea forms of N are available after the first irrigation. Caution should be used when applying anhydrous and aqua ammonia to avoid plant injury from ammonia toxicity, especially on very sandy soils.

- **Methods of application**

Nitrogen should be applied directly in the irrigation water or else placed such that water movement will carry soluble N into the root zone. Solutions of ammonium sulfate, ammonium nitrate, calcium nitrate, and urea can be injected into both surface and pressurized irrigation systems. Anhydrous ammonia or aqua ammonia should be used with nonpressurized, surface irrigation systems only. The uniformity of N applied with the irrigation water will only be as good as the uniformity of water applications.

Dry N fertilizers can be applied in spots or bands at the drip line of trees and incorporated below the soil surface either mechanically or with a surface irrigation. Incorporation is especially important to reduce volatilization of ammonium forms of N.

- **Nutrient removal**

A harvest of 1500 lbs. of pistachio nuts per acre will contain about 40 lbs. N.

Potatoes

The level of nitrogen fertility has more influence on the growth, yield and quality of potatoes than any other single plant nutrient because it is the nutrient most often deficient in Arizona soils. With good management, a total of about 150 to 200 lbs. N per acre is usually needed for optimum production. Preplant soil analysis and leaf petiole analysis during the season can be useful in monitoring the N status of the crop.

Proper irrigation management is particularly important in obtaining high yields of good quality tubers. An adequate supply of N from planting through tuber development is required, although excessive rates of N can reduce tuber quality, delay maturity and add to production costs.

The actual amount of N fertilizer that is required depends on the preceding crop, the amount of residual N remaining in the soil from the preceding crop and the likelihood of leaching losses due to over-irrigation.

Fertilizer recommendations in this guide apply to all potato varieties grown in Arizona and are based on a yield potential of 10 to 20 tons per acre. Rates may need to be adjusted for significantly different yield goals.

- **Estimating crop N requirement**

Use either Table 46 or Table 47 to estimate the fertilizer N requirement for potato production.

- **Early season nitrogen**

Up to 60 lbs. N per acre should be applied before or at planting. Nitrogen can be broadcast on the surface and incorporated or placed in a band two inches below and two inches to the side of the seed piece. Placement of N along with phosphorus fertilizers in this band configuration is probably the most efficient method of preplant nutrient application. Urea (46-0-0) or diammonium phosphate (18-46-0) forms of N may cause seedling injury if banded close to the seed, especially on sandy soils.

- **Mid-season nitrogen**

All remaining N should be sidedressed or applied in the irrigation water between the 6- to 8-leaf stage and mid-season. Periodic sampling of leaf petiole tissue during the growing season for NO_3-N analysis can be useful in monitoring the N status of the crop.

Table 46.
Estimated seasonal nitrogen fertilizer rates for potatoes based on preplant soil NO_3-N levels. These guidelines have not been verified for potatoes grown in Arizona.

NO_3-N Soil Test Level	Apply this Amount of N
ppm	lbs./acre
0 - 10	150 - 200
10 - 20	100 - 150
20 - 50	100 - 100
above 50	50

Table 47.
Estimated seasonal nitrogen fertilizer rates for potatoes based on the preceding crop. These guidelines have not been verified for potatoes grown in Arizona.

Previous Crop	Apply this Amount of N
	lbs./acre
Small grain* or non-legume hay	150 - 200
Row crops	120 - 150
Alfalfa	100 - 140

**Some additional N may be required if grain straw or non-legume residue is incorporated after October 1.*

Petioles (leaf stem) from the youngest full-sized leaves should be sampled. This is normally the fourth or fifth leaf from the terminal of the vine (Figure 51). Do not sample petioles from diseased, damaged or unrepresentative leaves. All leaflets should be stripped off the petiole immediately after sampling. About 25 to 50 petioles per sample are adequate for analysis. The number of samples tested from each field depends on the uniformity of the field. Samples should be collected from randomly selected plants within uniform areas representing portions of a field that can be fertilized separately. Samples should be placed in a paper bag and dried at about 150°F (65°C) or refrigerated as soon as possible and submitted to a laboratory for NO_3-N analysis.

Use Table 48 and Figure 52 as guides to interpret potato petiole nitrate levels throughout the growing season.

