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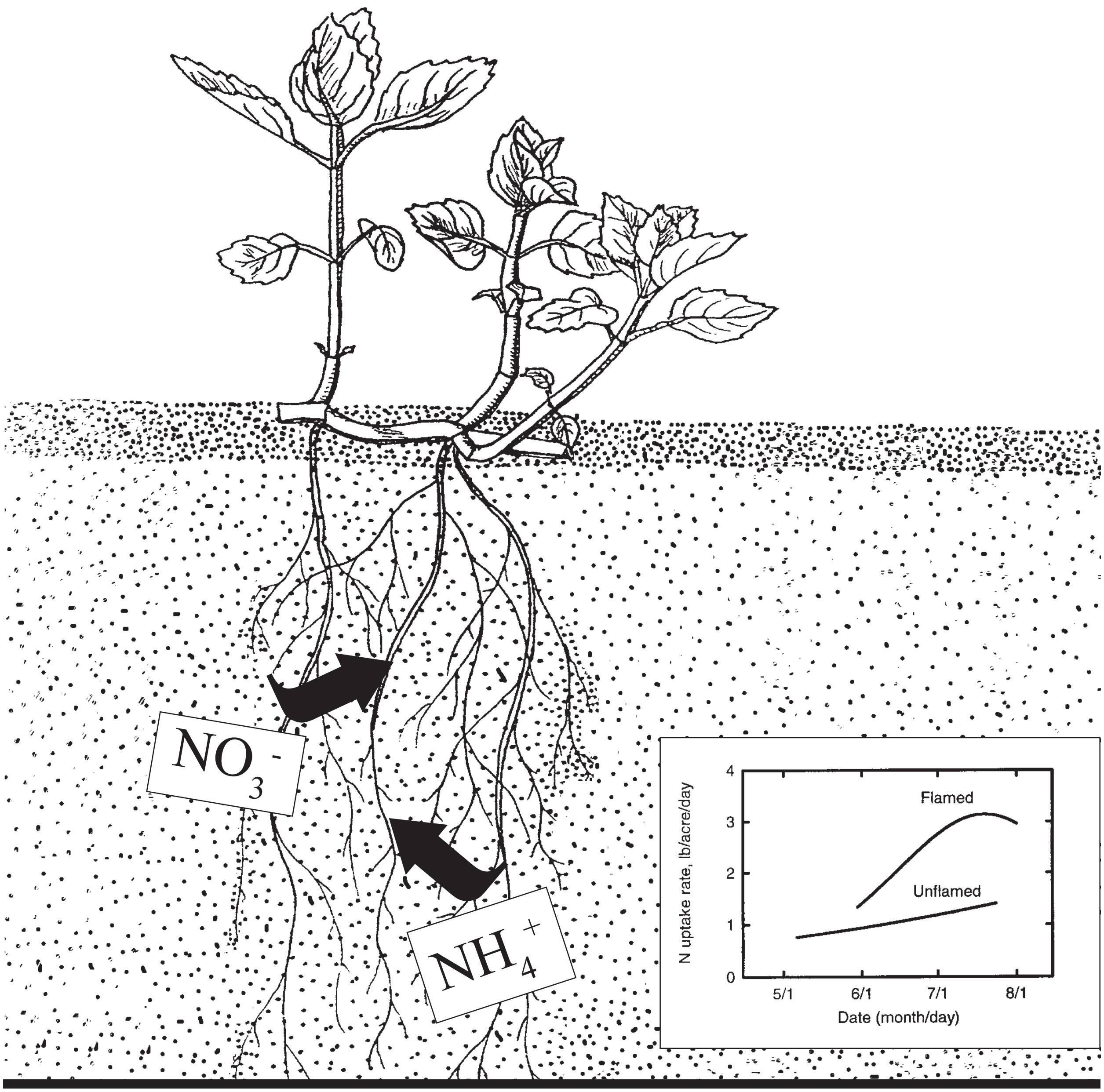
Nitrogen Uptake and Utilization

by Pacific Northwest Crops



A Pacific Northwest Extension publication
Oregon • Idaho • Washington

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Nitrogen Uptake and Utilization by Pacific Northwest Crops

D.M. Sullivan, J.M. Hart, and N.W. Christensen

Contents

This publication provides information on the timing and pattern of biomass accumulation and nitrogen (N) uptake for a variety of Pacific Northwest crops. You can use this information to schedule N fertilizer applications for maximum efficiency. To achieve near-maximum crop yields, an adequate supply of available N must be present during the period of rapid N uptake by the crop. Supplying N when it's most needed usually reduces the amount of N lost via nitrate leaching, denitrification, and other processes.

Improving the timing of N applications can provide three benefits:

- It can improve crop yield and quality.
- It can reduce fertilizer costs.
- It can help protect the environment.

How to use this publication

This publication is a resource for refining the timing of N applications. It is not a fertilizer guide with specific recommendations for crops in a designated geographic area. Use it together with other resources (your observations, crop production and soil test data, and other publications) to improve N management practices for your cropping system.

Biomass accumulation and N uptake for a number of crops are described in this publication. A consistent format, as shown in Figure 1, is used throughout the publication. For a given crop, each of the three graphs presented has the same time scale (days or date) on the X axis. For any time during the growing season (x value on the graph), the cumulative biomass accumulation, cumulative N uptake, and N uptake rate can be read directly from the graphs.

Dan Sullivan, Extension soil scientist; John Hart, Extension soil scientist; and Neil Christensen, professor of soil science; Oregon State University.

Cumulative biomass accumulation

This graph (Figure 1a) shows the cumulative biomass accumulation by the crop during the growing season. The sigmoid, or S-shaped, crop growth curve can be divided into three parts (designated by dotted lines):

- Slow growth early in the season (exponential)
- Rapid growth during midseason (linear)
- Slow growth (approaching a plateau) late in the season as the crop matures

For most crops, the shift from vegetative growth (leaves, stems) to reproductive growth (seeds, tubers) occurs shortly after the crop attains maximum leaf area. Some crops (wheat, grass seed, potatoes) are harvested at plant maturity. Other crops (broccoli, cauliflower, peppermint) are harvested during the period of rapid, linear growth.

Cumulative N uptake

This graph (Figure 1b) shows the cumulative above-ground N uptake by the crop during the growing season. Cumulative N uptake also follows a sigmoid curve over the growing season. This sigmoid curve is divided into three phases:

- Phase I: Slow N uptake corresponding to slow early growth
- Phase II: Rapid N uptake as the crop grows rapidly, increasing its leaf area
- Phase III: Slow or no crop N uptake. During this phase, nitrogen is redistributed within the plant from leaves to stems or reproductive structures (tubers, seeds). Biomass continues to accumulate.

The period of rapid N uptake begins about the time of rapid biomass accumulation (see Figure 1a); it is complete long before the crop reaches maturity. The maximum amount of above-ground crop N is called "maximum N uptake." For crops that are not grown to maturity, maximum N uptake is the N uptake at harvest.

Nitrogen uptake rate

The N uptake rate curve in this graph (Figure 1c) is mathematically derived from the cumulative N uptake graph (Figure 1b). Nitrogen uptake rate is the slope of the cumulative N uptake curve at any point in time. The maximum N uptake rate gives an indication of how rapidly the crop utilizes N during the period of rapid N uptake.

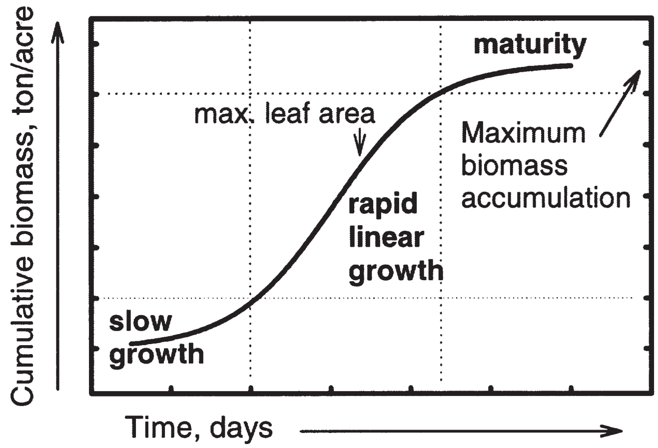

Figure 1a.—Example biomass curve.

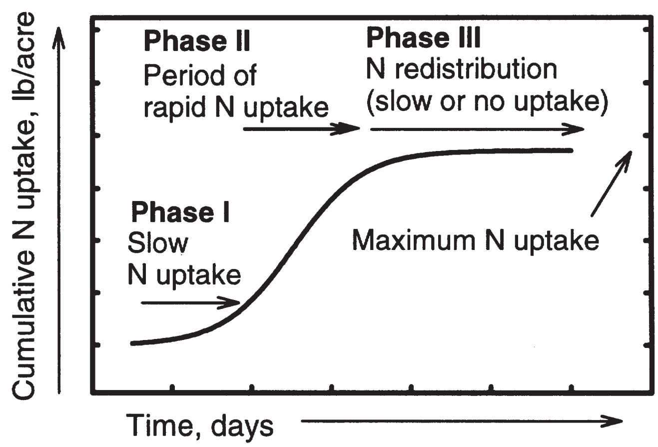

Figure 1b.—Example cumulative N uptake curve.

