THE SOIL PROFILE

A newsletter providing information on issues relating to soils and plant nutrition in New Jersey

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Comparative Crop Nutrient Demand and Fertilizer Practice

In New Jersey, a great variety of horticultural and agronomic crops are grown on a wide range of soils. While all of these crops require the same seventeen essential elements, fertilizer practice varies by amount and timing of nutrient application. In any given crop-soil combination, the objective is to synchronize crop demand for nutrients with supply from the soil. An understanding of the physiology of crop demand for nutrients is therefore crucial to optimizing fertilizer practice for individual crops. Although both plant and soil testing are useful to monitor nutrient status and guide fertilizer practice, any interpretation of the test results must also consider each crop's unique physiology and how it regulates nutrient demand, and furthermore how that demand varies with stage of growth.

The objective of this article in comparative crop nutrition is to examine how crop characteristics influence nutrient demand and thereby fertilizer practice. This issue of The Soil Profile will primarily focus on N because N is a nutrient that has a dominating influence on plant growth and development (another reason to focus on N is that fertilizer applied P and K are more stable in soil, and time of application is less critical). Also, the seasonal pattern of N uptake by a particular crop is often closely tied to the patterns of vegetative and reproductive growth. In general, the period of most rapid N uptake by a crop corresponds with the period of most rapid vegetative growth. Leaf tissue is a major reservoir of nitrogenous compounds such as protein. On a dry matter basis, leaf tissue N concentrations are typically in the range of 2 to 6% N. About half of the total leaf protein is present in one photosynthetic enzyme, (ribulose–1,5-bis phosphate carboxylase) which is probably the most abundant enzyme in nature. Thus, crop demand for N is in large part a function of leaf area development and its vital role in photosynthesis.

Comparative plant nutrition may be defined as a study in how characteristics of various crops influence nutrient demand and fertilizer practice. That fertilizer practice varies depending on the crop may seem obvious, yet understanding of the physiology of crop nutrient demand is less well appreciated but crucial to knowing how to optimize fertilizer practice for individual crops. For purposes of discussing concepts in comparative plant nutrition, crops are placed into several broad classifications: Annual Crops, Herbaceous Perennial Crops, Deciduous Woody Perennial Crops, Evergreen Perennial Crops, and Leguminous Crops (Table 1). Specific crops from each category will sometimes be used to illustrate concepts.

Annual Crops

Annual crops, which reach maturity within a single growing season, have been extensively studied and characterized with respect to growth pattern and N uptake. Typical patterns of dry

Table 1. Functional crop categories with respect to nutrient demand and fertilizer practice with a focus on nitrogen.

- Annuals (corn, wheat, barley, cabbage, cucumber, lettuce, etc.)
- Deciduous Woody Perennials (tree fruit, grape, etc.)
- Evergreen Woody Perennials (Christmas trees, holly, etc.)
- Herbaceous Perennials (turfgrass, forage grass, etc.)
- Legumes (soybean, alfalfa, snap bean, lima bean, peas, etc.)

matter and N accumulation for annual crops are shown in Fig. 1 and 2. The accumulation of dry matter over the growing season may also be viewed as a measure of net photosynthesis over time. The accumulation of N by an annual crop over the growing season has a pattern that is similar to dry matter accumulation. This suggests that the accumulation of dry matter and N are closely linked. Nitrogen accumulation, however, more closely follows the pattern of dry matter accumulation during vegetative growth than during reproductive growth and maturation. This is because the maturing crop slows the uptake of N, as much of the N already in the plant is redistributed from vegetative tissues to reproductive tissues. The important point with respect to fertilizer practice is that the pattern of N uptake by an annual crop is approximated by its pattern of growth, and that this pattern suggests the appropriate times for soil nitrate testing and N fertilization.

Best Fertilizer Practices for Annual Crops

Information about the total amount of N accumulated by an annual crop and its pattern of N uptake during the growing season suggests the following best fertilizer practices for N application:

1. The total amount of N accumulated in the biomass of a mature crop is a useful factor to consider in determining the N requirement of the crop. However, the amount of fertilizer N to apply is often different than the crop's total N uptake. Additional considerations that go into the development of an N fertilizer recommendation include crediting N available from the soil and the efficiency of fertilizer N uptake by the crop. For grain crops, such as corn, the maximum economic yield is also a consideration. This refers to the point where the value from a yield increase from applied N just equals the cost of the additional unit of fertilizer to get that increased yield. In the case of vegetable crops, the potential detrimental effects of excess N on crop quality are also important considerations that could limit N application. Another consideration with some vegetable crops, such as lettuce, spinach, or cole crops, is that the crop is harvested before physiological maturity. For these crops, the total N accumulation is based on the N accumulation at the harvest growth stage rather than physiological maturity.