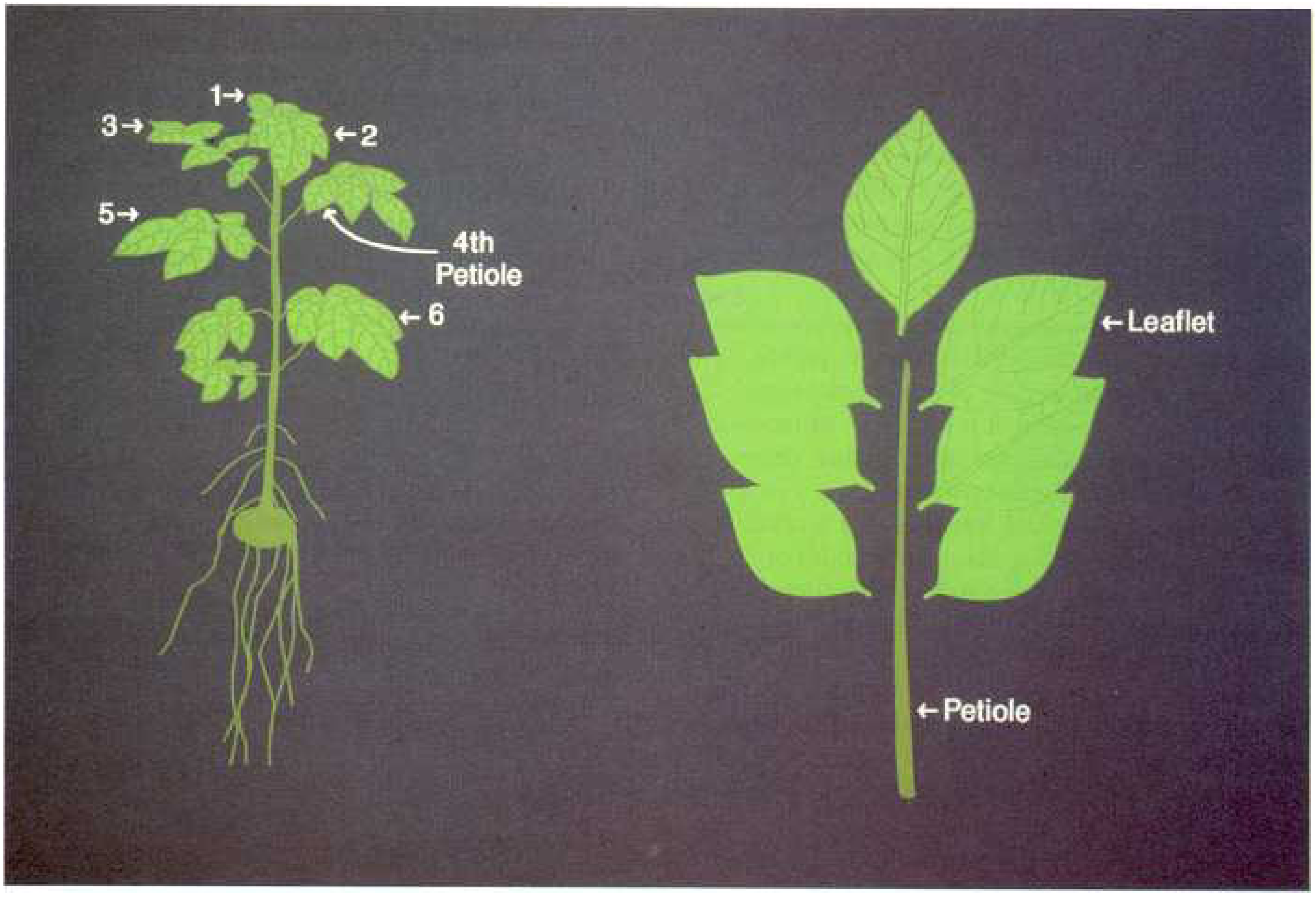

Figure 51.
Diagram of a potato plant at the 6- to 8-leaf stage when petiole sampling should begin (left). Remove all leaflets from the petiole immediately after sampling (right) (after Kleinkopf et al. 1984. Tissue Analysis: A Guide to Nitrogen Fertilization for Russet Burbank Potatoes. CIS No. 743, University of Idaho).

Table 48.
Interpretation of nitrate-nitrogen levels in potato petioles at various stages of growth. These guidelines have not been verified for potatoes grown in Arizona.

Stage of Potato Growth	Petiole NO3-N Interpretations		
	Deficient	Intermediate	Sufficient
	ppm		
6- to 8-leaves, stolons forming	<16,000	16,000 - 22,000	>22,000
Tuber initiation	<10,000	10,000 - 15,000	>15,000
Tuber growth	< 8,000	8,000 - 15,000	>15,000
Late season	< 4,000	4,000 - 10,000	>10,000

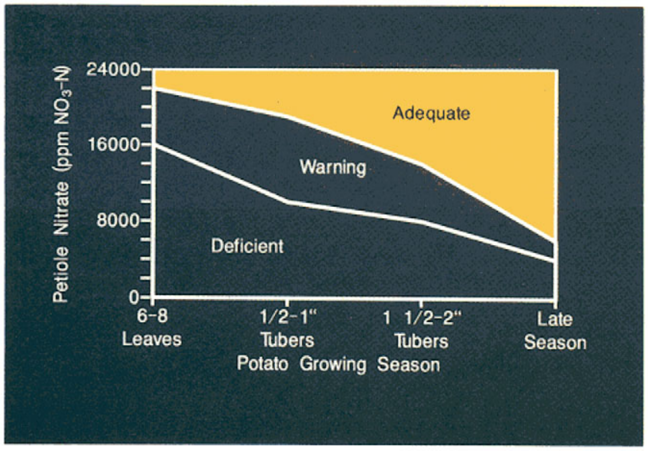

Figure 52.
Interpretation of NO_3-N levels in potato petioles at different stages of growth.