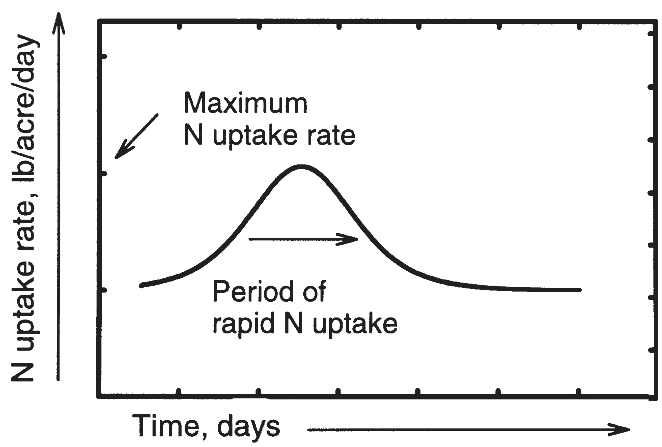

Figure 1c.—Example N uptake rate curve.

Table 1 shows the crops included in this publication and summarizes biomass and N accumulation data from Figures 2–10. The yield and N uptake attained in the examples presented do not represent a "maximum" for all growing conditions. Cumulative biomass and N accumulation vary with cultivar, plant population, cultural practices, climate, and other factors. The "maximum cumulative biomass" and "maximum N accumulation" listed in Table 1 refer only to points on the yield and N uptake curves as illustrated in Figure 1.

Where did we get the data presented here?

The data presented here were developed from field studies where crops were fertilized with adequate N for near-maximum yield. To measure biomass accumulation, we repeatedly collected samples of the above-ground portion of the crop during the growing season. Rapidly growing crops usually were harvested at 7- to 14-day intervals. Biomass samples were oven dried to determine tons of dry matter per acre. Nitrogen uptake was calculated by multiplying the biomass by its N concentration.

For some crops, we collected more data than are presented here. For field studies with multiple locations, years, and other management factors, we selected the most representative data. Crop cultivar and plant population sometimes affected the quantity of maximum N uptake, but did not change the timing of N uptake.

You will need to adapt the biomass and N uptake curves presented here for local and seasonal environmental conditions. Variations in weather from year to year affect the calendar date at which a crop reaches Phase II (the period of maximum N uptake). However, the crop growth stage corresponding to Phase II (e.g., jointing for winter wheat) remains the same from year to year. Growing degree days can be used to predict the onset of growth stages and the period of maximum N uptake for most crops.

For additional data on nitrogen management for a specific crop, see publications listed in "For more information."

Matching crop N needs

Table 2 summarizes our data for crops during Phase II, the period of rapid N uptake. This is the critical period for adequate available N in the root zone. Phase II lasts from 30 to 60 days for most crops. Crop N uptake during Phase II accounts for 50 to 85 percent of cumulative N uptake during the growing season. The maximum N uptake rate usually is in excess of 2 lb N/a/day.

Postharvest N management

The crop N uptake values presented here also can be used to plan for N carryover to the succeeding crop. Table 3 shows the amount of N removed from the field with the harvested crop, and the amount remaining in the field. For example, for a 100 bushel/a wheat crop, the unharvested straw contains about 35 lb N/a. As wheat straw decomposes, only a small amount of plant-available N is released ("low" residue N availability in

Table 1.—Examples of crop biomass accumulation and crop nitrogen uptake measured at harvest.[a]

Example figure	Crop	Location[b]	Yield level (unit/a)	Maximum cumulative biomass (dry ton/a)	Maximum N accumulation (lb/a)
2	Winter wheat (soft white)	WV	100 bu	10	120
3	Tall fescue and perennial ryegrass for seed	WV	1,500 lb	5	110
4	Hops	WV	7 bales	2	90
5	Broccoli	WV	6 ton fresh	3	190
6	Cauliflower	WV	10 ton fresh	4	200
7	Peppermint (unflamed)	WV	100 lb oil	5	170
7	Peppermint (flamed)	WV	100 lb oil	4	200
8	Potatoes (Russet Burbank)	CB	660 cwt (33 ton)	—	240
10	Onions (dry bulb)	TV	630 cwt (32 ton)	4	120

[a] Example data are derived from data presented in Figures 2–10. The maximum values listed are maximums for the example field data. Maximum cumulative biomass and N accumulation vary with cultivar, plant population, cultural practices, and climate.

[b] Locations: WV = Willamette Valley, OR; CB = Columbia Basin, WA; TV = Treasure Valley, ID.

Table 3). Therefore, wheat contributes little N to succeeding crops. In contrast, broccoli and cauliflower contribute more than 100 lb N/a in crop residues with high N availability.

The relative "N availability" listed for the residues in Table 3 is related to N concentration. Immature plants with much leaf tissue have high tissue N concentrations (>1.5 percent N) and high N availability (similar to animal manure). This residue group includes hops, peppermint, broccoli, and cauliflower. Grass seed straw (0.8–1.5 percent N) has moderate N availability. Wheat straw (0.3–0.5 percent N) has low N availability.

Table 2.—Examples of crop N uptake during the period of rapid N uptake (Phase II).[a]

Example figure	Crop	Location[b]	Phase II period dates	Phase II period growth stage		Maximum N uptake rate (lb N/a/day)	Phase II N uptake (lb N/a)
2	Winter wheat (soft white)	WV	1 Mar to 30 Apr	jointing	heading	2 to 3	60
3	Tall fescue and perennial ryegrass for seed	WV	1 Apr to 30 Apr	jointing	heading	2 to 3	70
4	Hops	WV	10 Jun to 10 July	vegetative	cone initiation	3 to 4	80
5	Broccoli	WV	50 to 90 days after seeding	4 to 6 leaf	head formation	4 to 7	160
6	Cauliflower	WV	40 to 90 days after transplanting	4 to 6 leaf	curd formation	2 to 4	160
7	Peppermint (unflamed)	WV	10 May to 1 Aug	3 to 6 in high	harvest	1 to 2	80
7	Peppermint (flamed)	WV	1 June to 1 Aug	3 to 6 in high	harvest	2 to 3	160
8	Potatoes (Russet Burbank)	CB	40 to 100 days after planting	late vegetative Growth Stage I	middle of tuber Growth Stage III	4 to 5	150
10	Onions (dry bulb)	TV	1 July to 15 Aug	6 to 8 leaf	tops down	1 to 2	70

[a] Example data are derived from crop N uptake curves presented in Figures 2–10. Crop N uptake rate varies with cultivar, plant population, cultural practices, and climate.

[b] Locations: WV = Willamette Valley, OR; CB = Columbia Basin, WA; TV = Treasure Valley, ID.

Table 3.—Examples of nitrogen removed from the field and recycled via crop residues.[a]

Example figure	Crop	N removed via harvest (lb N/acre)	Crop residue (lb N/acre)	Crop residue N availability
2	Winter wheat (soft white)	85	35	low
3	Tall fescue and perennial ryegrass for seed	35	75	medium[b]
4	Hops	45	65	high[c]
5	Broccoli	85	105	high
6	Cauliflower	90	110	high
7	Peppermint (unflamed)	210		high[c]
7	Peppermint (flamed)	190		high[c]
8	Potatoes (Russet Burbank)	210	30	high
10	Onions (Sweet Spanish)	70	50	high

[a] Other data for these examples are presented in Tables 1 and 2, and Figures 2–10.

[b] For perennial grasses, substantial amounts of N (100–300 lb/a) are stored in the unharvested portions (crowns and roots) and in soil organic matter. A portion of this stored N becomes available to the succeeding crop when perennial grass sod is plowed down.

[c] Although these residues are removed via harvest, they usually are field applied after processing.

Nitrogen fertilizer management

The goal of N fertilizer management is to provide adequate N for maximum crop yield and quality, while minimizing nitrate leaching. The data presented here on the rate and pattern of crop N uptake can be used to help you decide what timing, rate, and form of N fertilizer is most appropriate. Important questions relating to N fertilizer management include:

Is the amount of N accumulated by the crop the amount of fertilizer N I should apply?

No. In developing a fertilizer recommendation, you should consider other N sources besides fertilizer N as well as the efficiency of fertilizer N uptake by the crop. The major source to consider is N mineralized (converted to available forms) as organic matter decomposes in the soil. Mineralization occurs in the absence or presence of fertilizer N.

Estimates of soil N supply or mineralization in the Willamette Valley commonly range from 40 to 120 lb N/a, depending on soil type and crop management practices. Crop residues that are relatively high in N, such as those from alfalfa, hop vines, mint residues, cole crops, or sugar beets, can increase the N supplied from the soil for the next crop. Sites with a history of repeated applications of animal manure or other organic byproducts also have greater amounts of N supplied by mineralization.

In drier areas of the Northwest, some of the N for the crop can be provided by nitrate that remains in the soil profile over the winter. In drier areas, spring soil tests for preplant nitrate-N provide important information for determination of appropriate N fertilizer rates.

How far in advance of crop needs should I apply N?

Generally, applying available N just before it is needed by the crop is the most efficient strategy. Where irrigation water is available to move N into the root zone, N can be applied in split applications during the period of rapid uptake.

West of the Cascades, for rain-fed crops that take up most of their N over a 30- to 60-day period, a single N application 2 to 4 weeks prior to the rapid uptake period usually is a good strategy. This allows enough time for urea or ammonium-N conversion to nitrate-N and for movement into the top foot of soil with rainfall.

How can I be certain that enough N will be present during the period of rapid crop N uptake?

