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.

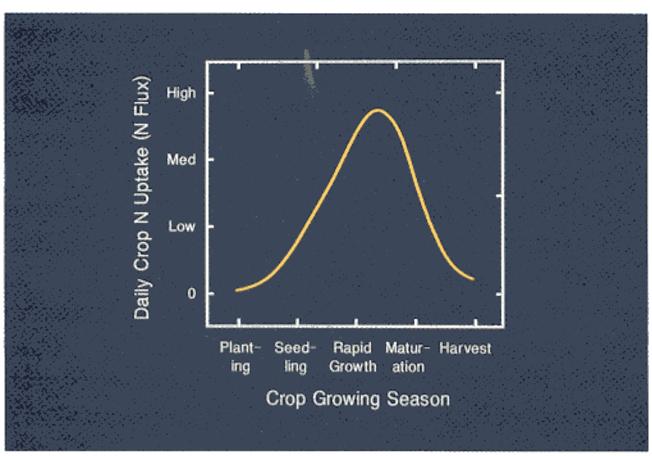

Figure 15.
Generalized pattern of daily nitrogen uptake (N flux) by annual crops.

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

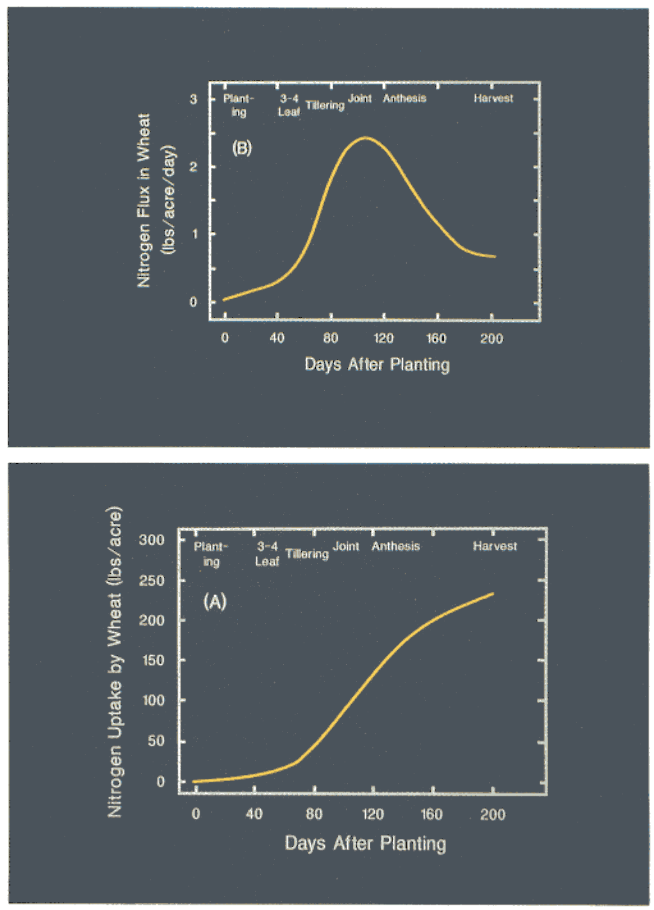

Figure 16.
Cumulative (A) and daily (B) nitrogen uptake patterns for a durum wheat crop yielding 6700 lbs. grain per acre.

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).

Soil Texture	Preceding Crop*	Preplant Soil Test NO3-N	Optimum N Application Schedule** — Times of N Application: 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.*

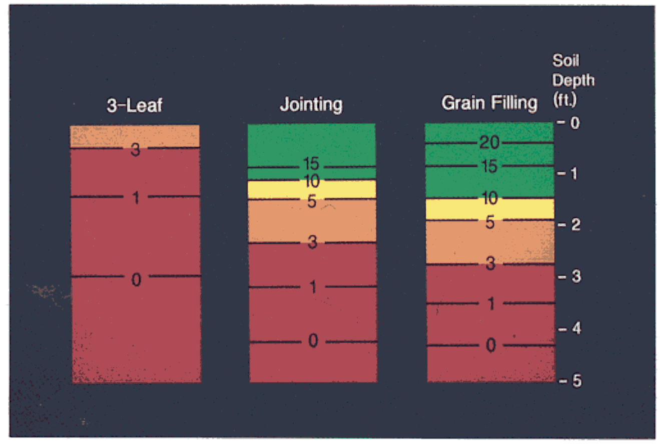

Figure 17.
Measured root densities in basin irrigated durum wheat at three stages of growth. Densities are in number of roots per square inch.

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.