If a nitrogen deficiency is detected at any time through the 2-inch tuber stage, then an application of a nitrate or urea source is recommended. These forms of N move readily in soil solution and are immediately available to the plant roots with the first irrigation after the fertilizer has been applied. This decreases the time necessary for recovery from the nitrogen deficiency. Otherwise, the N source is of less importance because nitrification of ammonium (NH_4) forms can take place rapidly enough to permit the resulting NO_3 to be moved into the root zone to supply the needs of the crop. Caution should be used when applying ammonium sources of nitrogen such as anhydrous or aqua ammonia in order to avoid plant injury from ammonia toxicity, especially on very sandy soils.

- **Nutrient removal**

A harvest of 15 tons of potatoes per acre will contain about 100 lbs. N. The entire crop will contain about 200 lbs. N per acre.

- **Nitrogen uptake patterns**

Nitrogen uptake by potatoes is very low during the first 40 to 50 days after planting. As the stolons and vines become fully grown and tubers begin to enlarge, N flux reaches a maximum of more than 6 lbs. per acre per day. After tubers have reached their full size and vine senescence begins, N flux drops rapidly. An actual net loss of N from the whole plant prior to harvest probably does not occur. Negative N fluxes at this time probably reflect incomplete recovery of dead foliage as the plant completes its life cycle.

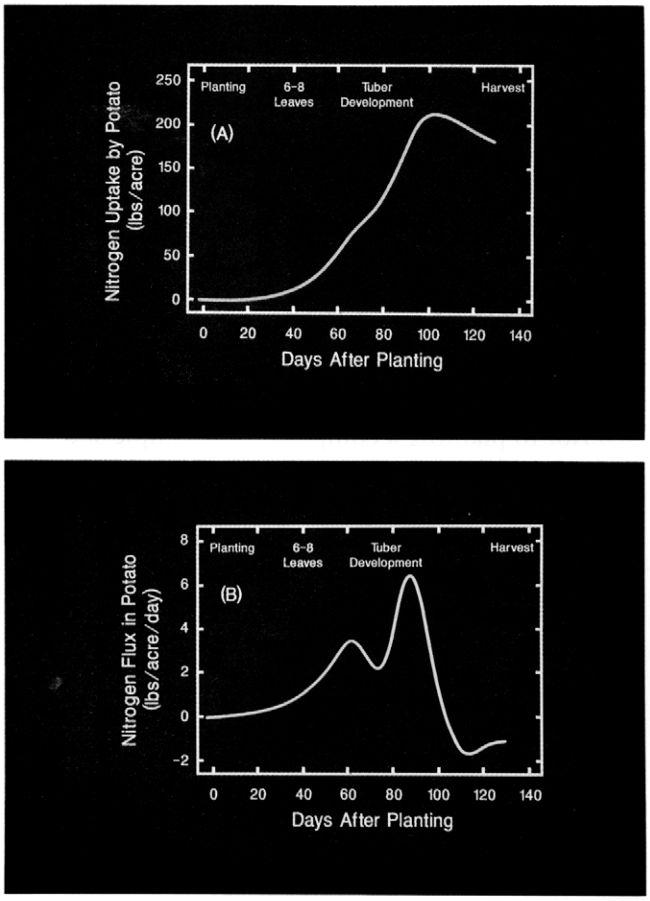

Figure 53.
Cumulative seasonal nitrogen uptake (A) and daily nitrogen flux (B) patterns for Kennebec potatoes at a yield level of 12 tons per acre.

Grain Sorghum

The level of nitrogen fertility has more influence on the growth and yield of grain sorghum than any other single plant nutrient because it is the nutrient most often deficient in Arizona soils. The amount of fertilizer N required will vary depending on the yield potential of the crop and the amount of residual N in the soil prior to planting. Preplant soil analysis can be very useful in estimating the nitrogen needs of the crop.

Fertilizer recommendations in this guide apply to all grain sorghum varieties grown in Arizona and are based on a yield potential of 6,000 to 7,000 lbs. (107 to 125 bushels) of grain per acre. Rates may need to be adjusted for significantly different yield goals.

- **Estimating crop N requirement**

Prior to planting a composite soil sample should be analyzed for NO_3-N content. Estimate the total amount of N fertilizer that is required from Table 49. Adjust this N rate as needed depending on crop appearance, mid-season plant tissue test results and previous experience.

Table 49.
Estimated seasonal nitrogen fertilizer rates for grain sorghum based on preplant soil nitrate-nitrogen levels. These guidelines have not been verified for grain sorghum grown in Arizona.

Soil Test NO_3-N	Approximate N Fertilizer Rate*
ppm	lbs./acre
0 - 10	150 - 200
10 - 20	100 - 150
20 - 50	30 - 100
above 50	0 - 30

**decrease this N rate by 60 lbs./acre if sorghum follows alfalfa.*

- **Early season nitrogen**

Up to 60 lbs. N per acre can be applied before or at planting, particularly if the NO_3-N soil test value is below 20 ppm. Nitrogen can be broadcast on the soil surface and incorporated or placed in a band two inches below and to the side of the seed. Band applications of N above 60 lbs. per acre increase the risk of salt damage to young seedlings, especially on sandy textured soils. Placement of urea (46-0-0) or diammonium phosphate (18-46-0) with or near the seed is not recommended due to the risk of seedling injury from ammonia toxicity.