2. The pattern of cumulative N uptake over the growing season follows a sigmoid curve that may be divided into three phases. The first of the phases is a period of slow N uptake, which corresponds with slow early plant growth. Because demand for N early in the growing season is relatively low, it can be satisfied with small applications of N. The N fertilizer should be placed where it can be intercepted by the roots of

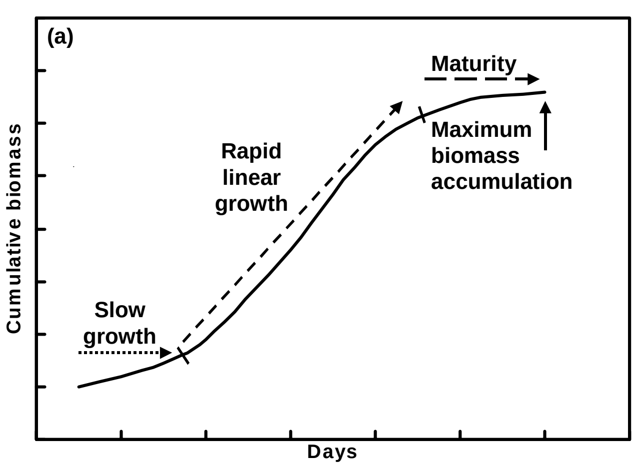

Fig. 1. Typical biomass accumulation curve for annual crops.

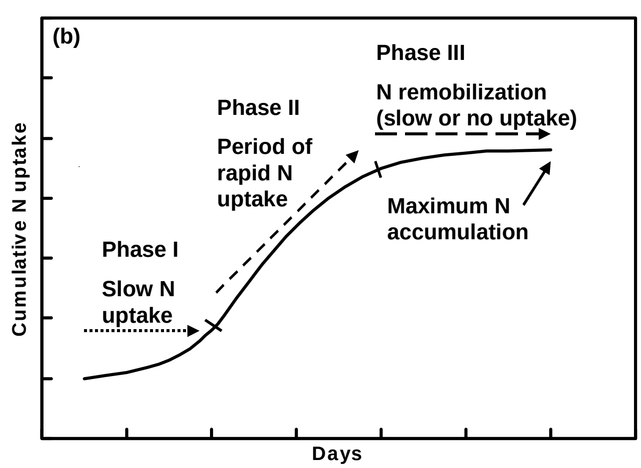

Fig. 2. Typical N accumulation curve for annual crops.

the young plant but not so close as to cause burning. This fertilizer placement, which may use a blend of NPK, is generally applied at the time of planting and is often referred to as starter fertilizer. In the case of transplanted crops, some fertilizer may be applied in solution with the transplant water.

3. In the second phase of the sigmoid curve, there is a period of rapid N uptake, which corresponds with rapid vegetative growth. Demand for N during this growth phase is the highest of the growing season. As much as 50 to 85% of the total N uptake for the growing season is taken up during this growth phase. It is important to be familiar with the growth pattern of the particular annual crop so that this growth phase can be anticipated. Any needed N fertilizer should be applied in advance of this growth phase to insure that N is not limiting. The value of soil nitrate testing performed before the second growth stage is that the soil nitrate N concentration can be used to predict whether the supply of N from soil is adequate to meet the demands of the second growth phase. Another practical concern is the rapidly increasing size of the crop and canopy closure may make later application of fertilizer difficult. Where fertilizer can be applied with irrigation water, such as with trickle systems, it may be advantageous to split fertilization into a series of applications during this growth phase. Split applications of N can also increase the efficiency of N fertilizer use and reduce the risk of N leaching.

4. Another important consideration that may influence fertilizer practice during the rapid growth phase is the maximum rate of N uptake (which occurs at the point of greatest slope on Fig. 2). Depending on the crop (Table 2), the maximum rate of N uptake may range from about 2 lbs N/acre/day to possibly as high as 10 lbs N/acre/day. Soils must be capable of supplying N at a rate that matches the maximum rate of N uptake by the crop. For crops that have a relatively low maximum rate of N uptake, slow release N fertilizers or N that becomes available from mineralization of soil organic matter may be able to satisfy the crop's peak rate of demand for N. However, crops such as corn, which has among the highest rates of N uptake, often need to be fertilized with a soluble N source in order to satisfy the peak rate of demand for N.

