NUTRIENT MANAGEMENT guide
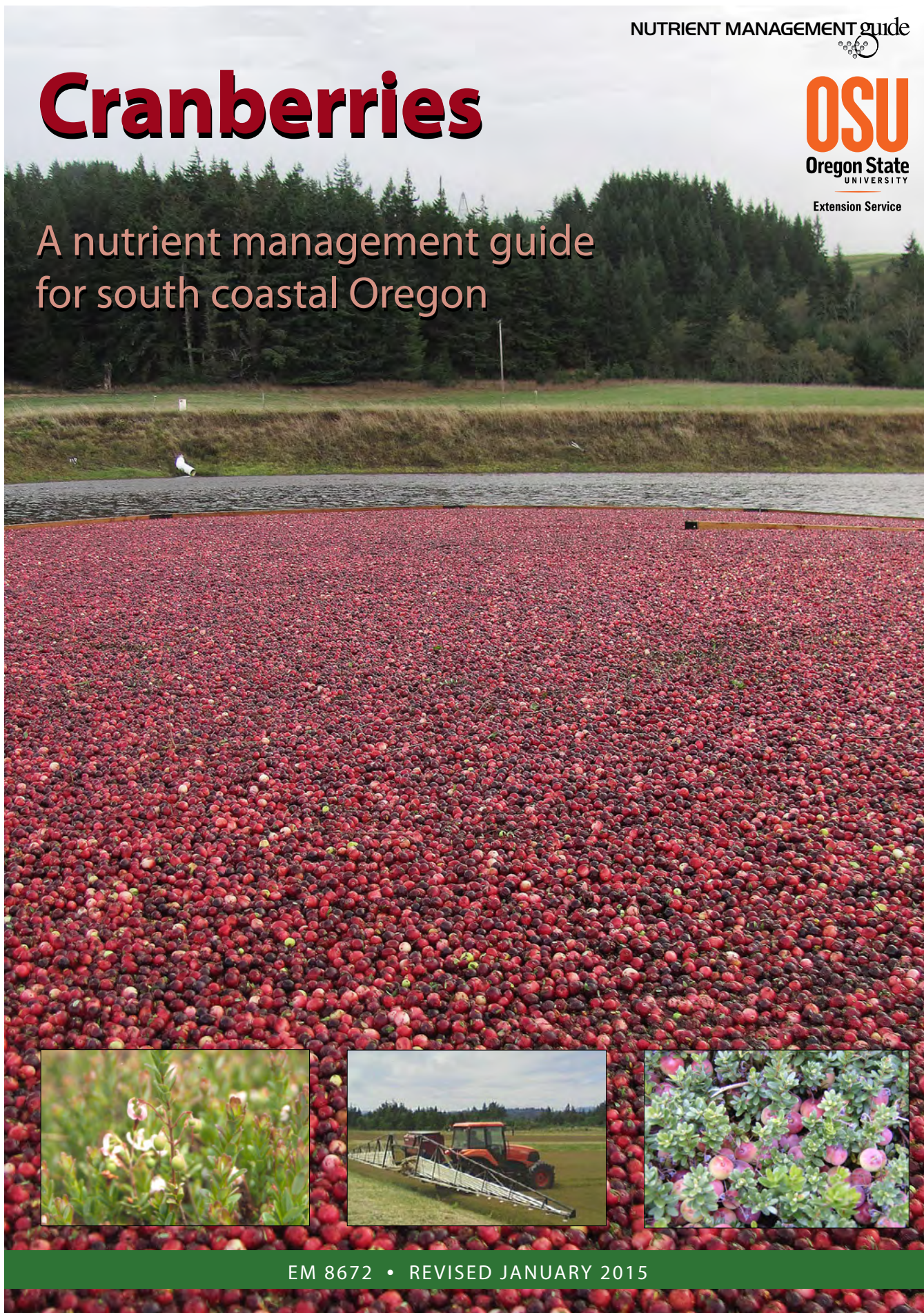
Cranberries

A nutrient management guide for south coastal Oregon

OSU
Oregon State
UNIVERSITY
Extension Service

EM 8672 • REVISED JANUARY 2015

Cranberries
(South Coastal Oregon)

John M. Hart, Bernadine C. Strik, Carolyn DeMoranville, Joan R. Davenport, and Teryl Roper

Cranberries are produced on approximately 3,000 acres in Coos and Curry counties. This nutrient management guide provides nutrient application information and recommendations for south coastal Oregon.

Oregon cranberry production benefits from a long, reasonably moderate growing season. These conditions produce fruit that is high in anthocyanin concentration (TAcy) and slightly higher in sugar concentration (°Brix) than fruit from other growing areas (Figure 1). The high TAcy gives Oregon berries a dark red color. This trait is valued by processors, and juice from Oregon-produced cranberries is blended with lighter colored juice from other areas to produce the rich red color expected by consumers. The higher °Brix concentration is another trait desired by processors.

The average Oregon cranberry yield is slightly less than the national average of 200 barrels (bbl)/a. Even though average yield is less than 200 bbl/a, Oregon growers can produce 400 to 500 bbl/a or more. The nutrient amounts recommended in this guide are sufficient to support these higher yields.

Cranberries are long-lived woody perennials. From planting until establishment of a mature canopy, when the bed is 3 to 4 years old, soil and fertilizers are the primary nutrient sources for growth. After a mature canopy is developed, decomposition and growth reach equilibrium. Nutrients are recycled from old leaves to new growth. Decaying leaves and roots also supply nutrients to the crop. The combination of nutrient cycling and decomposition supplies at least half of crop need for most nutrients.

Bernadine Strik, © Oregon State University

Figure 1.—Oregon cranberries are high in anthocyanin and sugar concentrations, giving them qualities preferred by processors.