- **Mid-season nitrogen**

All remaining nitrogen should be sidedressed or applied in the irrigation water between the 3- to 4-leaf stage and flowering. Applications of N after the flowering stage should only be made if a N deficiency has been positively identified.

If a nitrogen deficiency is detected at any time through the flowering stage, then application of a nitrate or urea source is recommended. These forms of N move readily in soil solution and are immediately available to the plant roots with the first irrigation after the fertilizer has been applied. This decreases the time necessary for recovery from the nitrogen deficiency. Otherwise, the nitrogen source is of less importance because nitrification of ammonium (NH_4) sources can take place rapidly enough to permit the resulting NO_3 to be moved into the root zone to supply the needs of the crop. Caution should be used when applying ammonium sources such as anhydrous or aqua ammonia in order to avoid plant injury from ammonia toxicity, especially on very sandy soils.

- **Nutrient removal**

A harvest of 7560 lbs. of sorghum grain per acre will contain about 125 lbs. N. The entire crop will contain about 185 lbs. N per acre.

- **Nitrogen uptake patterns**

The seasonal uptake of nitrogen by grain sorghum consists of three distinct phases. The first is characterized by a low but increasing N flux between the seedling and 3- to 4-leaf stage. Nitrogen flux rises rapidly to a maximum, exceeding 4 lbs. N per acre per day at the 10- to 12-leaf stage, followed by an equally rapid decline until half-bloom. Nitrogen flux during the grain filling period which follows is moderately low, generally averaging 1 to 2 lbs. N per acre per day.

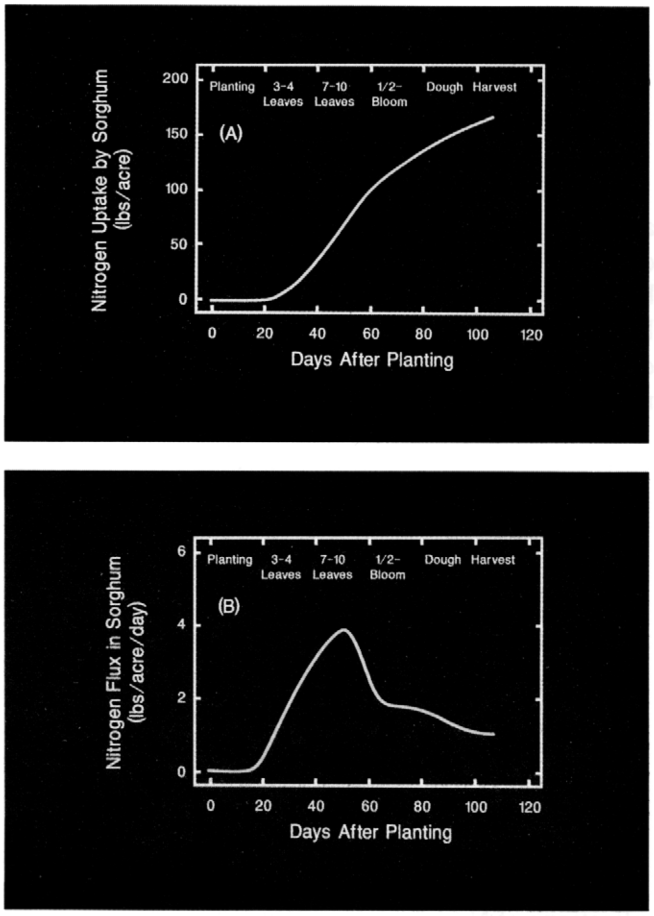

Figure 54.
Cumulative seasonal nitrogen uptake (A) and daily nitrogen flux (B) patterns for grain sorghum at a yield level of 7560 lbs. per acre (after Vanderlip. 1979. How a Sorghum Plant Develops. Publication No. 1203. Kansas State University).

Turfgrass

Plantings of turfgrass for athletic fields and other recreational activities are widespread in Arizona. Unlike other "crops" which are harvested and sold, turfgrass derives its value from its visual appearance and durability. Many interrelated management practices such as timely irrigation, pest and disease control, use of proper mowing and aeration techniques and sound fertilization practices are all necessary to grow high quality turf that can recuperate quickly under heavy use.

The fertilizer recommendations in this guide are for high quality bermudagrass turf. Rates may need to be adjusted for different levels of management and turf quality or if other turfgrass varieties are grown. With good management, a total of about 3.5 to 5.5 lbs. of N per 1000 square feet per year (150 to 250 lbs. per acre per year) are required for high quality bermudagrass turf.

- **New plantings**

Lawns, golf course fairways and athletic fields are generally intended as permanent installations. Proper seedbed preparation and amendment applications are essential if optimum responses to N fertilization are to be realized. A soil test before stand establishment can be useful in determining the suitability of a particular site for turf, as well as indicate the need for nitrogen during the establishment year.

Nitrogen should not normally be applied to newly seeded, sprigged or sodded areas. An application of 1/3 to 1/2 lb. N per 1000 square feet can be uniformly incorporated into the seedbed if the preplant soil test level for NO_3-N is below 5 ppm. Nitrogen applied to newly seeded stands may burn the tender young seedlings and encourage the growth of competing weeds.