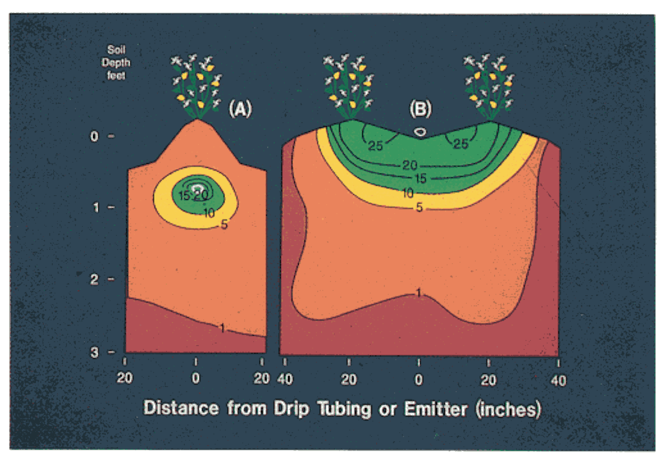

Figure 18.
Measured root densities in subsurface (A) and surface (B) drip irrigated Upland cotton. Densities are in number of roots per square inch measured at the peak bloom stage.

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.

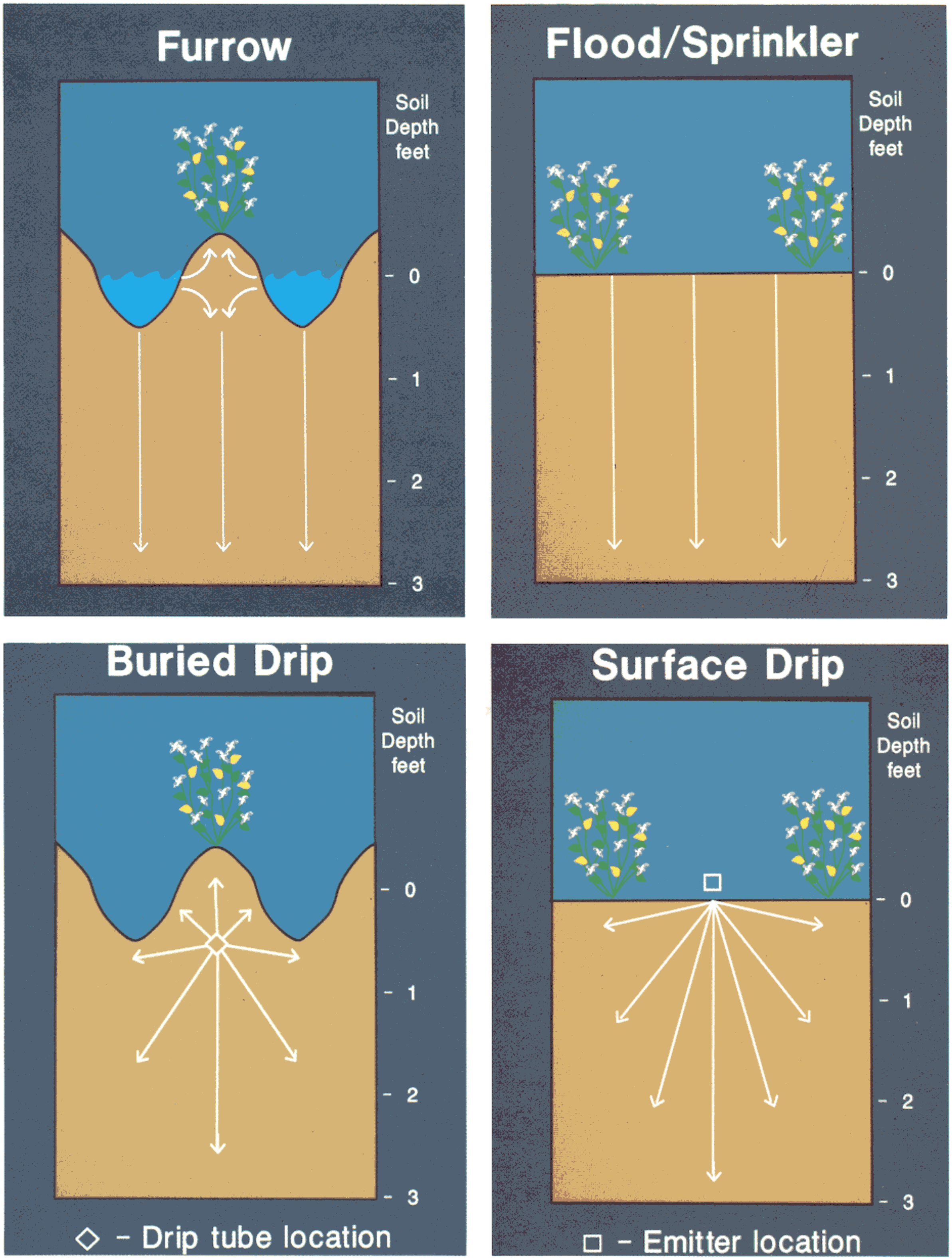

Figure 19.
Soil profile diagrams showing the direction of irrigation water movement into the soil for the irrigation methods commonly used in Arizona.