Table 2. Annual crop maximum N uptake rate.

Crop	lbs N/acre/day
Corn	8 to 10
Wheat	2 to 3
Broccoli	4 to 7
Cauliflower	2 to 4
Potato	4 to 5
Onion	1 to 2

5. In the third phase of the sigmoid curve, vegetative growth (stems, leaves, etc.) has largely ended while reproductive structures (seed, fruit, tubers) are in development. As the crop approaches maturity, N is redistributed within the plant from vegetative to reproductive tissues. Nitrogen uptake from soil is slow. Applying N fertilizer during this final growth phase is seldom effective for increasing crop yields. Late applications of N may also slow maturation and reduce crop quality. A possible exception where late season N fertilization may be useful is on an indeterminate fruiting crop such as tomato or pepper.

Summary of Fertilizer Practices for Annual Crops

- Apply a relatively small amount of N for crop establishment and early growth.

- Where soil nitrate tests are being used to predict if sidedress N fertilizer is needed, the soil samples should be collected before the second growth phase.

- Anticipate the period of rapid vegetative growth and apply most of the N fertilizer just before this period.

- Soluble N sources should generally be used on crops, which exhibit very rapid N uptake over a short growth period.

- Slow release sources of N may be appropriate for crops with relatively slow rates of N uptake over a longer growth period.

- Avoid application of N late in the season following the peak growth period.

- After harvest, grow a cover crop to retrieve residual N from soil.

Deciduous Woody Perennial Crops

Deciduous woody perennial crops may include any tree or woody ornamental. Tree fruit crops, such as apple and peach, have received more research attention and are better understood than most other woody perennial crops. While deciduous tree fruits will serve as the model crop, much of the discussion to follow likely pertains to woody perennials in general. The principals outlined below should be applied with caution to other woody perennials until confirmed by specific crop research.

A major factor influencing fertilizer practice for tree crops is that they have the capacity to store nutrients and carbohydrates in woody tissues (twigs, stems, bark, and roots) from the present growing season for use in the next. The fertilizer program for tree crops should therefore be developed in the context of observations on growth, yield, and leaf tissue analysis from the previous season along with any cultural objectives of the current and subsequent growing season. Information on seasonal patterns of nutrient uptake and nutrient cycling within trees is critical in developing nutrient management programs for orchards. For example, knowing when the periods of high nutrient demand and uptake by trees are likely to occur may serve as a guide to timing fertilizer applications which may lead to improved recovery of applied nutrients.

Nitrogen uptake by deciduous trees may occur throughout the year, but demand for N fluctuates over the growing season depending on the strength of the various vegetative and reproductive sinks for N. In general, N uptake is at its lowest point when leaves are absent, and at some point when leaves are present, the peak rate of N uptake occurs. For tree fruit crops, the peak demand for N occurs during the summer period when there is a high demand for N in developing leaf tissue and fruit.

The amount of N uptake during a single year is generally small in relation to the total amount of N already present in the biomass of a mature tree. The capacity of trees to recycle a pool of N internally from season to season influences tree demand for N and this has an effect on regulating N uptake. The temporal pattern of N reutilization within trees is key to understanding N demand and N uptake.

In the spring before bud break there is very little uptake of N from the soil into the woody parts of the tree. There is also little N uptake from the soil during the first spring growth flush. The developing new leaf, shoot, and flower tissue is furnished with N primarily from nutrient reserves accumulated in bark and wood of roots, trunk, and stems during the previous year. During the second flush of shoot growth, the tree has an increasing demand for external N, which is accompanied by increasing N uptake from the soil.

Trees generally respond well to application of N fertilizer towards the end of the first spring growth flush. In deciduous fruit trees, this timing of initial N application may correspond with approximately 4 to 6 weeks after bud break. The peak demand for external N (uptake from soil) is generally expected to occur in late spring or early summer. Most of the season’s total N fertilizer should be applied in advance of this peak demand. The amount of N fertilizer to apply depends on tree age or size but application rate should be adjusted based on other growth and cultural factors to be discussed later.