After the grass has been mowed for the first time, apply up to 1 lb. N per 1000 square feet per month during the growing season. Acceptable growth may be achieved at lower N rates. In general, use the lowest N rate that gives adequate appearance and durability, as higher N rates usually require more mowing and maintenance.

- **Established plantings**

On established stands, the first application of N should be made as the grass begins vigorous growth in the spring. The last application should be in September or October prior to dormancy. Application rates should be about 1 lb. of N per 1000 square feet every 4 to 6 weeks, decreasing to 1/4 to 1/2 lb. N in early September. Applying excessive levels of N will usually require more mowing and maintenance and can hasten thatch buildup and increase susceptibility to disease. Soils containing 80% or more sand will require more frequent, lighter applications of N.

Municipal sewage effluent is increasingly being used to irrigate many turf plantings. In many cases effluents contain appreciable amounts of nitrogen which should be considered when formulating a nitrogen fertilizer program. A periodic test for total nitrogen content in the effluent is recommended.

Table 50.
Quantities of various nitrogen fertilizers which contain one pound of actual N.

Fertilizer Name	Fertilizer Analysis	Weight Containing 1 lb. of Actual N
	% N-P_2O_5-K_2O	lbs.
Ammonium sulfate	21-0-0	4.8
Ammonium nitrate	33.5-0-0	3.0
Calcium nitrate	15.5-0-0	6.5
Urea	46-0-0	2.1
Ammonium phosphate sulfate	16-20-0	6.2
10-6-6 Blend	10-6-6	10.0
Solution urea ammonium nitrate	32-0-0	3.1 (or 2.3 pints)

- **Importance of forms of N**

All sources of N are similar in their effectiveness if equivalent amounts of actual N are applied (Table 50).

A variety of slow-release N fertilizers may also be used on turf areas to supply N over extended periods. The convenience of using these materials rather than conventional water-soluble products must be considered in light of their higher unit cost and the unpredictability of their nitrogen release characteristics. To be effective, slow release N fertilizers should release available N at about the same rate as N is needed by the growing turf. A brief listing and description of the more common types of slow-release N fertilizers is given in Table 14 in Section II.

If manure is used, it should be applied in the fall or early spring and supplemented with other N sources during the growing season.

- **Methods of application**

Nitrogen fertilizers should be applied *uniformly* to turf areas. Application patterns with overlap or skips will give an uneven appearance. Use a well calibrated ground applicator or inject N into the irrigation water. This injection is best accomplished when using a well designed sprinkler system with uniform coverage. Solutions of ammonium nitrate, calcium nitrate, urea or ammonium sulfate are suitable for injection into pressurized sprinkler systems. Anhydrous ammonia or aqua ammonia should not be used in sprinkler or drip systems. An application of soluble N fertilizer should always be followed immediately with a thorough irrigation to rinse nutrients off the leaves to reduce the risk of foliar burning and reduce the potential for ammonia volatilization losses. Excess watering can promote N deficiency in turf by leaching soluble N below the root zone.

- **Nutrient removal**

A well fertilized bermudagrass turf will produce 3 to 5 tons of clippings per acre per year, containing about 175 to 275 lbs. N.

Watermelon

The level of nitrogen fertility has more influence on the growth and yield of watermelon than any other single plant nutrient because it is the nutrient most often deficient in Arizona soils. With good management a total of about 125 to 175 lbs. N per acre is usually needed for optimum production.

Preplant soil analysis and leaf petiole analysis during the season can be useful in monitoring the nitrogen status of the crop. Deficiencies of nitrogen at any time of the season are to be avoided, as marketable yield and general plant vigor and appearance will usually suffer. Deficiencies after fruits are 4 to 6 inches in diameter are especially serious, as nitrogen applications after this stage may not completely correct the problem.

Fertilizer recommendations in this guide apply to all watermelon varieties grown in Arizona and are based on a population of 5000 to 7000 plants per acre and a yield potential of 30 to 40 tons per acre. Rates may need to be adjusted for significantly different plant populations or yield goals.

- **Early season nitrogen**

Preplant applications of nitrogen are not often required since early season uptake of N prior to the early runner stage is very low. If the soil test value for NO_3-N taken before planting is below 10 ppm then apply 50 lbs. N per acre. Nitrogen should be broadcast on the soil surface just prior to listing and shaping of the melon beds.

- **Mid-season nitrogen**

At the 3- to 4-leaf stage of growth, collection of leaf petioles for nitrate (NO_3-N) analysis should begin. The petiole (leaf stem) from the youngest full-sized leaves should be sampled. This is normally the fourth or fifth leaf from the end of a vine (Figure 55). Do not sample petioles from diseased, damaged or unrepresentative leaves. About 25 to 50 petioles per sample are adequate for analysis. The number of samples tested from each field depends on the uniformity of the field. Samples should be collected from randomly selected plants within uniform areas representing portions of a field that can be fertilized separately. Samples should be placed in a paper bag and dried at about 150°F (65°C) or refrigerated as soon as possible and submitted to a laboratory for NO_3-N analysis.

Figure 55.
Begin collecting watermelon petioles at the 3- to 4-leaf stage, sampling the youngest full-sized leaf. Once runners begin to form, this is usually the fourth or fifth leaf from the end of the vine as shown above.