After a mature canopy is developed, the nutrient management goal is to maintain sufficient tissue nutrient concentration to produce a full crop. Annual nutrient concentration from plant tissue samples collected in late summer should be stable, not increasing or declining. Routine tissue analysis is crucial. "Interpreting tissue analyses" (pages 13–15) provides information on how to use tissue test results for nutrient management planning.

The combination of nutrient cycling and soil nutrient supply creates tissue analysis results in the sufficient range for most beds, ensuring that nutrient supply does not limit yields. Nitrogen is the only nutrient *required* annually when tissue analysis indicates sufficient concentrations of other nutrients. Usually, however, growers supply

John M. Hart, professor emeritus, crop and soil science, Oregon State University; Bernadine C. Strik, Extension berry crops specialist and professor of horticulture, Oregon State University; Carolyn DeMoranville, Extension associate professor, University of Massachusetts Amherst Cranberry Station; Joan R. Davenport, professor of soil science, Washington State University; and Teryl Roper, professor of horticulture, Utah State University. Cover photos by Cassie Bouska (background) and Bernadine Strik (bottom left), © Oregon State University, and by Bob Donaldson (bottom middle and right).

at least maintenance or replacement amounts of other macronutrients.

Insufficient nutrition is only one cause of reduced yield. Healthy plants with adequate root systems are required to obtain the greatest return from your fertilizer investment. Saturated or dry soils; high temperatures; frost; shading; weed, insect, or disease pressure; or herbicide injury reduce yield. Fertilizer application will not compensate for these problems. Uniform irrigation is essential, since moist, but not saturated, soils are required.

While yields of 400 bbl/a or greater are possible, adding fertilizer won't produce this yield when genetics, environmental limitations, and management are primary limiting factors. If adequate nutrition is present, fertilizer application is an unnecessary expense and potentially detrimental to the environment.

Nutrient recommendations in this guide are appropriate for producing sand-based, water-harvested beds in south coastal Oregon. Tissue and soil test values considered sufficient in this publication can be used in both conventional and organic production systems. However, nutrient recommendations are provided only for conventional production. These recommendations are based on grower experience and on research performed over the past 40 years in grower beds in Oregon and other production areas. For more information about the production environment for south coastal Oregon cranberries, see the sidebar "Bed configuration and drainage" (page 4).

The nutrient recommendations in this publication should be used as a starting point for decision making. Modify them as needed, based on soil and plant analyses, plant vigor, and crop performance.

Summary

The following guidelines provide a starting point for choosing fertilizer application rates. However, factors such as previous year's yield, current-season upright growth, soil analysis, and weather should also be taken into account when making decisions about application rates. See the referenced pages for additional guidance. *Note*: Tissue concentrations are based on samples taken in August or September of the previous year.

Nutrients for producing beds

Nitrogen (N)	In general, 40 to 60 lb/a of applied N is adequate. In some circumstances, the N rate may be as low as zero. Wait until the first pea-sized berries are observed before beginning N fertilization. Apply 10 to 20 lb N/a every 7 to 14 days until the last petals fall. Make no more than three applications, with the third being lighter than the first two. See pages 15–23.
Phosphorus (P)	If tissue P is below 0.1 percent, apply 20 to 45 lb P_2O_5/a (Table 7, page 24). If making a single application, do so at or before the roughneck development stage. Alternatively, wait until late spring, and then apply P in two or three doses. See pages 23–25.
Potassium (K)	If tissue K is below 0.4 percent, apply 60 to 100 lb K_2O/a (Table 9, page 26). If making a single application of K, do so at or before the roughneck development stage. However, multiple applications are recommended, especially for higher rates. If making multiple applications, wait until late spring, and then apply K in two or three doses. See pages 25–28.
Calcium (Ca)	If tissue Ca is below 0.3 percent, apply 50 to 100 lb gypsum/a between bud break and roughneck (Table 10, page 28). For maintenance applications, see pages 28–29.
Magnesium (Mg)	If tissue Mg is below 0.15 percent, apply 20 lb Mg/a (Table 11, page 29). Apply Mg at cabbage head/bud break. See page 29.
Sulfur (S)	If tissue S is below 0.08 percent, apply 10 to 20 lb S/a (Table 12, page 30). Apply at the same time as N. See pages 29–30.
Micronutrients	Application of micronutrients is not recommended unless tissue concentration is low or dropping. See pages 30–31.
Soil pH	Optimal soil pH for cranberry production is between 4.0 and 5.5. If lime is needed to raise pH, apply no more than 100 to 150 lb/a. Fall application is recommended. To lower pH, proceed with great caution. Apply no more than 100 to 500 lb granular elemental S/a annually, at any time during the growing season when the soil is not saturated. See pages 31–34 .

Before making decisions about fertilizer application, you need to understand answers to three key questions about the cranberry plant: (1) How does it grow? (2) What nutrients does it need? (3) What factors determine yield? These topics are discussed in the following sections. The final question about yield is the bottom line: all growers want to maximize yield in the most economically and environmentally efficient way, i.e., to maximize return on investment.

Crop growth and fruit production

How does the plant obtain nutrients?

For the most part, cranberry plants obtain nutrients from the soil via the roots (Figure 2). Nutrients in the soil come from both fertilizer and the breakdown of organic compounds by soil microorganisms (a process known as mineralization).

A plant's ability to obtain nutrients from the soil depends on the status of both the soil and the plant. Soil factors that are important include moisture, aeration, nutrient content, soil pH, and temperature.

Bed configuration and drainage

A cranberry bed is commonly constructed by placing sandy soil on a subgrade containing high levels of both organic matter and clay. Most beds fewer than 200 feet wide are constructed with the center of the bed higher than the edges, making a "crown." This configuration provides reasonable drainage so that whole beds rarely have drainage problems. Limited drainage sometimes occurs along bed edges or in localized areas. However, border ditches usually provide adequate drainage along bed edges. Drainage for beds wider than 200 feet is accomplished with tile drains and level construction.