For some crops, soil testing for nitrate-N 2 to 4 weeks before the period of rapid N uptake will allow enough time for supplemental N fertilizer applications. This is the principle behind the pre-sidedress soil nitrate test for corn (see publication EM 8650).

A similar approach can be used for other crops. If the soil test shows substantial nitrate-N already present in the soil, then you can apply lower rates of N to meet crop needs. Plant tissue tests can provide an assessment of current plant N status, but generally do a poor job of predicting the quantity of available N in the soil.

For most irrigated crops, irrigation water must be managed carefully to keep soluble nitrate-N in the root zone. For additional information on irrigation management, consult the publications listed in the "For more information" section of this publication.

In what situations are split N fertilizer applications more effective than a single N application?

Split N fertilizer applications often increase the efficiency of crop N use for crops with a long interval between planting and Phase II (e.g., fall-planted crops). For such crops, a small amount of N is applied at seeding, with the remainder applied shortly before Phase II.

A single N fertilizer application shortly before Phase II often is as effective as split N applications during Phase II. Split applications have the most value on soils with high leaching potential (sandy soils), if irrigation is imprecise (e.g., furrow irrigation), or for crops with shallow root systems (e.g., onions). Sprinkler irrigation systems are ideal for delivering split N applications.

When is slow-release N most effective?

Slow-release N sources (e.g., sulfur or resin-coated urea) sometimes are used as a substitute for split applications of soluble N fertilizers. Like split N applications, slow-release N applications can be beneficial in situations where a high potential for nitrate loss from the root zone exists. The best timing for slow-release N application is prior to Phase II, the period of rapid N uptake. Slow-release N applied after the crop has achieved its maximum N uptake rate is less effective than soluble N.

When is it too late to apply N fertilizer?

N fertilizer applied when Phase II is complete is not effective in increasing crop yields. For most crops, late N fertilizer applications reduce crop quality. Some examples of the detrimental effects of excessive N late in the season include high protein in soft white winter wheat and high sugar content and dark fry color in potatoes. In addition, N remaining in the soil after harvest is vulnerable to loss by leaching during winter. Excess soil N after harvest is a potential pollutant of groundwater.

Biomass accumulation and N uptake for selected crops

Seed crops

Winter wheat

Biomass. Winter wheat planted in October typically accumulates 400 to 500 lb dry matter per acre by late tillering, Feekes growth stage 5, which occurs between February 1 and mid-March in western Oregon and between mid-March and mid-April in eastern Oregon. Beginning at jointing, Feekes growth stage 6, biomass accumulates rapidly, reaching a maximum during grain filling.

N uptake. A small amount of N, 20 to 40 lb/a, is accumulated through the end of tillering, Feekes growth stage 5. As jointing begins at Feekes growth stage 6, so does rapid accumulation of N. In a 5- to 8-week period, wheat takes up 100 to 150 lb N/a, with a peak N uptake rate of 2 to 3 lb N/a/day. By the boot stage, Feekes 10, the plant has accumulated most of its N, but only about half of its biomass. As grain begins to form, N is translocated from leaves and stems to the head.

Management. Sufficient N early in the growth of winter wheat is extremely important. A shortage of N during jointing (Feekes 6–8) cannot be overcome by adding fertilizer N late in the growing season. Split applications of N (a small application during tillering, with the remainder at Feekes 5–6) can provide benefit where substantial early season losses are expected (sandy soils with high rainfall).

An adequately fertilized wheat crop will not produce additional yield if fertilized with N after Feekes 8, the appearance of the last or flag leaf. Late-season N fertilization will make N vulnerable to loss before the next cropping season. Late-season N has been shown to increase grain protein, particularly if applied as a foliar application.

For more information

Christensen, N.W., and M. Brett. 1998. Wheat yield and N uptake as influenced by treating crop residue with urea-sulfuric acid, *J. Fertilizer Issues* 5(2):50–55.

*Hart, J., N.W. Christensen, T.L. Jackson, R. Karow, and W.E. Kronstad. *Winter wheat—western Oregon, west of Cascades fertilizer guide*, FG 9 (Oregon State University, Corvallis, OR, 1992). No charge

Locke, K.A. *Nitrogen and dry matter relationships for winter wheat produced in western Oregon*, Doctor of Philosophy Thesis, Crop and Soil Science (Oregon State University, Corvallis, OR, 1991).

Nelson, J.E., K.D. Kephart, A. Bauer, and J.E. Connor. *Growth staging of wheat, barley, and wild oat: A strategic step to timing of field operations* (University of Idaho, Moscow, ID, 1988).

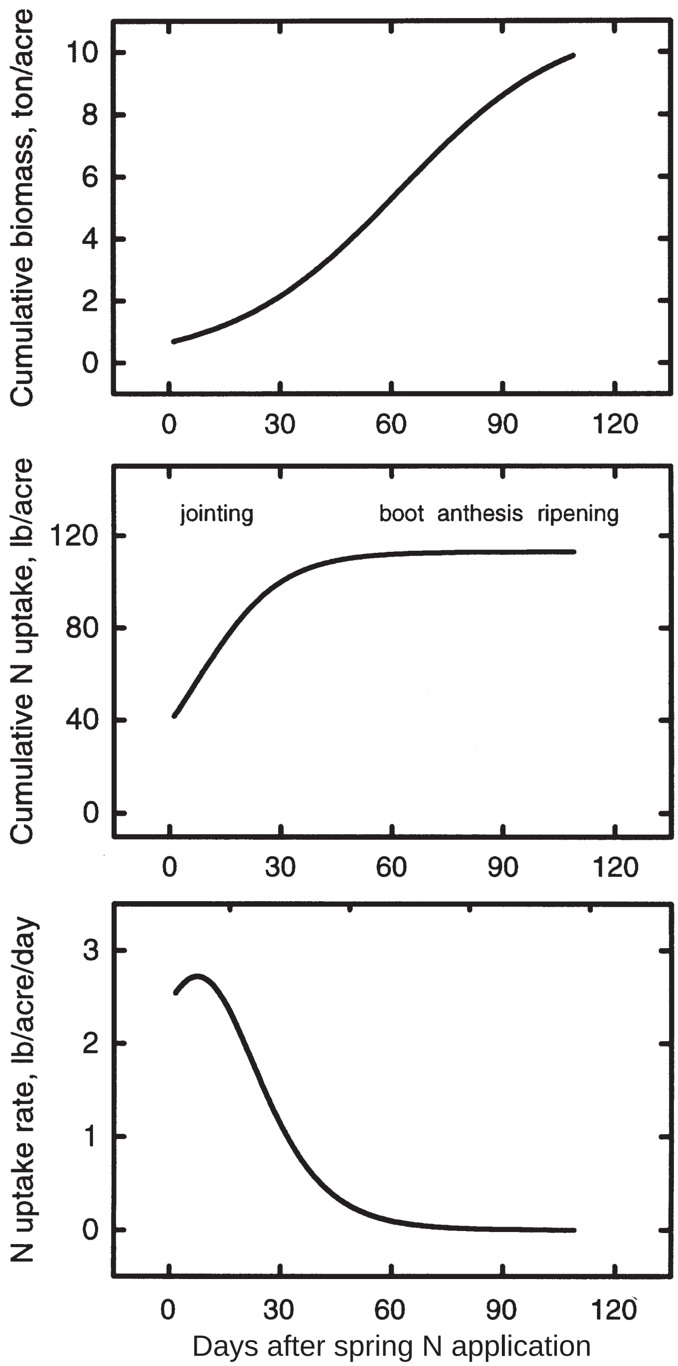

Figure 2.—Biomass accumulation and N uptake for winter wheat grown in the Willamette Valley. Day 0 is approximately March 1 (tillering growth stage). Data from one growing season. Source: Christensen and Brett, 1988.

*See ordering instructions on page 18.

Grass for seed

Biomass. For perennial grasses, the slow growth of Phase I occurs in the fall and early spring. Depending on species and cultivar, 300 to 2,000 lb/a dry matter is accumulated above ground from regrowth in the fall to mid-March. Less than 20 percent of the above-ground biomass is accumulated by the latter half of March. The rate of biomass accumulation is almost linear from the end of March to harvest in western Oregon.

N uptake. N uptake is rapid during April and essentially complete by mid-May, or more than 6 weeks before harvest. The amount of N taken up by a grass crop is cultivar-dependent, primarily a function of biomass production. Total N uptake usually ranges from 100 to 150 lb/a. Peak N uptake of 2 to 4 lb/a/day occurs in April.

Management. Nitrogen fertilizer rates of 75 to 150 lb N/acre are adequate for grass seed during the rapid vegetative growth period (Phase II) in April. Most growers choose to split N applications. Research in the Willamette Valley has shown no seed yield advantage for split N application compared to a single application. Late-season N application, after May 1, does not increase yield or crop N uptake.

At harvest, the straw contains most of the N. One thousand pounds of seed contains 20 to 25 lb N. One ton of straw contains 15 to 30 lb N. At harvest, a crop producing 1,500 lb of seed and 4.5 tons of straw/a removes 30 to 40 lb N in seed and contains 70 to 135 lb N in straw. Thus, when straw is chopped back on the field, N is recycled on-site.

Growers often are concerned with slow growth or with yellow grass plants during the early spring growth period. Cool weather and/or saturated soil generally are the cause of slow growth. Additional N will not stimulate plants to grow in this situation. Be patient and wait for warmer, drier weather to stimulate plant growth. Soil analyses for ammonium + nitrate-N also can be used to assess the need for additional N.