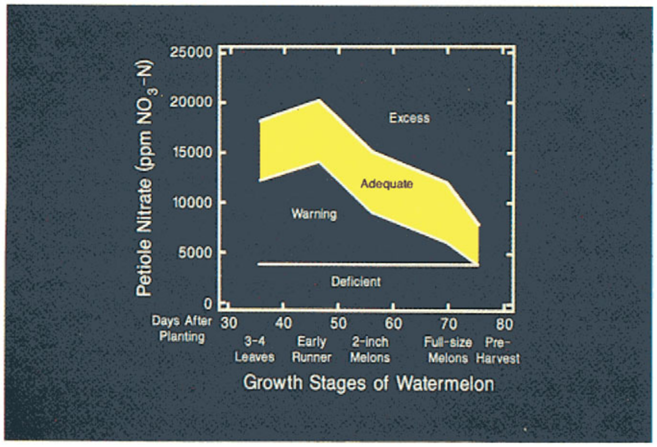

Figure 56.
Interpretation of nitrate-nitrogen in watermelon petioles at different stages of growth.

Petioles should be collected at the 3- to 4-leaf, early runner, 2-inch melon and full-size melon stages.

- **Interpretation of petiole nitrate levels**

The petiole nitrate level is normally high (with adequate soil fertility) early in the season during vegetative growth and declines as the season progresses. The interpretation of petiole nitrate values and corresponding midseason fertilizer application are shown in Table 51 and Figure 56.

Petiole nitrate concentrations should be maintained above 4000 ppm NO_3-N throughout the season. Visual symptoms of N deficiency such as

Table 51.
Interpretation of NO_3-N levels in watermelon petioles and corresponding nitrogen fertilizer recommendations at various growth stages.

Stage of Growth	Petiole NO_3-N Ranges	Apply this Amount of N Fertilizer
	ppm	lbs./acre
3- to 4-leaves	>12,000	none
	4,000 to 12,000	25 to 50
	<4,000	50 to 75
Early runner	>14,000	none
	4,000 to 14,000	50 to 75
	<4,000	75 to 100
2-inch melons	>9,000	none
	4,000 to 9,000	0 to 40
	<4,000	40 to 60
Full-size melons	>6,000	none
	4,000 to 6,000	0 to 20
	<4,000	20 to 30

pale green foliage or reduced vine growth appear when the petiole nitrates drop below about 2000 ppm NO_3-N. This should be avoided as some reduction in yield will probably occur even if the deficiency is corrected. No losses of yield or quality have been observed when high rates of N fertilization have resulted in excessive levels of petiole NO_3-N.

Applications of N after melons have reached full size but before harvest will be of little or no help in correcting late season nitrogen deficiency. This is because N uptake decreases very rapidly once melons have reached their full size. In addition, ammonium forms of N applied at this time may not have sufficient time to convert to NO_3 and thus will remain positionally unavailable to plant roots.

If the nitrate-N level is below 4,000 ppm NO_3-N prior to the full-size melon stage, then application of a nitrate or urea source is recommended. These forms of N move readily in soil solution and are immediately available to the plant roots with the first irrigation after the fertilizer has been applied. This decreases the time necessary for recovery from a nitrogen deficiency. At higher levels of petiole N, the nitrogen source is of less importance because nitrification of ammonium (NH_4) sources can take place rapidly enough to permit the resulting NO_3 to be moved into the root zone to supply the needs of the plants. Caution should be used when applying ammonium sources such as anhydrous or aqua ammonia in order to avoid plant injury from ammonia toxicity especially on very sandy soils.

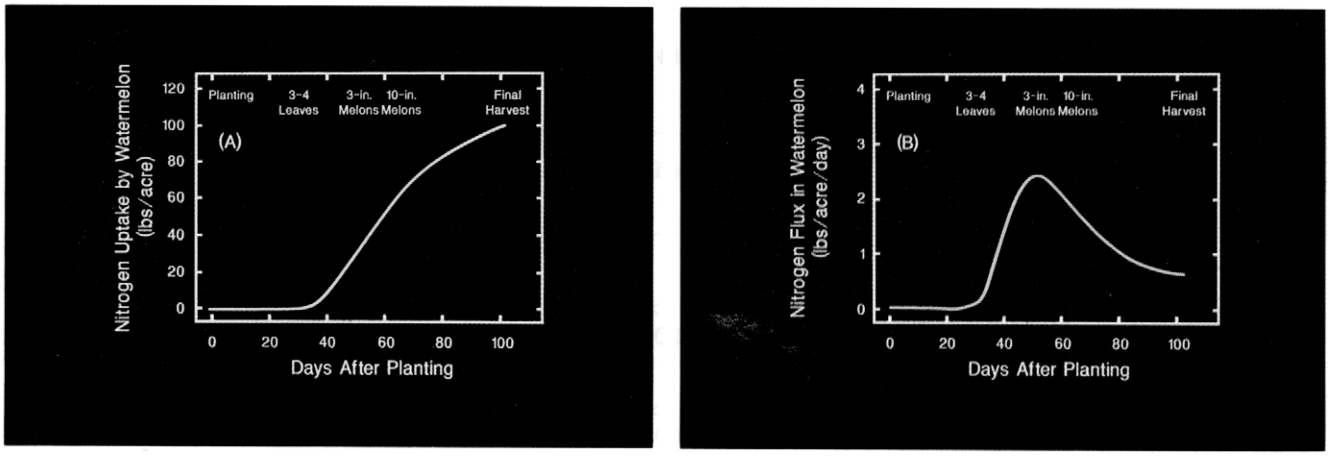

Figure 57.
Cumulative seasonal nitrogen uptake (A) and daily nitrogen flux (B) patterns for Mirage watermelon at a yield level of 40 tons per acre.