Drainage is important because nutrient uptake requires the expenditure of energy, and oxygen is required for this process. When soils are saturated, air is excluded and nutrient uptake stops.

Cranberries growing in areas of poor drainage often have high tissue Mn concentration. They sometimes seem to be deficient in nutrients, as they grow slowly and may have a pale color. Fertilizer application will not "cure" this situation since the plants cannot absorb adequate nutrients in saturated soil.

- **Moisture:** Soil moisture is necessary so that fertilizer material can be dissolved and absorbed by the roots.

- **Aeration:** Uptake of nutrients by roots requires energy, which in turn requires the presence of oxygen. When soils are saturated with water, oxygen is unavailable.

- **Nutrient content:** Nutrients must be in available form to be used by plants.

- **Soil pH:** The form of N found in the soil is partly determined by soil pH. The initial product of mineralization is ammonium, a form preferred by cranberry plants. At low soil pH, the bacteria that further convert ammonium to nitrate are suppressed, so N remains in the ammonium form. See the sidebar "Soil pH and nitrate leaching" (page 5) for more information.

- **Temperature:** Nitrogen release from mineralization increases when soil temperature reaches 75°F.

A grower can control most of these factors. Moisture and aeration are controlled with irrigation and drainage. Nutrient content can be supplemented with fertilizer, and pH can be monitored and adjusted with lime or sulfur. While temperature cannot be controlled, it can be monitored and factored into decisions about the timing of fertilizer applications.

B. Miller, © Oregon State University

Figure 2.— Cranberry plants obtain nutrients primarily through the roots. Thus, soil conditions such as moisture, aeration, nutrient content, and pH are important to ensuring optimal growth and yield.

Soil pH and nitrate leaching

The nitrate (NO_3^-) form of nitrogen readily leaches with rainfall or irrigation. In contrast, ammonium-N (NH_4^+) does not readily leach, although it is soluble and may run off in surface water if significant amounts of rain fall immediately after application.

Ammonium is changed to nitrate by the action of soil microbes. This conversion is controlled by soil pH. As soil pH decreases, nitrate production diminishes (Figure 3). If soil pH is 5.5, little nitrate is produced within a month of spring ammonium application. Because soil pH is usually 5.5 or below in cranberry beds, little nitrate is produced. Thus, little, if any, N is available for leaching.
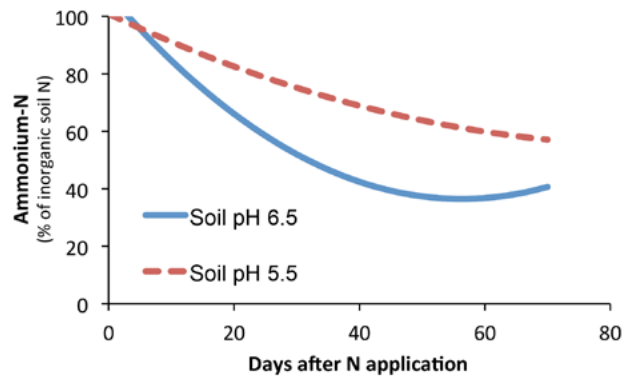
Figure 3.—Soil pH dictates the rate of ammonium change to nitrate following ammonium sulfate application. Data from Christensen, et al. (2008); figure by John Hart.

How does the cranberry plant grow?

Cranberry is a low-growing plant that produces stolons (runners). Along the length of the stolons, buds produce leafy shoots known as uprights. The initial uprights generated on a stolon produce roots to anchor the uprights to the soil. These uprights are vegetative, bearing no fruit or flowers. Once the upright population is established, each upright produces a terminal bud in midsummer. These buds are either vegetative or mixed floral/vegetative (Figure 4).

The terminal buds overwinter and begin growth of a new upright segment in the spring. Vegetative buds produce vegetative (nonflowering) uprights (U_N), and mixed buds produce flowering uprights (U_F).

Flowering uprights bear flowers that may become fruit, as well as leafy growth above the flowers or fruit. The leaves above the flowers on U_F are the primary source of the carbohydrates that will move into

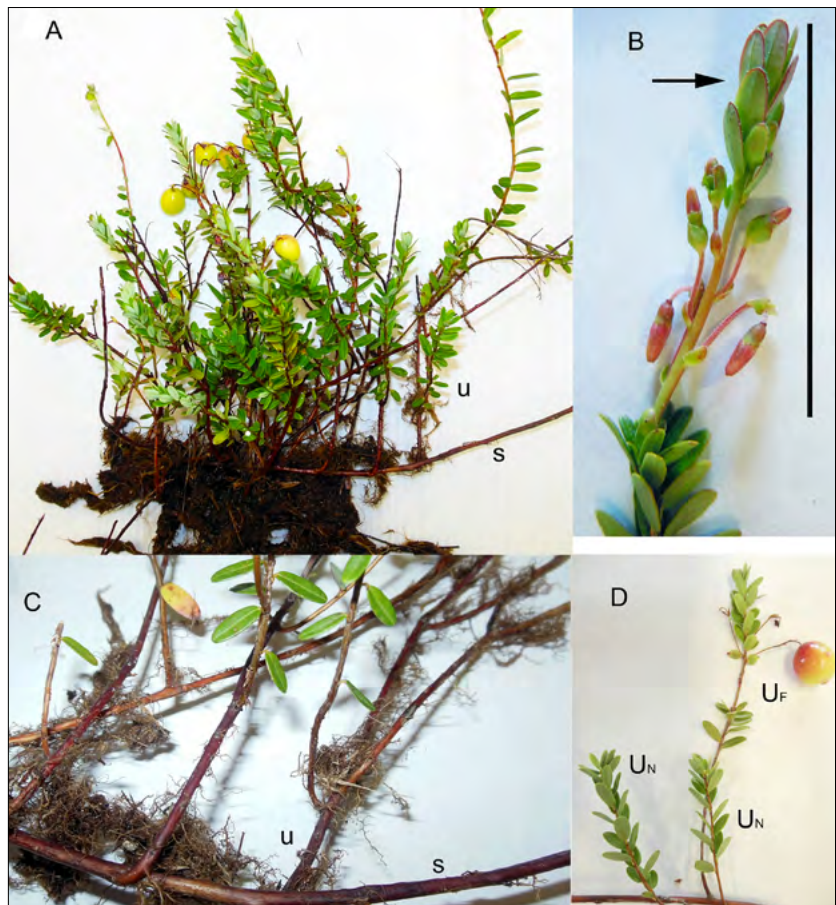Carolyn DeMoranville, UMass Amherst Cranberry Station