For more information

Griffith, S.M., T.W. Thomson, and J.S. Owen. Soil and perennial ryegrass seed crop N status and N management considerations for western Oregon, pp. 30–34 in W. Young, III (ed.), *1997 Seed Production Research* (Oregon State University and USDA-ARS, Corvallis, Oregon, 1998).

Griffith, S.M., and T. Thomson. N rate and timing relationships with tissue N concentration and seed yield in perennial ryegrass, pp. 41–42 in W. Young, III (ed.) *1996 Seed Production Research* (Oregon State University and USDA-ARS, Corvallis, Oregon, 1997).

Horneck, D.A. *Nutrient management and cycling in grass seed crops*, Doctor of Philosophy Thesis, Crop and Soil Science (Oregon State University, Corvallis, OR, 1995).

Qureshi, M.H. *Tall fescue growth and nitrogen uptake as influenced by non thermal residue management*, Master of Science Thesis, Crop and Soil Science (Oregon State University, Corvallis, OR, 1995).

Young, W.C., H.W. Youngberg, D.O. Chilcote, and J.M. Hart. 1997. Spring nitrogen fertilization of perennial ryegrass seed crop, *J. Prod. Agric*. 10:327–330.

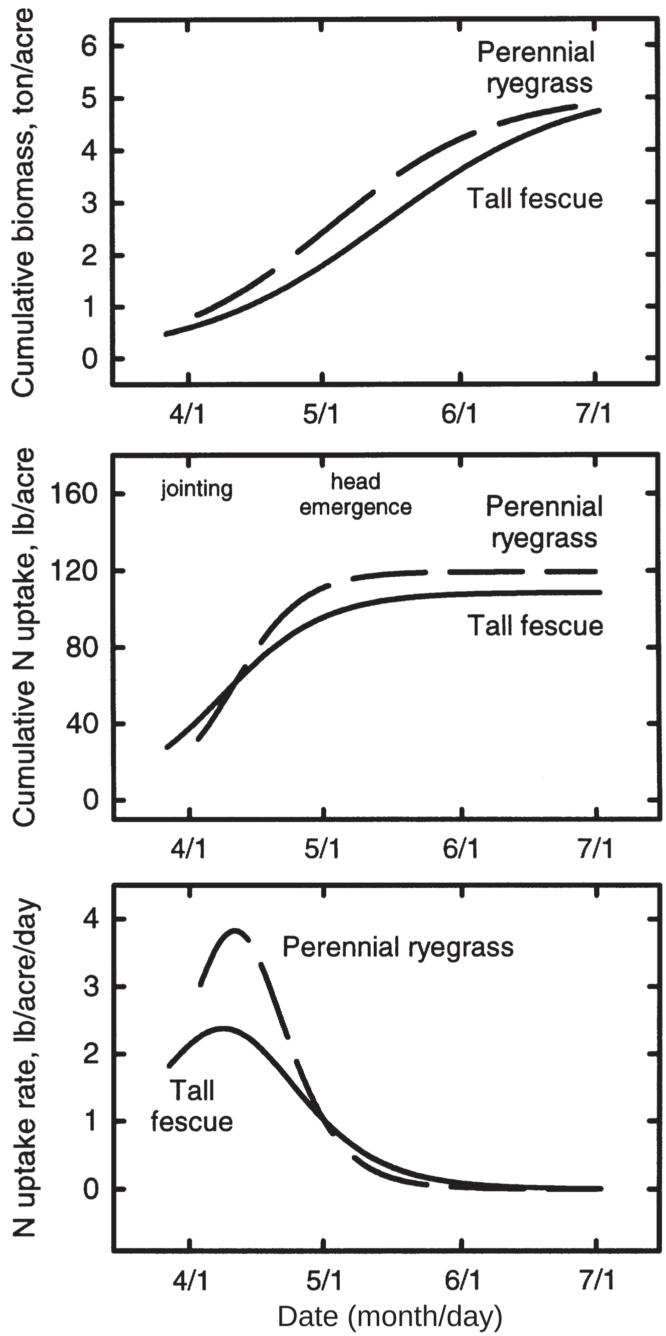

Figure 3.—Biomass accumulation and N uptake for tall fescue and perennial ryegrass grown for seed in the Willamette Valley. Data for tall fescue in 1993 combined across four field locations (Qureshi, 1995). Data for perennial ryegrass in 1997 from one field location (Griffith et al., 1998).

Hops

Biomass. Hops exhibit the same initial slow Phase I growth through the first half of June as do grass seed crops during the winter months. Spring growth produces long shoots with little leaf area. This growth depends primarily on rootstock reserves. Only 10 percent of total biomass is accumulated through mid-June. Phase II growth from mid-June until the latter part of July is linear and rapid. Maximum biomass accumulation occurs by the end of July.

N uptake. Nitrogen uptake and biomass accumulation occur at similar rates. Only 10 percent of total uptake is accumulated through mid-June. The 30-day period from mid-June to mid-July is the period of rapid uptake. The N uptake rate is 3 to 4 lb/a/day near the end of June. By the end of July, the crop has accumulated 80 to 150 lb N/a in the trained biomass.

Management. Apply nitrogen fertilizer by early June to mid-June so it will be available during the period of rapid uptake. A single N application in April was as effective as split applications in western Oregon trials. Consider yield levels when determining N fertilizer rate. Cones contain 5 to 6 lb N/bale or one-third to one-half the total amount of N harvested in the biomass.

Most yards are harvested by removing vines, leaves, and cones. After the cones are removed from the vines, the leaves and stems generally are returned to the yards. Leaves and stems contain approximately 40 lb N/t of dry material. Reduce N fertilizer inputs where hop vine residues are applied.

N status can be assessed by tissue testing. Collect hop petioles when hops are between three-fourths of the way to the wire and just reaching the wire. This amount of growth generally occurs by mid-June in the Willamette Valley. Choose petioles from mature leaves on the main vine, 5 to 6 feet from the ground. Have the petioles analyzed for nitrate-N. Small-scale N rate experiments and large-scale field demonstrations have shown no yield increase if additional fertilizer is applied when petioles contain more than 4,000 ppm nitrate-N in June.

For more information

Barth, A.W. *Verticillium wilt, nematodes, and soil fertility interactions in hop yards*, Master of Science Thesis, Crop and Soil Science (Oregon State University, Corvallis, OR, 1991).

*Gingrich, G., J. Hart, and N. Christensen, *Hops fertilizer guide*, FG 79 (Oregon State University, Corvallis, OR, 1994). No charge

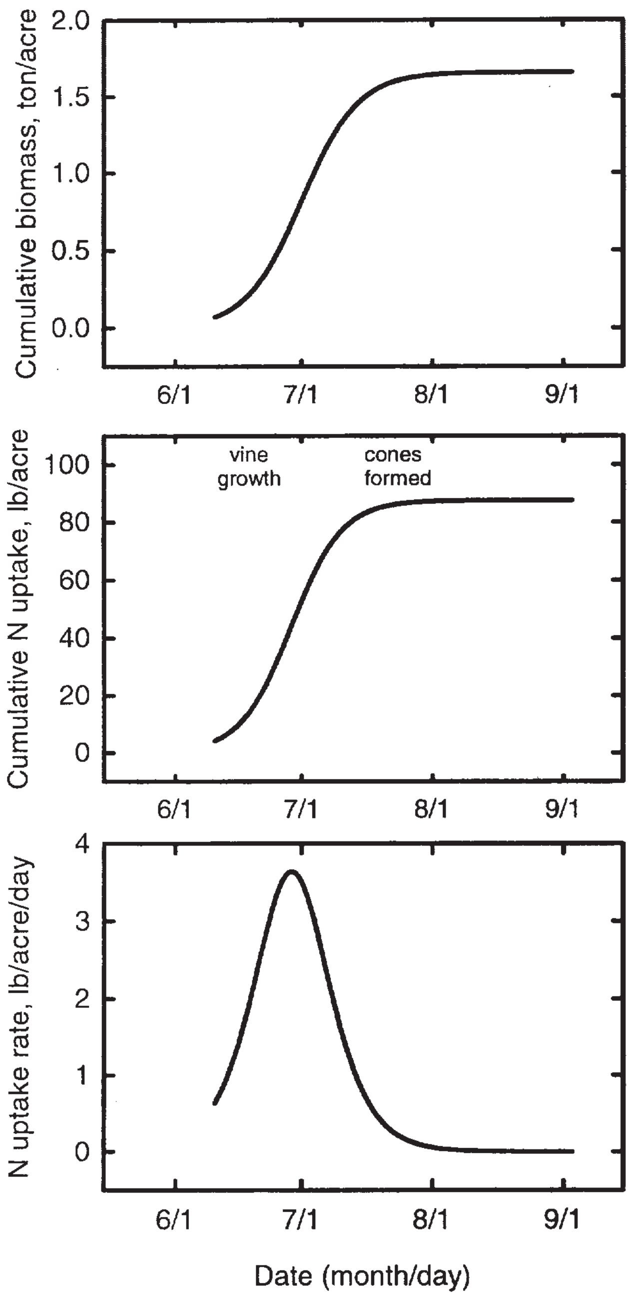

Figure 4.—Biomass accumulation and N uptake for hops grown in the Willamette Valley. Combined data from two field locations (1991). Source: N.W. Christensen, M.D. Kauffman, and G. Gingrich, Oregon State University.