- **Nutrient removal**

A harvest of 40 tons of marketable watermelons per acre will contain about 70 lbs. N. The entire crop will contain about 100 lbs. N per acre.

- **Nitrogen uptake patterns**

Nitrogen uptake by watermelon is very slow prior to the early runner stage. Nitrogen flux increases slightly as melons begin to form and reaches a maximum of 2.6 lbs. N per acre per day as fruits grow in size. Little N is taken up after melons approach full size.

Wheat and Barley (Small Grains)

The level of nitrogen fertility has more influence on the growth and yield of small grains than any other single plant nutrient because it is the nutrient most often deficient in Arizona soils. The amount of fertilizer N required will vary depending on the yield potential of the crop, the amount of residual N in the soil prior to planting, the amount and type of crop residues previously incorporated, the soil texture and the type of irrigation system that is used. With good management, a total of about 150 to 230 lbs. N per acre is usually needed for optimum production. Preplant soil analysis and plant tissue analysis during the season can be very useful in establishing the nitrogen needs of the crop.

Fertilizer recommendations in this guide apply to all durum wheat, bread wheat and full-season barley varieties grown in Arizona and are based on a yield potential of 6000 to 8000 lbs. grain per acre. Rates may need to be adjusted for significantly different yield goals. Suggested N rates assume that basin, border-flood or other surface irrigation methods are used. Well managed drip or sprinkler irrigated small grain crops may require somewhat less N than indicated.

- **Early season nitrogen**

Applications of N before or at planting should be based on a preplant soil test for NO_3-N as shown in Table 52.

Table 52.
Suggested preplant N fertilizer rates for small grains based on soil NO_3-N content.

Preplant NO_3-N Soil Test Value	Apply this Amount of N*
ppm	lbs./acre
0 to 5	50 to 75
5 to 10	0 to 50
above 10	0

**Add 15 lbs. N per acre per ton of non-legume residue recently incorporated, up to an additional 50 lbs. N per acre.*

Nitrogen can be broadcast applied prior to planting and shallowly incorporated, injected into the surface soil or placed with the seed at planting. On sandy soils, ammonium containing fertilizers such as ammonium sulfate (21-0-0), monoammonium phosphate (11-53-0), ammonium phosphate-sulfate (16-20-0) or solution ammonium polyphosphate (10-34-0) should be used rather than predominately nitrate or urea sources. Rates of banded N above 30 lbs. N per acre increase the risk of injury to germinating seedlings. Placement of urea (46-0-0) or diammonium phosphate (18-46-0) with or near the seed is not recommended due to the risk of seedling damage from ammonia toxicity. Anhydrous or aqua ammonia should be injected 6 to 9 inches below the soil surface prior to planting and should never be placed near the seed zone.

- **Mid-season nitrogen**

At the 3- to 4-leaf stage of growth, collection of lower stem samples for NO_3-N analysis should begin (Figure 58). The stem tissue between ground level and the seed should be sampled prior to the jointing stage and the 2 inches of stem above the ground level should be collected thereafter (Figure 59). Do not sample stems from damaged or unrepresentative plants. About 25 to 50 lower stems are adequate for analysis, depending on the size of the plants at the time of collection. The number of samples tested from each field depends on the uniformity of the field. Stem samples should be collected from randomly selected plants within uniform areas representing portions of a field that can be fertilized separately. Samples should be placed in a paper bag and dried at about 150°F (65°C) or refrigerated as soon as possible and submitted to a laboratory for NO_3-N analysis.

Figure 58.
Begin collecting stem tissue samples at the 3- to 4-leaf stage (above).

Figure 59.
The lower stem tissue between ground level and the seed should be sampled prior to the jointing stage (above).

Most N is broadcast applied just prior to an irrigation or injected into the irrigation water. For this reason it is suggested that stem samples be collected 7 to 10 days prior to each surface irrigation event before anthesis so that laboratory results will be available to guide mid-season N applications as shown in Table 53 and Figure 60.

Table 53.
Recommended sampling dates and interpretation of lower stem NO_3-N levels for intensive nitrogen management of surface irrigated small grains in Arizona.