Figure 4.—(A) Stolons (s) give rise to uprights (u) and a fibrous mat of roots. (B) Flowering upright with unopened flowers. The vertical line shows current-year growth; below is previous-year growth. The arrow indicates leafy growth that will provide carbohydrates to developing berries. Upright length (total new portion above the flowers) can help determine whether nitrogen nutrition is adequate. (C) Uprights (u) growing from a stolon (s). Note fibrous roots. (D) Vegetative (U_N) and flowering (U_F) uprights.

Table 1.—Nutrient content, concentration, and recycling for a 250 bbl/a cranberry crop.[1]

Component	Weight (lb) Wet ("as is")	Dry	Nutrient concentration and amount N (%)	N (lb/a)	P (%)	P (lb/a)	K (%)	K (lb/a)	S (%)	S (lb/a)
Fruit	25,000	3,000	0.45	14	0.07	2	0.85	26	0.1	3
New shoots	9,000	5,200	1.0	52	0.2	10	0.7	36	0.2	10
Recycled from old growth	—	—	—	-30	—	-5	—	-25	—	-7
Total	34,000	8,200	—	36	—	7	—	37	—	6

[1]Data from DeMoranville (1992).

the developing fruit. Therefore, adequate growth on the U_F is essential to support overall plant growth and good fruit production.

The ideal upright length to support fruit production varies with growing region and variety. New upright growth should be about 2 to 4 inches above the flowers before early bloom. For 'Stevens' cranberry grown in Massachusetts, 2¼ to 2¾ inches of growth above the flowers is considered adequate.

Based on limited data from Wisconsin, Figure 5 shows a decrease in yield with increasing upright length beyond 4 inches. When upright length exceeds 4 inches, yield decreases sharply, most likely due to a shift in resources away from fruit production and into vegetative growth.

Seasonal nutrient carryover and recycling

In perennial crops such as cranberry, nutrients are stored in roots and mature stems. A survey of 30 cranberry plantings in Massachusetts showed that N applied the previous year was an important determinant of yield, while N application during the crop year was of little significance.

When fertilizer N enriched with a heavy stable isotope (^{15}N) was applied to cranberries in Oregon prior to fruit set, at least one-half of the ^{15}N was later found in old stems and roots. In Wisconsin research, one-third of ^{15}N taken into the plant from soil application moved into new growth and fruit during the year of application. The following year, 70 percent of the remaining ^{15}N was in mature tissue, while 30 percent had been remobilized into that season's new leaves and fruit. These studies illustrate the ability of cranberry plants to store nutrients and remobilize them for growth and fruiting.
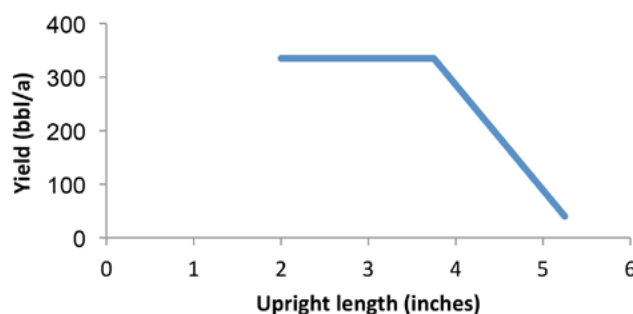

Figure 5.—Cranberry yield decreases sharply as upright length increases. Unpublished data from Wisconsin; figure by John Hart.

Nutrient requirements

Most of the cranberry plant is composed of water and organic compounds. The organic compounds, in large part carbohydrates, are the product of photosynthesis. Photosynthesis is the process by which plants harvest light and carbon dioxide from the air to make carbohydrates.

As in most plants, nutrients account for less than 10 percent of the dry mass in cranberry. Plant nutrients consist of the essential major nutrients nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), and magnesium (Mg) and the essential minor nutrients manganese (Mn), copper (Cu), zinc (Zn), molybdenum (Mo), boron (B), iron (Fe), and chlorine (Cl).

The terms major and minor (sometimes macro- and micronutrients) are used to distinguish nutrients needed in relatively large amounts from those required in tiny amounts. These names do not mean that any nutrient is less "essential" than any other. In this publication, we focus mostly on the macronutrients, since micronutrients are seldom limiting in cranberry production.

Table 2.—Estimate of nutrients removed from a cranberry bed annually.[1,2]

Component	Weight (lb/a)		Concentration or amount														
			N		P		K		S		Ca		Mg		B		Zn	
	Wet	Dry	(%)	(lb/a)	(%)	(lb/a)	(%)	(lb/a)	(%)	(lb/a)	(%)	(lb/a)	(%)	(lb/a)	(%)	(lb/a)	%	(lb/a)
Fruit	25,000	3,000	0.45	13.5	0.07	2.1	0.85	25.5	0.1	3	0.075	2	0.055	1.7	0.004	0.12	0.002	0.07
Pruned vines	500	275	1	2.8	0.2	0.55	0.55	1.5	0.2	0.6	0.75	2	0.27	0.7	0.004	0.01	0.002	0.01
Harvest trash	—	2,300	0.7	16.1	0.1	2	0.17	3.9	0.05	1.2	0.75	17	0.15	3	—	0	0.002	0.05
Total	—	5,575	—	32	—	5	—	31	—	5	—	21	—	5	—	0.13	—	0.13

[1] Assumes pruning of 500 lb vines/a and harvest of 250 bbl fruit/a.