*See ordering instructions on page 18.

Broccoli and cauliflower

Broccoli and cauliflower are closely related and have a similar pattern of biomass and N uptake. Both crops are harvested at the end of rapid growth, Phase II, before nutrients are translocated from the leaves to seeds.

Broccoli

Biomass. June-seeded broccoli in the Willamette Valley exhibits typical Phase I growth for the first 60 days after seeding. Less than 10 percent of the biomass is accumulated when the plant has four to six leaves. The next 30-day period, August, is characterized by typical rapid Phase II growth.

N Uptake. Nitrogen uptake and biomass accumulation occur at similar rates. Less than 50 lb N/a is taken up by broccoli in the first 60 days of growth or until four to six leaves have emerged. The limited uptake observed in the first 60 days is in sharp contrast to the N uptake that follows. During the rapid growth period between four to six leaves and the appearance of the first buds, a broccoli crop takes up 5 to 7 lb N/a/day. As the head develops, translocation of nutrients from leaves to the newly forming heads occurs.

Total N uptake is a function of cultivar, plant density, and environmental conditions. Nitrogen uptake of "Gem" broccoli seeded at a density of 35,000 plants/a and grown in the Willamette Valley is 200 to 250 lb N/a. The expected yield is 5 to 6 tons of fresh heads/a. Nitrogen uptake as high as 350 lb/a has been reported from British Columbia and Arizona in higher density plantings.

Management. Since most of the N is accumulated 90 to 100 days after seeding, an adequate supply of N during rapid growth is crucial, as yield will be decreased if a shortage of N occurs during this time. Late-season high rates of N cannot overcome an early-season N deficit.

Fresh broccoli heads contain 15 to 20 lb N/t. A 5 t/a yield (fresh wt. basis) removes 75 to 100 lb N/a. More than 150 lb N/a remains in the field in the leaves and stems. When this crop residue is tilled into the soil, it rapidly decomposes, releasing available N.

For more information

Hemphill, Jr., D.D., and J. Hart. *Effect of nitrogen rate, timing, placement, and catch crops on yield and nitrogen utilization in vegetable crops*, Project Report to the Oregon Processed Vegetable Commission (Oregon State University, Corvallis, OR, 1991).

Hemphill, Jr., D.D., J. Hart, and D. McGrath. *Effect of nitrogen source and nitrogen rate on yield and nitrogen utilization by broccoli*, Project Report to the Oregon Processed Vegetable Commission (Oregon State University, Corvallis, OR, 1990).

Kowalenko, C.G., and J.W. Hall. 1987. Nitrogen recovery in single- and multiple-harvested direct-seeded broccoli trials, *J. Am. Soc. Hort. Sci.* 112(1)4–8.

Letey, J., W.M. Jarrell, N. Valoras, and R. Beverly. 1983. Fertilizer application and irrigation management of broccoli production and fertilizer use efficiency, *Agron. J.* 75:502–507.

Magnifico, V., V. Lattanzio, and G. Sarli. 1979. Growth and nutrient removal by broccoli, *J. Am. Soc. Hort. Sci.* 104(2):201–203.

*Mansour, N.S., H.J. Mack, H. Gardner, T.L. Jackson, and T.A. Doerge. *Broccoli, Brussels sprouts, cabbage, cauliflower (western Oregon—west of Cascades) fertilizer guide,* FG 27 (Oregon State University, Corvallis, OR, 1983). No charge

*See ordering instructions on page 18.

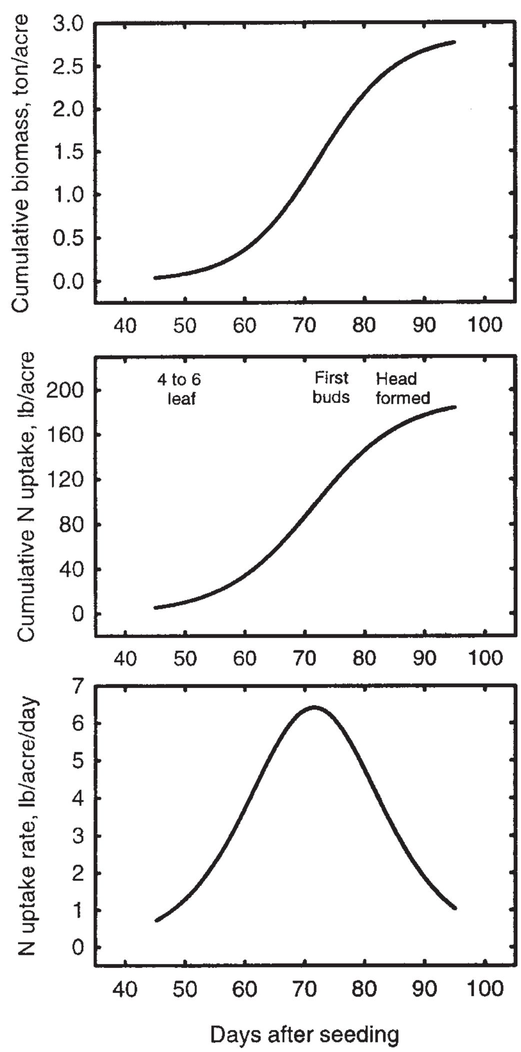

Figure 5.—Biomass accumulation and N uptake for early-June-seeded broccoli in the Willamette Valley. Data from one field location (1991). Source: J. Hart and D. Hemphill, Oregon State University.

Cauliflower

Biomass. Cauliflower transplanted in early July exhibits gradual Phase I growth for the first 40 to 50 days, accumulating approximately 25 percent of its biomass in this period. In contrast, Phase II growth in the next 50 days produces approximately 75 percent of the crop biomass.

N Uptake. Nitrogen uptake and biomass accumulation occur at similar rates. Approximately 50 lb N/a is taken up by broccoli in the first 50 days of growth or until four to six leaves have emerged. The limited uptake observed in the first 60 days is in sharp contrast to the N uptake that follows. During the rapid growth period between four to six leaves and curd formation, a cauliflower crop takes up about 3 lb N/a/day. As the head develops, translocation of nutrients from leaves to the newly forming heads occurs.

Management. Since most of the N is accumulated by 90 to 100 days after transplanting, an adequate supply of N during rapid growth is critical. Yield is decreased if a shortage of N occurs during the rapid growth period. Apply N fertilizer in late July through early August to ensure the crop a sufficient and timely nutrient supply. Cauliflower transplanted in early July accumulates N at the highest rate in early September.

Cauliflower contains substantial N in the leaves and stems that remain in the field after harvest. Live plants can hold N during winter months. Spring desiccation and tillage allows some of the N contained in the plants remaining after harvest to become available for the subsequent crop. If broccoli or cauliflower residues are incorporated shortly after harvest, the best N management practice is to seed a fast-growing crop soon after tillage. Nitrogen uptake by the following crop will reduce the amount of nitrate-N available for leaching.

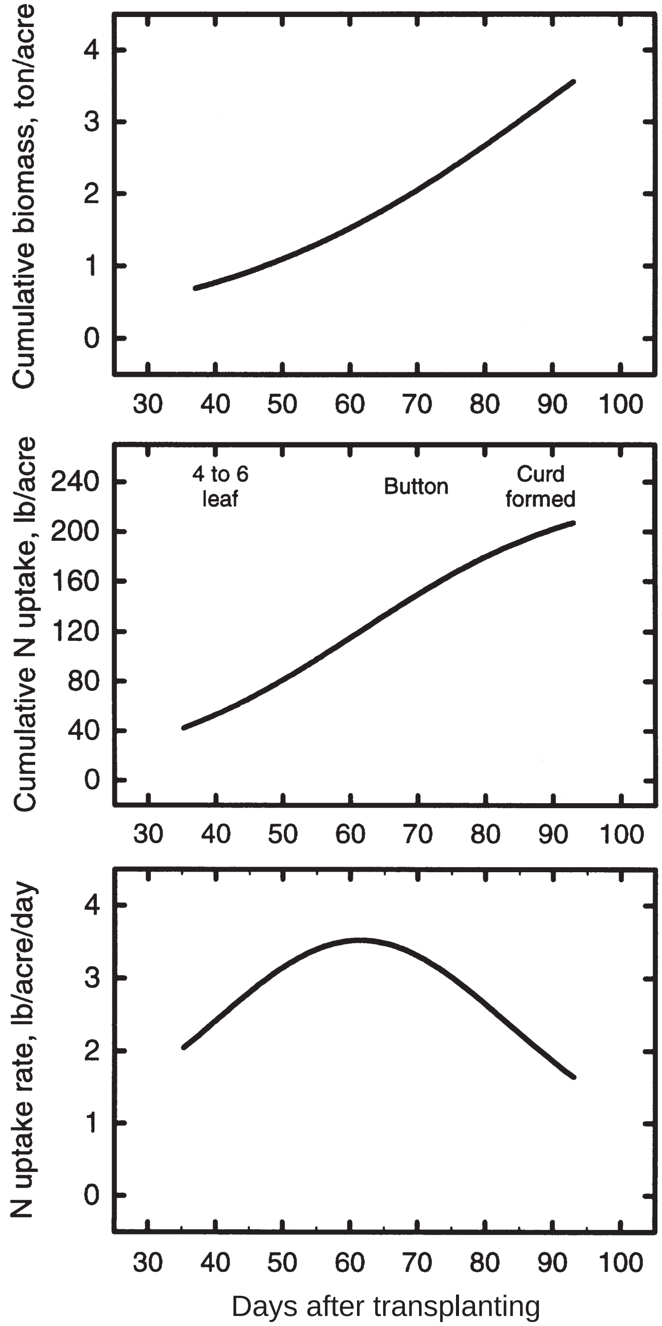

Figure 6.—Biomass accumulation and N uptake for early-July-transplanted cauliflower in the Willamette Valley. Data from one field location (1992). Source: J. Hart and D. Hemphill, Oregon State University.