A significant portion of the N absorbed during summer becomes stored in woody perennial tissues. Also in late summer, soon after maximum leaf area expansion, the N concentration in leaf

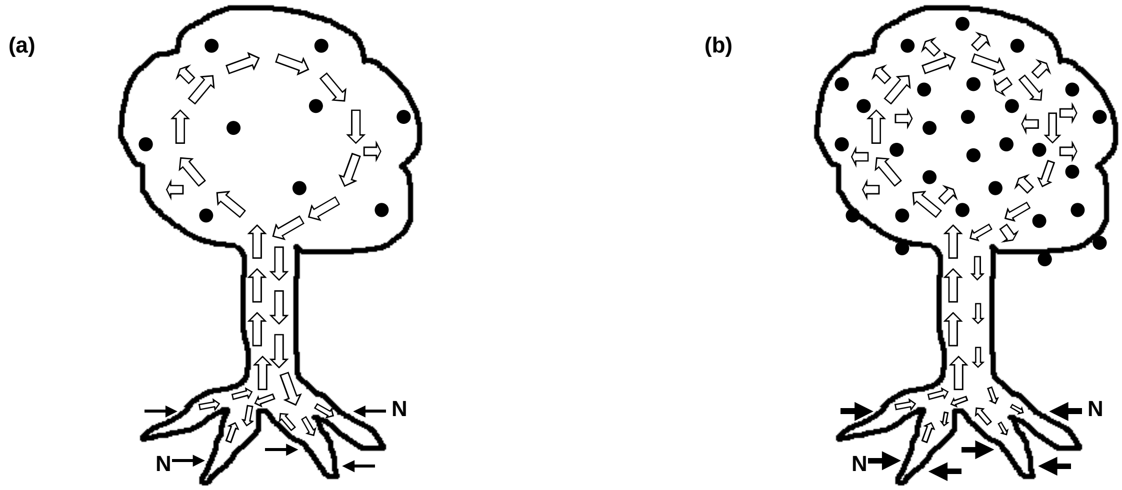

Fig 3. A tree with a small fruit load (a) has a larger pool of cycling amino N that inhibits N uptake from soil. A tree with a large fruit load (b) has a depleted pool of cycling amino N that has less inhibition of N uptake from soil. Arrow size and direction illustrates the amino N concentration in the tree and demand for N uptake from soil. (Adapted from Youssefi et al. 1999)

tissue begins to decrease as N is exported from leaves to perennial tree parts. This process marks the onset of senescence when protein is exported from leaf tissue to storage in woody perennial tissues. As much as half of the N in leaves may be remobilized to storage tissues. This reabsorbtion of leaf N by deciduous trees conserves N that would otherwise be lost by leaf abscission. The stored N is used to support the initial tree growth and development the following spring. New shoot growth in the spring is correlated with the amount of N held in storage tissues over winter.

Proteins are the major chemical form in which trees store N, but amino acids are the primary chemical forms of N that move within the tree from senescing leaves in the fall to woody storage tissues and from storage back to developing tissues in the spring. The pool of amino-N that cycles within the vascular system of the tree has a regulatory influence on N uptake. When this cycling pool of amino-N is large, such as during the spring growth flush, N uptake from soil is inhibited. As the pool of amino-N becomes depleted, there is less inhibition on N uptake by the roots and greater N uptake from the soil is allowed. A heavy fruit load also draws from the pool of cycling amino N and reduces the inhibition on N uptake from the soil. In the fall with the onset of senescence, the pool of cycling amino N increases as leaf N is mobilized to storage tissues and N uptake by roots from the soil is again inhibited (Fig. 3).

In summary, N fertilizer practice should be coordinated with the cycles of plant demand for N. Plant growth rate largely determines the rate of N uptake from the soil. In perennials, however, the changing seasonal supply N stored internally also regulates N uptake from the soil.

In general, deciduous woody perennial crops should receive the major portion of their seasonal N application just after the initial flush of spring growth. Apply the N in advance of the second flush of growth. This should coincide with the peak demand for N and improve recovery and efficiency of fertilizer N. Late season and excess applications of N should be avoided because this may increase the susceptibility of buds and perennial tissues to cold injury. The N application rate should be adjusted based on a leaf tissue analysis performed the previous season and coordinated with cultural practices to minimize plant disease and enhance crop quality. In the case of fruit trees, N management should consider the potential influence of N supply on the fruit quality, vigor of shoot and spur growth, and flower development and fruit set in the following growing season.