[2] Data from DeMoranville (1992).

Table 1 shows the typical amounts of N, P, K, and S found in cranberry plants. It also shows the amounts of these nutrients that are recycled from old growth into new growth and fruit production. Recycled nutrients are shown as a negative number in the table, as recycling decreases the amount needed for a replacement or maintenance nutrient application ("total" in table). Table 2 shows the amount of nutrients removed with harvest and pruning.

What factors determine yield?

Yield is determined by a wide range of factors, including plant physiology, genetics, and management actions. This section discusses the key factors that determine yield. The sidebar "The concept of limiting factors" discusses how these factors interact. See the sidebar "How can I maximize yield?" (page 8) for a summary of yield-limiting factors and ways that you can affect them. See Appendix A for information about how to estimate cranberry yield.

Yield components

Yield components are the factors that determine potential yield. To maximize return on investment, management practices must promote transformation of yield components into cranberries. Actual yield is determined by the effects of sunlight, water, nutrients, temperature, and pests. For example, weather and pest pressure can affect pollination, fruit set, and marketable yield. Based on genetic limitations, approximately half the yield potential can result in cranberries if all other factors are optimal.

Cranberry yield components are as follows:

- Total number of uprights (U_T)
- Number of flowering uprights (U_F)
- Number of flowers
- Number of berries (fruit set)
- Individual berry weight

The concept of limiting factors

When managing cranberry nutrition, growers are most interested in determining the factor(s) that limit growth and yield. Nutrients are not the only limiting factor. Most growers are well aware that pests or frost damage can limit growth and yield. Other limitations include plant genetics and physiology, as well as management factors such as soil moisture.

We can think of all of these potential limiting factors as staves in a barrel, each of a different length. The shortest stave determines how much the barrel can hold. If that stave is lengthened (e.g., a deficient nutrient is added), the barrel will hold more (plant growth and productivity will improve) until a new short stave (limiting factor) is reached.

Making one stave of the barrel longer will not allow the barrel to hold more if that stave was not the shortest. Likewise, while a nutrient deficiency can limit yield, once nutrients are within the required range, adding more will not overcome other limitations to yield.
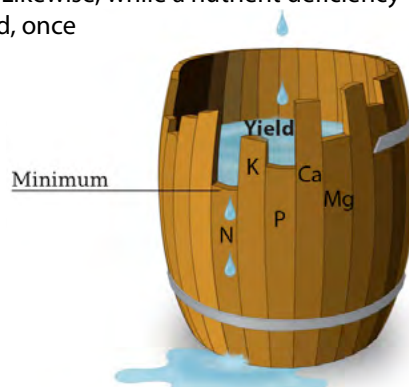
Oregon research showed that while nonflowering uprights (U_N) do not contribute to the current season's yield, they are important for next year's yield. Many uprights (up to 75 percent) do not produce fruit 2 years in a row, so chances are that a U_F this year will not be one next year. Thus, similar numbers of U_F and U_N in a bed each year will assure uniformity of yield from year to year. One of the characteristics of high-yielding hybrid varieties is their greater ability for uprights to flower and fruit in successive years.

How can I maximize yield?

Crop yield is determined by the following factors.

- **Yield components** (total number of uprights, number of flowering uprights, number of flowers, fruit set, and individual berry weight): The most important and variable yield components are the number of flowering uprights and fruit set.

- **Photosynthesis and carbohydrate production:** These processes provide the resources needed for bud initiation, upright growth, fruit set, and fruit development. Development of flowering uprights for next year and current-season fruit set overlap in time and may compete for resources.

- **Genetics:** Research has shown that, for most cranberry cultivars, flowering uprights can support a maximum of two berries.

Within the limitations imposed by genetic factors, you can maximize yield by ensuring optimal plant growth and carbohydrate production. This goal can be achieved through management of the following factors:

- Nutrient supply
- Soil moisture
- Soil aeration
- Soil pH

Remember that unless nutrients are deficient, the addition of fertilizer will not increase yield.

Ensuring an optimal number of total uprights (U_T) and flowering uprights (U_F) per unit area is the best way to ensure high yield. With too few uprights, U_F will be low and yield suppressed. Excessive uprights restrict light penetration into the canopy. Reduced light decreases not only photosynthesis but also fruit bud set for next year's crop. Dense canopies may limit the number of U_F, the number of flowers per upright, fruit set (due to reduced bee activity), and fruit color.

Optimal upright density falls within a range and varies depending on variety (Table 3). Upright density can be managed with sanding or pruning, along with judicious use of N fertilizer.

The number of flowers per upright and fruit set likely are limited by genetic factors. Thus, increasing these yield components is difficult. Short of genetic improvements, the minor increases that can be achieved are unlikely to result in significant yield increase. Research in Oregon, Massachusetts, and Wisconsin documented 40 to 57 percent fruit set.

Average berry weight falls within a narrow range for each variety and, in the absence of any deficiency, is not especially responsive to fertilizer application, as it is largely determined by genetics.

For more information, see Appendix B, "Nitrogen Fertilization and Yield Components" (page 38).

Photosynthesis and carbohydrate production

Over the past 30 years, research has shown that the predominant limitation to yield is photosynthesis. Carbohydrates produced by photosynthesis are used to make plant cellulose, lipids, and proteins (including chlorophyll needed for photosynthesis). This body of research is summarized in *The Physiology of Cranberry Yield* (see "For more information," page 35).