For more information

Dick, R.P., D.D. Hemphill Jr., J. Hart, and D. McGrath. *Effect of alternative crop rotations and cover crops on productivity and input efficiency in vegetable crop systems*, Addendum to interim report to CAAR (Oregon State University, Corvallis, OR, 1992).

Federico Jr., J. *Nitrogen utilization by cauliflower*, Master of Agriculture Thesis, Crop and Soil Science (Oregon State University, Corvallis, OR, 1994).

Peppermint

Biomass. The major factor affecting time of biomass accumulation for peppermint is the method of rust control (flaming vs. chemical control). Peppermint that is flamed produces biomass over a shorter growing season than do fields where chemical rust control is used. Fields flamed for rust control begin harvestable biomass accumulation approximately 30 days later than unflamed fields. Vigorously growing fields where chemical control is used produce more biomass than fields that are flamed. Peppermint growth follows a similar pattern when either method of rust control is used, producing between 8,000 and 10,000 lb dry matter/a.

N Uptake. Peppermint that is flamed accumulates N at a faster rate than fields where chemical control of rust is practiced. However, both techniques produce plants at harvest with approximately the same amount of N, 170 to 250 lb/a. This conclusion is based on data collected over 3 years from large on-farm plots in the Willamette Valley.

Flamed and unflamed peppermint have different N uptake rates. Flamed mint has a maximum N uptake rate of approximately 3 lb/a/day, while unflamed peppermint's maximum N uptake rate is about 1.5 lb/a/day. The peak N uptake period is between June 15 and July 15.

Management. Nitrogen fertilizer rates of no more than 200 to 250 lb/a are necessary for adequately irrigated peppermint. N can be supplied through the irrigation water or to the soil early in the growing season. Supply approximately 175 lb/N/a before mid-June where peppermint is flamed or by mid-May where chemical rust control is used. N applied in late July or August is likely to remain in the soil after harvest.

For more information

Christensen, N.W., J. Hart, M. Mellbye, and G. Gingrich. Peppermint growth and nutrient uptake, p. 4 in *Oregon Mint Commission Update*, Spring 1998 (Oregon Mint Commission, Salem, OR, 1998).

Hart, J., M. Mellbye, G. Gingrich, E. Marx, and M. Kauffman. Interim report to the Oregon Mint Commission for the field project "Biomass and Nitrogen Accumulation" in *1995–96 Reports to the Agricultural Research Foundation for the Oregon Mint Commission* (Oregon State University, Corvallis, OR, 1995).

Hee, S.M. *Effect of nitrogen fertilization on peppermint oil quality and content*, Master of Science Thesis, Crop and Soil Science (Oregon State University, Corvallis, OR, 1975).

Huettig, M.A. *The effect of fertilizer treatments on oil content and nutrient concentration of peppermint in western Oregon*, Master of Science Thesis, Crop and Soil Science (Oregon State University, Corvallis, OR, 1969).

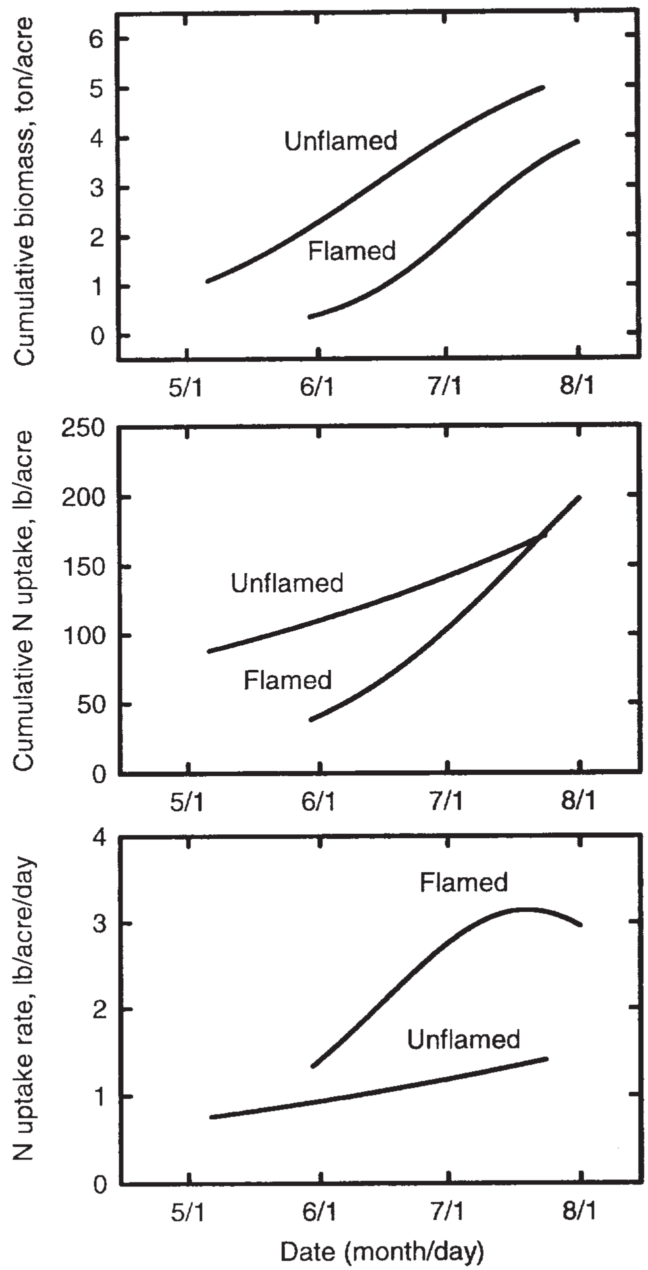

Figure 7.—Biomass accumulation and N uptake for peppermint in the Willamette Valley. Representative data selected from among six field locations (1995–97). Source: N.W. Christensen, J. Hart, G. Gingrich, and M. Mellbye, Oregon State University.

Tuber, bulb, and root crops

The seasonal pattern for potato biomass and N uptake, highlighted here, has similar characteristics to the pattern for crops with vegetative storage organs (e.g., onions, sugar beets, carrots).

Potatoes

Biomass. Potato dry matter accumulation and distribution in the plant can be described by dividing growth stages into four periods, based on top and tuber growth and N uptake. The description used by Kleinkopf et al. (1981) follows:

- During growth stage I, “vegetative,” plants develop from planting until the start of tuber initiation. This period ranges from 30 to 70 days, depending upon planting date, soil temperatures, seed age, variety, and other environmental factors affecting growth.
- Growth stage II, “tuberization,” lasts 10 to 14 days, with tubers being formed at the tips of the stolons but not appreciably enlarging. The primary inflorescence may have a few open flowers at the end of this stage.
- Growth stage III, “tuber growth,” is the phase when tuber growth is linear if all growing conditions are adequate.
- During growth stage IV, “maturation,” vines start to yellow, leaf loss is evident, and tuber growth slows.

Nitrogen uptake. Nitrogen uptake by a potato crop is a function of yield potential and variety. Tuber yield and N uptake usually are not limited by growing season in the Columbia Basin or the Treasure Valley. A limited growing season reduces yield and N uptake in the Klamath Basin, central Oregon, and eastern Idaho.

During vegetative vine growth in growth stage I, about 80–100 lb N/a is taken up. In the figure for Russet Burbank potatoes planted about April 20, growth stage I ends approximately 60 days after planting.

Growth stage II, tuberization, is characterized by rapid N uptake with 4–5 lb N/a/day taken up by the potato crop.

Maximum whole plant N uptake is reached at about 100 days after planting in growth stage III, tuber growth. During this growth stage, the tuber N uptake rate peaks about 110 days after planting. At the peak N demand, tubers accumulate 3 to 4 lb N/a/day.

During growth stage IV, beginning about 120 days after planting, tubers continue to accumulate N. The source of N for tubers in the last month of growth is primarily translocation of N from vines.

Management. Excessive amounts of nitrogen at planting can elevate salt levels, adversely affecting moisture availability in the root zone. Providing adequate, but not excessive N during growth stages I and II favors a balanced proportion of roots and shoots, resulting in enhanced tuber initiation and set. For indeterminate cultivars such as Russet Burbank, the most critical time for supplying nitrogen is from 40 to 100 days after planting (late vegetative growth stage I through the first half of tuber growth stage III).

The effects of deficient, adequate, and excess N application are demonstrated for Russet Burbank potatoes in the Columbia Basin (Patterson, WA) in Figure 9. When N is applied in excess of crop needs, vines accumulate excess N. Excessive N fertilization delays maturity and may result in reduced crop quality and crop value for fresh market or for processing. Negative effects of excessive N can include lower dry matter (specific gravity), lower market grade, and higher sugar content. At adequate or deficient rates of N, the plant moves N from the vine to the tubers, starting with the period of rapid tuber development.