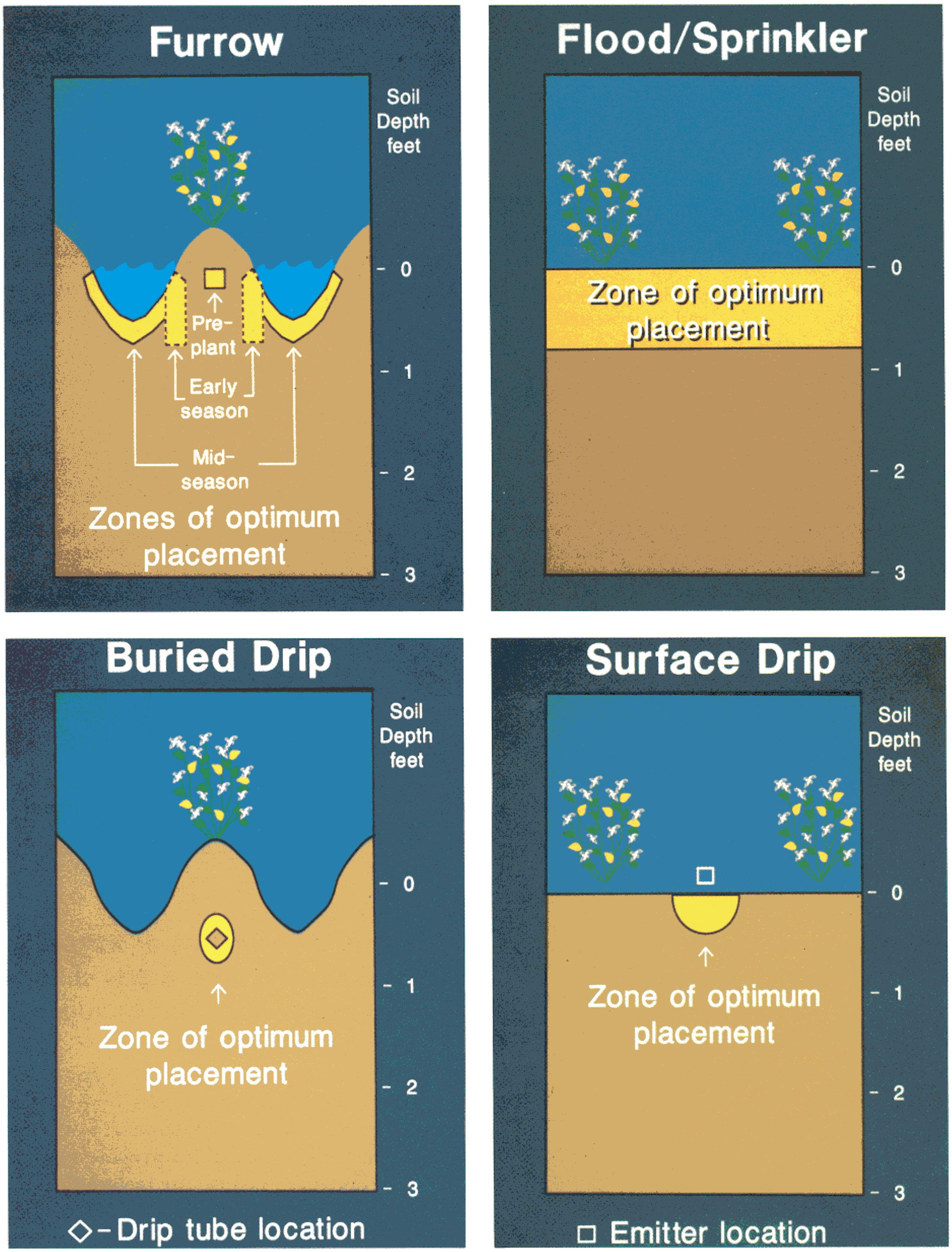

Figure 20.
Soil profile diagrams showing the zone(s) of optimum nitrogen fertilizer placement in conjunction with the irrigation methods commonly used in Arizona.

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