Another advantage of delaying a portion of a fruit crop's total N application until after fruit set is that this practice allows for adjustment of the N fertilizer rate in the even of a late spring frost.

Annuals verses Perennials

A common principal of N nutrition in all plants is that N promotes growth and leaf expansion. Export of N from senescing leaf tissue occurs in both annual crops and perennial crops. In annual crops this remobilized N is stored in seeds, while in perennial crops it is stored primarily in woody tissues. In either case, the function of this stored N is to support the initial growth in the following season. It should be noted here that there is a close connection between carbohydrate and N metabolism/storage in both annual and perennial crop tissues. The pool of N and carbohydrates stored in seeds is probably more limited than the pool of N and carbohydrates stored in woody perennial tissues. This factor, along with the shorter growth and smaller root system of the annual crop, accounts for why the N supply must be more concentrated and immediately available to annual crops. This also explains why managing the nutrition of annuals emphasizes soil testing while for perennials the emphasis is on plant tissue analysis.

Evergreen Woody Perennials

Evergreen woody perennials are similar to deciduous woody perennials with aspect to storage of nutrients in woody tissues over winter and use of these reserves during growth resumption in spring. The major difference is that newly developed leaves/needles do not senesce within the period of one season. Leaves or needles may be present for two or more years but nevertheless the eventual onset of senescence is similarly accompanied by an export of leaf/needle N to storage (or into new growth). Fertilizer practice for evergreen woody perennials is similar to deciduous woody perennials - the major N application should be scheduled to correspond with the expected period of major N uptake. A possible important difference, however, is that an evergreen which remains photosynthetically active in the fall may continue to take up N from the soil much later in the season.

Herbaceous Perennial Crops

In New Jersey, important herbaceous perennial crops include turfgrasses, forage grasses, strawberry, asparagus, horseradish and rhubarb. Just as with woody perennials, carryover of some accumulated nutrients and carbohydrates from the current growing season supports the initiation of growth the following spring. Roots or crowns are the primary storage organs of herbaceous perennials. Grasses, which have fine roots, probably have a lower capacity to store nutrients and carbohydrate reserves than herbaceous perennials having thicker roots or large taproots.

Nutrient demand from the soil by an herbaceous perennial crop is largely a function of its growth potential, stored nutrient reserves, and the status of environmental factors that determine growth rate. Cultural practices related to the purpose for which the crop is being grown are also a factor. In general, herbaceous perennial crops are not grown in New Jersey to produce seed. These crops are typically managed to keep them in a perpetual vegetative state. The vegetative growth phase is also associated with rapid leaf growth and a high demand for N uptake.

Kentucky bluegrass, for example, may be grown for turfgrass in a well-maintained lawn, or it may be grown as a forage crop. In either case, the management practices associated with crop purpose, such as mowing schedule, will influence the pattern of regrowth and hence the temporal pattern of Kentucky bluegrass demand for N (Fig. 4).

Although herbaceous perennials exhibit some common features as a group, individual growth habits suggest a need to discuss some of them separately. For example, cool season and warm season grasses have obviously different temporal patterns of growth and N demand. The discussion will begin with cool season grasses (Fig. 5).

In general, most of the growth of cool season grasses is concentrated in the early part of the growing season (May and June). This is also the period during which these grasses have their greatest demand for N from the soil. If soil moisture and temperatures are favorable, growth and demand for N will continue at a moderate rate through July and August. However, in the case of hot dry summer conditions, cool season grasses grow very slowly or may even go dormant. Applying N under these conditions may be detrimental to plant health. Cool season grasses respond favorably to the cooler temperatures of late summer and fall with increased growth and demand for N.

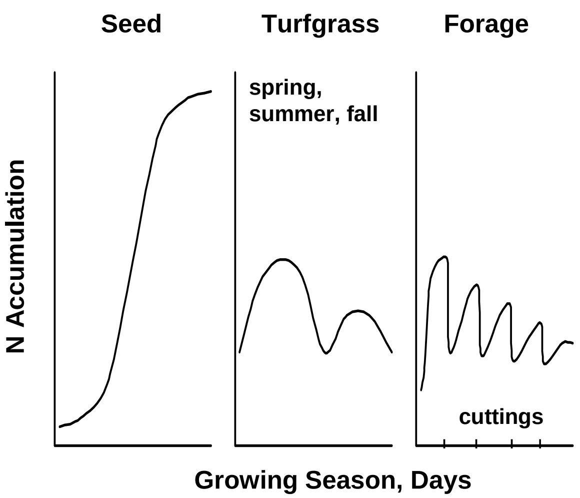

Fig. 4. An illustration of how N demand varies depending on how Kentucky bluegrass, for example, is managed.