Table 3.—Optimal number of uprights for south coastal Oregon cranberry production.[1]

Variety	Uprights/sq ft			
	U_T	U_N	U_F	U_F/U_T (%)
'McFarlin'	630 to 700	460 to 580	100 to 190	15 to 27
'Stevens' (new bed)	220 to 360	105 to 265	90 to 115	26 to 53
'Stevens' (old bed)	265 to 625	95 to 385	100 to 240	23 to 64

[1]Measurements were made in good-yielding Oregon cranberry beds. Data from Strik and Poole (1991 and 1992) and Strik, et al. (1991).

If photosynthesis is a major yield-limiting factor, do limitations to photosynthesis limit yield? Photosynthesis requires light and carbon dioxide. In cranberry beds, neither is limiting. Ample carbon dioxide is present in the atmosphere, and cranberries have a fairly modest light requirement. However, individual uprights can be light limited due to shading by weeds or other uprights.

Competition within the plant for resources

Cranberry is a perennial crop with a 15- to 16-month cycle from the initiation of flower buds ("fruit bud set") to harvest of the crop produced from those flowers (Figure 6). Because the cycle is longer than 12 months, the final stages of the current crop cycle overlap the early stages of the next cycle. Next year's buds begin to form during sizing of current-year berries, setting up competition for carbon and nutrient resources.

A Wisconsin study of cranberry photosynthesis confirmed that carbon resources in U_F growth are at their lowest during fruit and bud development. At this time, carbohydrates are being moved into the developing fruit.

Research in Washington showed that when the number of berries on an upright was high, buds produced for next year's crop tended to be small. As mentioned above, Oregon data show that flowering uprights tend not to flower again next year. It is likely that competition for carbohydrates is mainly responsible. However, competition for nutrients may also play a part, as nutrients are moved from roots and storage tissues to both fruit and developing buds.
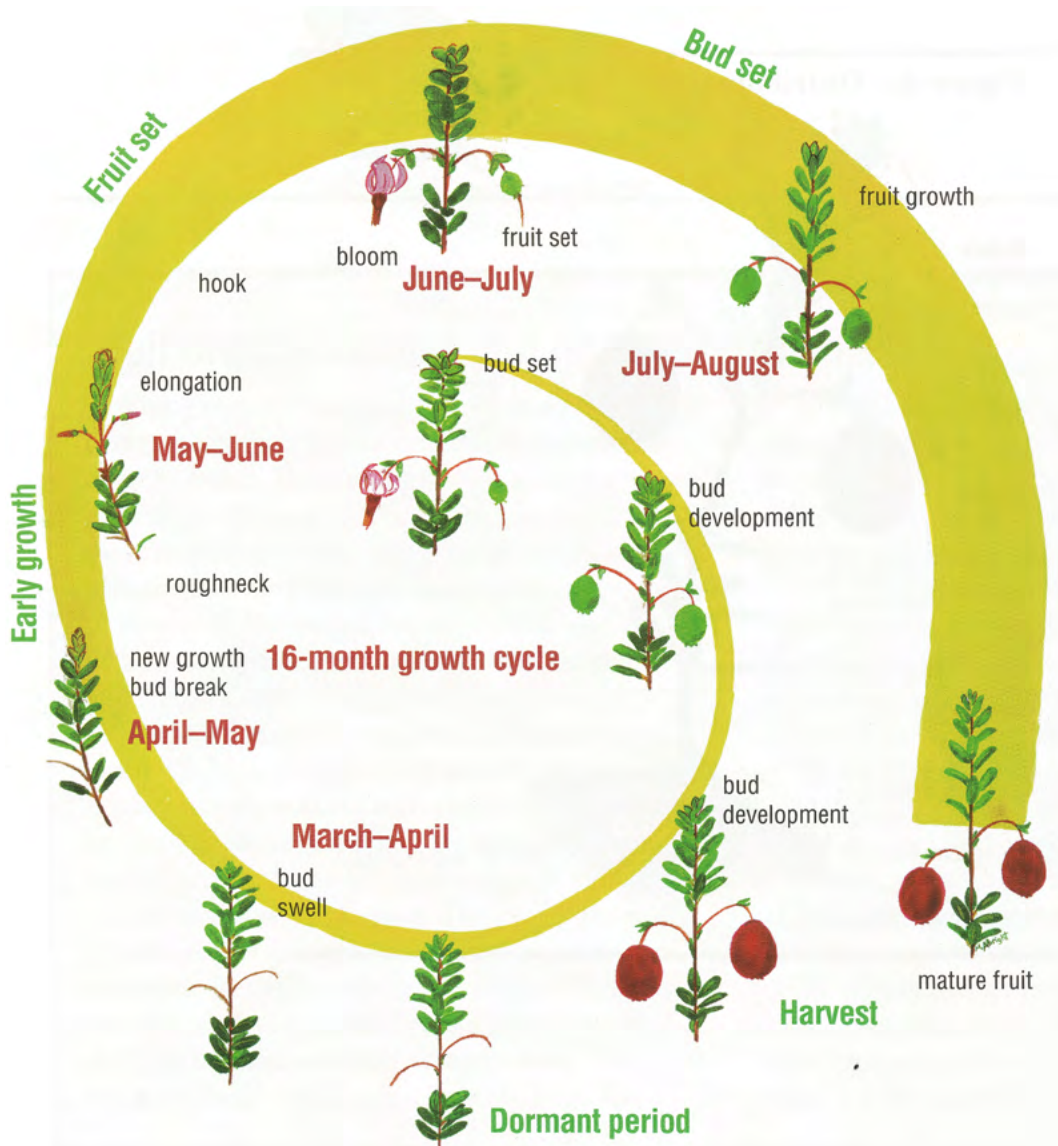

Figure 6.—Cranberry is a perennial crop with a 15- to 16-month cycle from the initiation of flower buds to the harvesting of the crop produced from those flowers. Because the cycle is longer than 12 months, some stages of the current crop cycle overlap the early stages of the next cycle. Importantly, the formation of next year's buds (floral initiation) happens during the sizing of the current year's berries, setting up competition for resources. Illustration by Meredith Albright, reprinted from OSU Extension publication EM 8741.