Stem Sampling Dates	Stem NO_3-N Levels	Suggested N Fertilizer Rates*
growth stage	ppm	lbs./acre
3-4 Leaves	>5000	None**
	2000 - 5000	0 - 50
	<2000	50 - 100
	>3000	None
	1000 - 3000	0 - 50
	<1000	50 - 75
	>3000	None
	1000 - 3000	0 - 30
	<1000	30 - 60

**Decrease N rates by 20% for barley crops or if expected wheat yields are less than 5400 lbs. grain per acre.*

***Apply 30 lbs. N per acre regardless of the stem NO_3-N content at the 3-4 leaf stage if the preplant soil test for NO_3-N was below 10 ppm.*

A timely application of N fertilizer can prevent or slow the decline of stem nitrate. If the NO_3-N level is below 2000 ppm prior to jointing or below 1000 ppm prior to heading, then application of a nitrate or urea source is recommended. These forms of N move readily in soil solution and are immediately available to plant roots with the first irrigation after the fertilizer has been applied. This decreases the time necessary for recovery from a nitrogen deficiency. At higher levels of stem NO_3-N, the nitrogen source is of less importance because nitrification of ammonium (NH_4) sources can take place rapidly enough to permit the resulting NO_3 to be moved into the root zone to supply the needs of the plants.

All forms of N are equally effective after the mid-tillering stage if the same amounts of actual N are applied. This assumes sound management is practiced with respect to the N form used and that severe N deficiencies have not occurred. However, caution should be used when applying ammonium sources of N such as anhydrous or aqua ammonia in order to avoid plant injury from ammonia toxicity, especially on very sandy soils.

An application of 20 to 30 lbs. N per acre in conjunction with the irrigation event occurring closest to the anthesis stage is effective in reducing the incidence of yellowberry and boosting grain protein levels. However, N applications at this time will rarely affect grain yield. Nitrogen applications are not normally needed after anthesis except perhaps on very sandy soils.

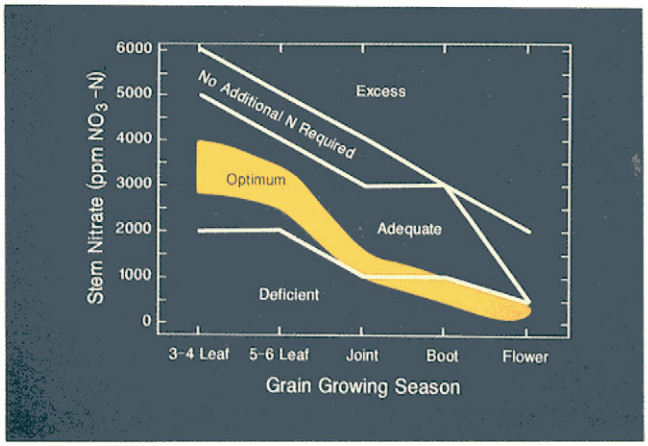

Figure 60.
Interpretation of lower stem NO_3-N concentrations in small grains at various stages of growth.

- **Nutrient removal**
  A harvest of 6700 lbs. of durum wheat per acre will contain about 175 lbs. N. The entire crop will contain about 230 lbs. N per acre.

- **Nitrogen uptake patterns**
  Nitrogen uptake in small grains proceeds very slowly until tillering begins. Nitrogen flux increases to a maximum of over 2.5 lbs. N per acre per day during the jointing stage. The N flux then decreases rather gradually over the remainder of the growing season, averaging between 0.5 and 1.5 lbs. N per acre per day during the grain filling period.

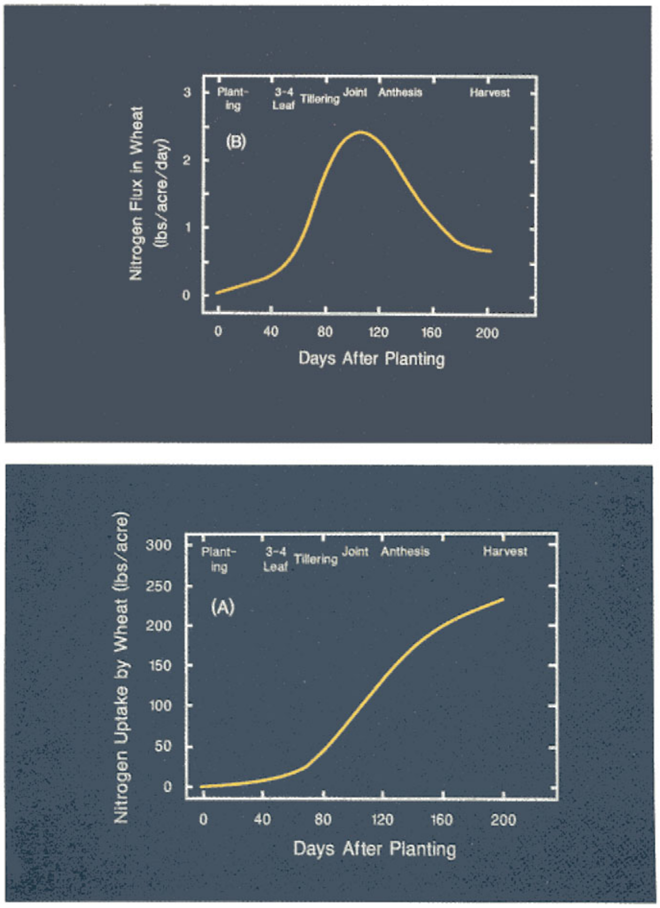

Figure 61.
Cumulative seasonal nitrogen uptake (A) and daily nitrogen flux (B) patterns for Aldura durum wheat at a yield level of 6700 lbs. per acre.