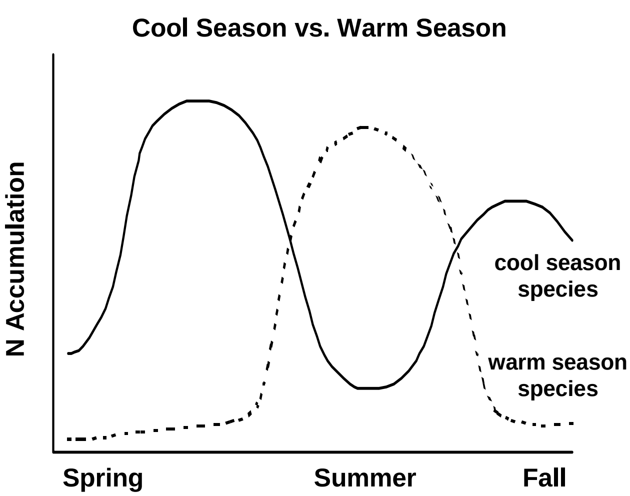

Fig. 5. An illustration of how N demand is different for cool season and warm season turfgrasses.

During periods of rapid growth, grasses have a very high demand for N and are very responsive to N fertilization. Scheduling of N applications or regulating N supply is an important cultural practice that varies depending on the purpose of the crop. In the case of grasses grown for forage or hay, the objectives of N applications are to promote rapid growth and maximum economic dry matter production of each cutting. Nitrogen should be applied to a grass hay crop early in the spring as growth begins and immediately after each harvest of hay. Dry matter production, however, is not the objective when grasses are grown for turf. Nitrogen supply to turf grass is carefully regulated by either frequent low application rates of N or by use of controlled release N products.

Heavy N applications to turf can cause extensive shoot growth, decreased carbohydrate storage, suppression of root development, and increased susceptibility to environmental stresses and diseases. Nitrogen deficient turf has poor color and density, is slow to recover from wear and cutting, is more susceptible to diseases, and has a low competitiveness against weeds. The objective of turf grass management with respect to N fertilization is to provide a continuous level of N inputs to maintain vegetative growth with the desired turf color and density while minimizing the undesirable qualities associated with either over or under fertilization. To accomplish this objective, total seasonal N applications to turf grass for cool season species are typically split about equally between spring and fall applications with perhaps some limited N applied in summer. Although shoot growth is slower in the fall than in the spring, late fall application of N is widely acclaimed to benefit winter turf color, improve root development, promote carbohydrate production and storage, and early spring green-up.

Warm season turf grasses, in contrast with cool season species, grow slowly in the spring and most rapidly during the summer (Fig. 5). This period of rapid growth during the warm summer months is associated with the highest demand for N. Nitrogen fertilizer should therefore be applied to have N available for uptake late in the spring after the arrival of warm weather and throughout the summer months.

Leguminous Crops

Important leguminous crops for New Jersey include soybean, forage legumes such as alfalfa, red and white clover, and vegetable legumes such as snap beans, lima beans, and peas. Soybean and the forage legumes are generally self-sufficient with respect to N supply because these crops, when properly inoculated, are effective at symbiotic N_2-fixation. The vegetable legume crops are considered to be less effective at symbiotic N_2-fixation and therefore typically receive applications of N fertilizer. Nitrogen fertilization of snap beans, lima beans, and peas is similar in practice to that of other annual vegetable crops.

Summary

Specific recommendations are available in the Rutgers Cooperative Extension Production Guides for fertilization of the major crops grown in New Jersey. Nevertheless, becoming familiar with and being conscious of the unique characteristics of a particular crop can serve to guide and improve fertilizer practice. The principles of comparative crop nutrient demand and fertilizer practice, as described in this newsletter, can be especially helpful when new crops are introduced for which we do not yet have official recommendations. In that case, consider the crop category and become familiar with its growth habit. In general, apply any needed N fertilizer in concert with the growth phases and management aspects of the crop.

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