Wisconsin research has also shown that the berries on an upright compete among themselves for resources (Figure 7). After fruit formed on the lower flowers of an upright (those first to open), percent fruit set was much lower on the upper flowers. Berries in upper positions were also smaller. In other words, as the first fruits utilized resources, fewer resources were available for later set fruit. When the lower flowers were removed, fruit set on the upper flowers increased dramatically.

Hybridization may decrease the importance of competition for carbon resources by producing varieties with greater leaf area or higher photosynthetic rates. These changes could provide more resources for fruit set, bud initiation, and repeat floral initiation.

Genetics

Research conducted in the 1990s showed that the carbon compounds produced by the leaves on a U_F are sufficient to support on average two full-sized berries on that upright. This limitation seemed to be genetic in origin, leading to the conclusion that short of breeding advances, the two-fruit-per-upright average maximum could not be overcome. Management cannot enable plants to surpass their genetic limitations. Management manipulations that increased the number of berries per upright *decreased* the average weight of the berries proportionally so that the total weight of fruit produced was no greater than with two full-sized berries per upright.

Nutrient supply

Cranberry plants must have sufficient amounts of required nutrients for optimal growth and fruit production. Aside from water, fruit consists primarily of carbohydrate compounds (structural components, acids, and sugars) produced in the leaves and transported to the developing fruit. Thus, optimal growth goes hand in hand with yield. If plant growth is limited in the spring, the plant will not produce the carbohydrates needed to support a large crop. In this case, no amount of added fertilizer at fruit set will make the plants achieve maximum yield.

Plants respond to additions of a deficient essential nutrient with increased growth and productivity until one of three things occurs:

- The requirement is satisfied, and growth and production reach a maximum, genetically determined, plateau.
- Response stops short of the potential maximum as a different factor becomes a new limitation.
- Growth and productivity decline due to an excess of the added nutrient.

In any of these situations, adding more of the originally limiting nutrient will not improve yield and may be harmful. Simply put, if some is good, more is not necessarily better. For example, while supplying enough N early in the season to ensure adequate leaf area and green pigment is important, too much N will cause plants to produce leaves and stems at the expense of fruit production.

Soil moisture, aeration, and pH

Soil moisture and aeration help determine nutrient availability. Plants use nutrients dissolved in the soil water. If soil is too dry, nutrients cannot dissolve and move to the roots, so uptake cannot occur. Conversely, if soil is waterlogged, roots are deprived of oxygen, and their ability to absorb nutrients is limited. Thus, proper soil drainage improves fertilizer efficiency so that less fertilizer is required.

Figure 7.—Developing berries compete among themselves for resources as well as with next year's newly developing buds.

Bob Donaldson

Table 4.—Distribution of uprights.[1,2]

Upright type	Percentage of uprights	
	Ideal irrigation	Too wet
Nonflowering	61.9	63.5
Flowering, no berries	13.6*	17.4*
One berry	21.2*	17.2*
Two berries	3.0*	1.8*
Three or more berries	0.3	0.1

[1]In each row, * indicates that the values for the two irrigation treatments were significantly different.

[2]Adapted from Lampinen and DeMoranville (2003).

Research in Massachusetts showed that when a bog is too wet, fruit set declines (Table 4). In excessively wet areas, a higher percentage of flowering uprights failed to retain even one berry. Areas with ideal soil moisture content had more flowering uprights with one or two berries.

Check soil moisture at least twice a week. Soil should be moist but not saturated in the top 6 inches. The use of water-level floats, sensors, and/or tensiometers is highly recommended for monitoring soil moisture. High tissue Mn levels may indicate poor drainage.

The importance and management of soil pH is discussed on pages 31–34.

Factors that do not seem to limit yield

Could temperature be a limiting factor? Research conducted in the major cranberry-growing areas, including Oregon, showed that the rate of fruit weight gain was influenced by temperature. The highest rates were associated with maximum daily temperatures between 68 and 86°F. Above and below that range, fruit weight gain slowed. Massachusetts research confirmed that cranberry growth is largely unaffected by temperatures within the range of 70 and 90°F. Temperatures in south coastal Oregon rarely fall outside this range during the growing season, so this factor is unlikely to limit yield.

What about limitations to fruit set such as pollination? Unless an adequate amount of pollen is transferred to the flower stigma, a fruit will not set and develop to full size. However,

Bernadine Strik, © Oregon State University

Figure 8.—Fertilizer application timing depends on matching nutrient availability to the time of peak crop use.

even when all flowers are fully pollinated (with supplemental hand transfer of pollen), fruit set seldom exceeds 40 to 50 percent. Thus, under normal circumstances, pollination does not seem to be the factor that limits yield. Pollination may be a limiting factor in cases of adverse weather during bloom, excess vegetative growth that limits pollinator access to flowers, or loss of pollinators.

Cranberry growth cycle and nutrient application timing

For optimal cranberry nutrient management, we need to answer three questions:

- How much of each nutrient do cranberry plants need (fertilizer rate)?
- How can we supply needed nutrients (method of application and type of material)?
- When are the nutrients needed (fertilizer timing)?

Fertilizer rates and materials are covered in sections for each nutrient. This section discusses nutrient application timing as it relates to the crop growth cycle.