Excess N fertilizer changes the amount of N in the vines more than in the tubers. Adequately fertilized potatoes (190 lb fertilizer N/a) contained 160 lb N in tubers, while potatoes grown with excess N (550 lb fertilizer N/a) contained 200 lb N in the tubers. Vines contained 300 lb N/a when excessively fertilized compared to less than 50 lb/a when adequately fertilized. Tuber yields were similar with adequate or excess N application.

For more information

Feibert, E.B.G., C.C. Shock, and L.D. Saunders. 1998. Nitrogen fertilizer requirements of potatoes using carefully scheduled sprinkler irrigation. *HortSci.* 32:262–265.

Kleinkopf, G.E., D.T. Westermann, and R.B. Dwelle. 1981. Dry matter production and nitrogen utilization by six potato cultivars, *Agron. J.* 73:799–802.

Lang, N.S., R.G. Stevens, R.E. Thornton, W.L. Pan, and S. Victory. Irrigated potato nutrient management guide for central Washington. In*: Proc. Washington State Potato Conference and Trade Show, 4–6 Feb 1997* (Washington State Potato Commission, Moses Lake, WA, 1997).

Lauer, D.A. 1985. Nitrogen uptake patterns of potatoes with high-frequency sprinkler-applied N fertilizer, *Agron. J.* 77:193–197.

Roberts, W., H.H. Cheng, and F.A. Farrow. 1991. Potato uptake and recovery of nitrogen-15-enriched ammonium nitrate from periodic applications, *Agron. J.* 83:378–381.

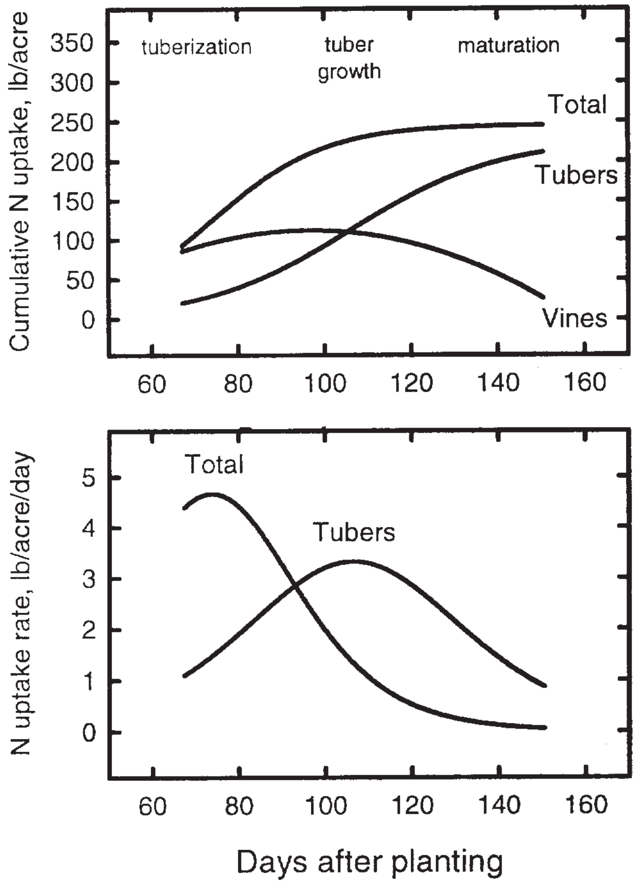

Figure 8.—Nitrogen uptake for Russet Burbank potatoes planted about April 20. Columbia Basin near Patterson, WA. Combined data from three growing seasons (1981–83). Source: Roberts et al. (1991).

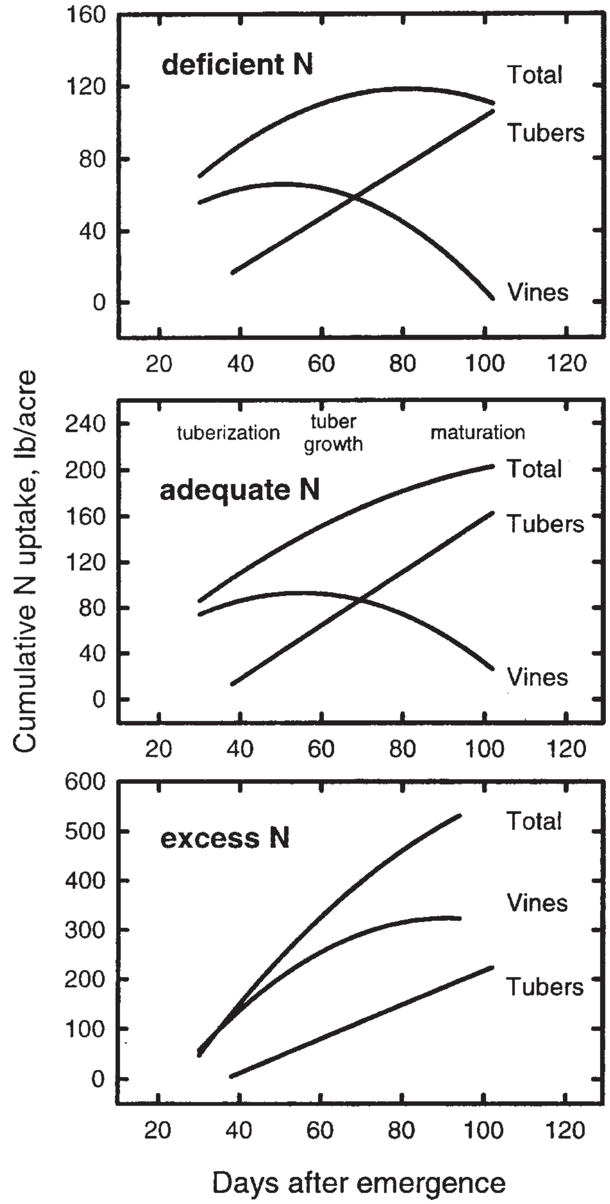

Figure 9.—Nitrogen uptake for Russet Burbank potatoes grown with deficient, adequate, and excessive levels of fertilizer N. Columbia Basin near Patterson, WA. Data from one growing season (1980). Source: Lauer, 1985.

Onions

Biomass. Onion biomass initially accumulates very slowly. From seeding in March or April to the six to eight-leaf stage in mid to late June, accumulated biomass is less than 40 lb/acre. Following rapid leaf production, bulb enlargement begins in July in response to day length and temperature. Bulb enlargement is complete by late August to early September, and maximum biomass is attained at that time.

In a recent eastern Washington field trial, sweet Spanish, globe, and red onion biomass and nutrient uptake were measured. The range of total biomass for all onion types was 9,000 to 12,000 lb/a (dry weight). Less than 2,000 pounds of the biomass was found in onion tops. In Malheur County, OR, sweet Spanish onions produced 6,500 pounds of biomass in bulbs and 1,300 pounds in tops. In both situations, approximately 85 percent of the biomass was in the bulbs. In Idaho, sweet Spanish type onions accumulated 1,000 to 2,000 lb biomass in plant tops by mid-July, when plants had 9 to 12 leaves (Figure 10).

N uptake. Rapid N uptake begins after the crop has six to eight true leaves and continues in a linear fashion through bulb growth. During the latter stages of bulb enlargement, generally August in irrigated onion-producing areas of the west, N is translocated from tops to bulbs, and little additional N is taken up from the soil. In a recent eastern Washington field trial, N uptake was 130 to 160 lb/a, with 10 to 30 lb N/a in the tops at harvest. A similar proportion of N was found in bulbs and tops in Malheur County, Oregon research: 80 to 90 lb/a N in the bulbs, and 15 to 20 lb/a N in the tops. In the Idaho studies summarized in Figure 10, a higher proportion of crop N uptake was found in onion tops.

Management. N uptake at harvest is a function of onion variety, plant population, and bulb size. Adjust the N fertilizer rate for projected yield. Crop N uptake (tops + bulbs) averages 0.15 to 0.20 lb N per cwt of harvested bulbs (3 to 4 lb N per ton of bulb fresh weight).

Research in Idaho and Colorado shows that seeded onions can benefit from split applications of N. Nitrogen applied preplant often is leached beyond the reach of roots by early-season rainfall or irrigation.

Preplant N also may reduce germination of onion seed and increase early-season weed control problems. Sidedress N can be applied several times during the growing season if soil or plant tissue tests indicate a need. Applying the initial sidedress N at the three- to five-leaf stage provides N just prior to the period of rapid biomass production and N uptake. The last application of N fertilizer usually should be in mid- to late June.

For more information

Horneck, D.A. 1997. Nutrient uptake of Columbia Basin onions, varietal differences, in *Proc. Pacific Northwest Vegetable Association*, 20–21 Nov 1997 (Pacific Northwest Vegetable Association, Pasco, WA).

Shock, C., T. Stieber, J. Miller, and M. Saunders. Improved nitrogen fertilizer efficiency for onion production, p. 66 in *Malheur County Crop Research, 1990*, SR 882 (Oregon Agricultural Experiment Station, Oregon State University, Corvallis, OR, 1991).

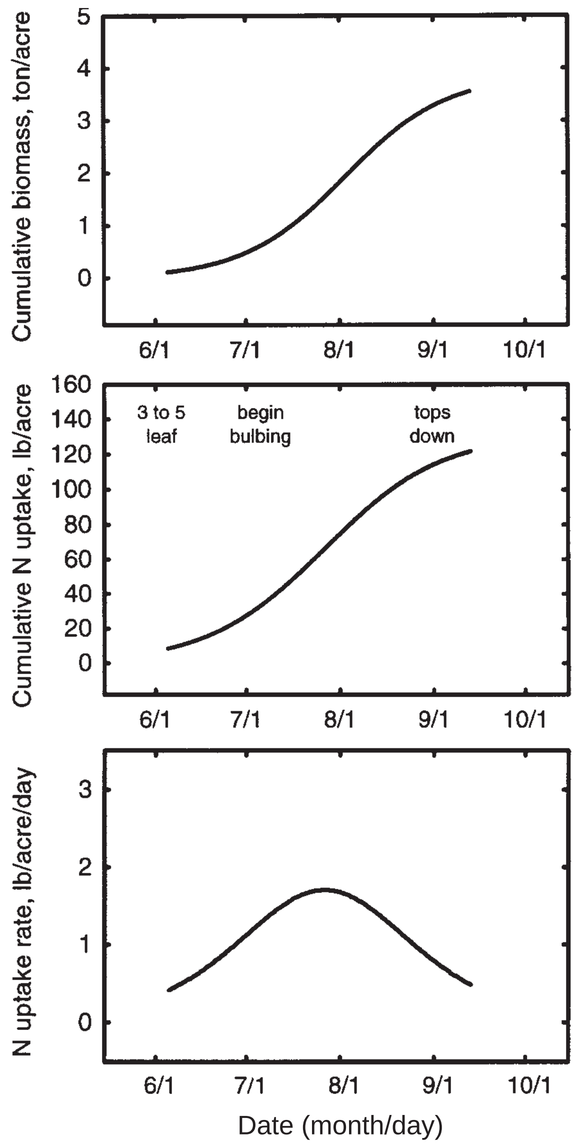

Figure 10.—Biomass accumulation and N uptake for seeded dry bulb onions in the Treasure Valley. Combined data from five locations. Source: Brad Brown, University of Idaho, Parma Research and Extension Center.

Questions and answers about nitrogen use by crops

Nitrogen management uses technical jargon. This section precisely defines our jargon, so you can compare the values presented here with other information on nitrogen management. This section also provides additional information for interpretation of the research results reported here.

What is plant-available N?

Plants utilize only the ammonium (NH_4^+) and nitrate (NO_3^-) forms of nitrogen. Nitrogen from the atmosphere and from organic sources is not available until conversion by microbial activity or a chemical reaction into ammonium or nitrate-N.

What sources provide available N for crops?

Crops utilize available N from several sources. Water-soluble N fertilizers supply N in an immediately available form. Plant-available nitrogen also is provided by bacteria living in association with the roots of legumes. The decomposition of organic N compounds in soil, a process called mineralization, also provides plant-available N. Organic sources of mineralizable N include soil organic matter, crop residues, manures, and other organic byproducts. In some areas, irrigation water may be a significant source of available N. Consider nitrogen from all of these sources when developing a plan for supplying N to meet crop needs.

Why are the N uptake values similar to recommended fertilizer rates for some crops?

This is the result of two factors that cancel each other out in some situations. First, as discussed above, available N is produced by the decomposition of soil organic matter and crop residues. This process reduces the amount of N needed from fertilizer. Second, some of the applied N is lost via volatilization, denitrification, immobilization, and leaching processes. This increases the amount of N needed from fertilizer. Sometimes, a balance between contributions from soil N mineralization and available N losses occurs. In these situations, crop N uptake and fertilizer rate recommendations are similar.

How is above-ground N uptake measured?

Nitrogen uptake, as reported here, is equal to the dry weight of the harvested above-ground biomass multiplied by the biomass N concentration. For example, for a peppermint crop producing 8,000 lb/a biomass (dry weight basis) and having an N concentration of 2.5 percent N, the calculated N uptake is 200 lb N/acre.

Did the measurement procedure recover all of the N that entered the plant?

No. We measured the N present in plants by harvesting at different growth stages. After uptake, some N is lost from small holes, called stomata, on the underside of leaves. Additional N is lost when leaves get old, turn yellow, and fall off the plant. Loss of N from the above-ground portion of the crop can account for 5 to 20 percent of the total above-ground N uptake by crops such as wheat or corn.

Except for potatoes, we do not report here the amount of N present below ground in roots and other vegetative structures. For actively growing crops, approximately one-quarter to one-third of the amount of N found in above-ground biomass usually is present in the roots. For annual crops, most of the N present in roots moves to plant tops by maturity. Therefore, the cumulative N uptake values reported here probably represent 75 to 95 percent of whole plant N uptake.

How efficient are plants in utilizing fertilizer N?

All of the N applied as fertilizer is not taken up by a crop, even when the fertilizer is applied at optimum rates. When crops are supplied adequate but not excess fertilizer N, between half and two-thirds of the fertilizer N will be found in the crop. Crop N uptake efficiency is less than 100 percent because of naturally occurring processes. Some of the N is lost as a gas via ammonia volatilization and denitrification. Some is incorporated into soil organic matter through microbial processes. Some is present in the soil at the end of the growing season as nitrate-N.

In developing an N fertilizer rate recommendation, crop N uptake efficiency usually is assumed to be 50 to 70 percent. This means that for 100 lb/a of fertilizer N applied, crop N uptake increases by 50 to 70 lb N/a.

What happens to nitrate-N not taken up by crops?

Nitrate-N moves with soil water. West of the Cascades, much of the nitrate remaining in the soil profile in October is lost over the winter. In lower precipitation areas, winter precipitation may not leach nitrate-N from the root zone but can move it deeper in the soil profile. Many crops are less efficient in utilizing available N that is below a depth of 2 feet.

Some nitrate-N is converted to organic N by soil microorganisms. Nitrogen stored in organic forms is not subject to leaching.

For more information

Irrigation

*Cuenca, R.H., J.L. Nuss, A. Martinez-Cob, G.G. Katul, and J.M. Faci Gonzalez. *Oregon crop water use and irrigation requirements*, EM 8530 (Oregon State University, Corvallis, OR, 1992). $5.00

*English, M.J., R. Mittelstadt, and J.R. Miner. *Irrigation management practices checklist for Oregon*, EM 8644 (Oregon State University, Corvallis, OR, 1996). $2.25

*Hansen, H., and W. Trimmer. *Irrigation system walk-through inspection analysis*, PNW 293 (Oregon State University, Corvallis, OR, 1997). $1.00

*Ley, T.W., R.G. Stevens, R. Topielec, and W.H. Neibling. *Soil water monitoring and measurement*, PNW 475 (Oregon State University, Corvallis, OR, 1994). $1.00

*Trimmer, W., and H. Hansen. *Irrigation scheduling*, PNW 288 (Oregon State University, Corvallis, OR, 1994). 50¢

Soil testing

*Marx, E.S., J. Hart, and R.G. Stevens. *Soil test interpretation guide*, EC 1478 (Oregon State University, Corvallis, OR, 1998). $1.50

*Marx, E.S., N.W. Christensen, J. Hart, M. Gangwer, C.G. Cogger, and A.I. Bary. *The pre-sidedress soil nitrate test (PSNT) for western Oregon and western Washington*, EM 8650 (Oregon State University, Corvallis, OR, 1996). 75¢

Additional sources of crop N uptake data

Doerge, T.A., R.L. Roth, and B.R. Gardner. *Nitrogen Fertilizer management in Arizona*, Publ. 191025 (College of Agriculture, The University of Arizona, Tucson, AZ, 1991).

Ritchie, S.W., J.J. Hanway, and G.O. Benson. *How a corn plant develops*, Spec. Report 48 (Iowa State University, Ames, IA, 1989).

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Quick summary

- This publication is a resource for scheduling N fertilizer applications for maximum efficiency. Improving the timing of N applications can provide the following benefits:
  - Reduced fertilizer costs
  - Improved crop yield and quality
  - Protection of water resources
- This publication summarizes, in a consistent format, above-ground crop N uptake data from project reports, conference proceedings, and journal articles.
- The crop N uptake data presented here were developed from field studies where crops were fertilized with adequate N for near-maximum yield.
- Crop N uptake occurs in three phases over the growing season:
  - Phase I: Slow crop N uptake corresponding to slow early growth
  - Phase II: Rapid N uptake as the crop grows rapidly, increasing its leaf area
  - Phase III: Slow or no crop N uptake. During this phase, nitrogen is redistributed within the plant from leaves to stems or reproductive structures (tubers, seeds). Biomass continues to accumulate.
- Crop N uptake during the phase of rapid N uptake (Phase II) accounts for 50 to 85 percent of cumulative N uptake during the growing season.
- Maximum crop N uptake rates during Phase II usually exceed 2 lb N/a/day.
- To achieve near-maximum crop yields, you must provide an adequate supply of available N during the period of rapid crop N uptake (Phase II).
- Crop cultivar and plant population affect the quantity of maximum N uptake, but not the timing of N uptake by a crop.
- The crop N uptake amounts listed here are not N fertilizer recommendations. Besides crop N uptake estimates, fertilizer recommendations consider:
  - The quantity of N supplied from other sources (e.g., decomposition of soil organic matter, manure, irrigation water)
  - Crop N uptake efficiency—the proportion of plant-available N removed by the crop (usually 50 to 70 percent)

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