Fertilizer application timing is based on the plant's demand for nutrients, which tends to be driven by production of plant biomass (Figure 8). Most nutrients are accumulated according to the time line shown in Figure 9 (page 12). The following important points are seen in Figure 9.

Little or no accumulation occurs early in the season (Phase I). This phase represents the period when soil temperature is below 55°F and when plants begin using stored nutrient reserves.

Rapid use of most nutrients (Phase II) occurs before bloom through early fruit development. Phase II corresponds to extension of new growth in the spring, fruit formation and initial filling (fruit set), and initiation of floral buds for next year. This period is especially important for N use. For most nutrients, application during this period is most efficient.

Phase III begins as fruit start to ripen in late August or early September. At this time, most nutrients are already present in the plant, and redistribution of nutrients within the plant is greater than uptake from the soil.

Using soil and tissue analyses for nutrient management

Soil and tissue tests can help you do the following:

- Choose fertilizer application rates
- Determine the adequacy of an existing fertilizer program
- Diagnose nutrient deficiency
- Monitor soil pH

A soil test alone is of little use in determining fertilizer rates for cranberry production. Tissue tests are much more useful. Ideally, soil and tissue tests should be used together.

Regular tissue and soil analyses can provide a long-term record of changes in your cranberry beds. This record can help you fine tune your nutrient management program from year to year.

Soil testing

Soil testing is not recommended as a predictor of nutrient need for producing cranberry beds. Like other woody perennial crops, cranberries pose challenges for the use of soil tests.

- Standard soil tests poorly predict availability of nutrients.
- Soil test results, especially those for P, correlate poorly with cranberry yield and tissue nutrient concentrations.
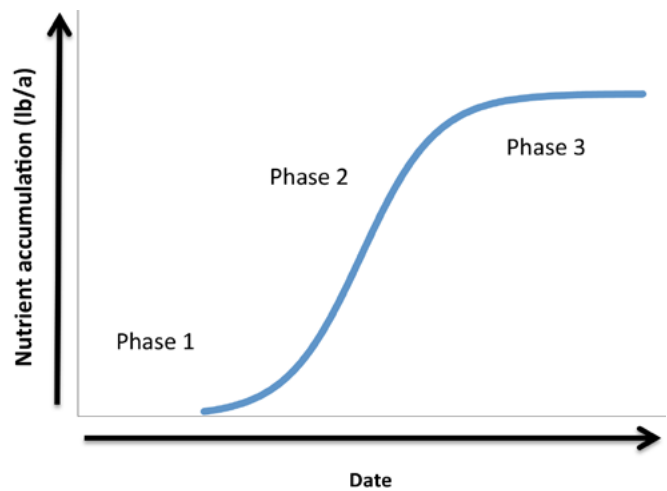

Figure 9.—Nutrient accumulation in cranberry plants. Figure by John Hart.

- Nitrogen soil tests do not predict N fertilizer need.
- Nutrient application creates stratification in cranberry beds. The surface 2 or 3 inches have the lowest soil pH and the highest concentrations of P, K, Ca, and Zn.
- Cranberries store nutrients from previous season(s) in perennial portions of the vines, so soil is not the plant's only source of nutrients.

For these reasons, soil analysis is best used in conjunction with tissue analysis. See Appendix C, "Considerations for Interpretation of Soil Analyses" (page 40), for more information.

Collect and analyze soil samples every 3 to 5 years at a similar time in late summer when tissue samples are collected.

Obtain 10 to 12 cores from the areas where tissue samples are taken. Collect samples randomly from representative areas of a bed. Avoid poorly drained areas, high spots, or other nonrepresentative areas. Sample problem areas separately.

Sample to a depth of 4 inches on new or young beds. On mature, well-established beds, sample to a depth of 6 inches, including surface duff. (See Appendix C for information about soil sampling when nutrient concentrations vary with soil depth.)

Have soil analyzed for pH, P, K, Ca, Mg, B, and Zn.

Tissue testing

The nutrient management goal for producing cranberry beds is to maintain sufficient tissue nutrient concentration. Nutrient concentration should be stable, not substantially increasing or declining over several years. Routine tissue analysis is crucial to achieving this goal.

Tissue tests have limitations. For example, N concentration depends partly on the length of uprights. Furthermore, N concentration is not always related to fertilizer N application rate.

Tissue analyses won't identify an exact amount of fertilizer to apply. They are useful, however, for monitoring nutrient sufficiency and evaluating the adequacy of previous fertilizer applications.

Tissue sampling is done in August or September, after current-year fertilizer is applied. Therefore, tissue test results are used to guide fertilizer decisions for the following year.

Fertilization may not affect tissue analysis levels until 1 or 2 years after application. Therefore, record keeping is a vital part of soil and tissue analysis interpretation. Recording data on fertilizer applications, weather, and yield is also helpful. Create graphs showing results over time.

Collect and analyze tissue samples every 1 to 3 years. Annual tissue sampling is advised where there is a known nutrient deficiency, when you wish to reduce the fertilizer application rate, or in the case of new beds.

Cranberry tissue test values are divided into low (deficient), sufficient, and high categories. These categories are based on grower observations, cranberry tissue analyses and field trials in Oregon, and data from other regions. If a tissue nutrient concentration is low (deficient), nutrient application is recommended.

Collecting samples and analyses to request

Collect tissue samples during mid-August to mid-September, before harvest. Clip current-season growth from a mixture of fruit-bearing (above the fruit) and nonfruiting uprights (Figure 10). Sample 20 tips from 10 representative areas of the bed for a total of about 200 tips per bed. See OSU Extension publication EM 8610, *Cranberry Tissue Testing for Producing Beds in*

Table 5.—Cranberry tissue nutrient concentration guidelines for producing beds.

Nutrient	Sufficient range (%)[1]	Nutrient	Sufficient range (ppm)[1]
N	0.9 to 1.1	B	15 to 60
P	0.1 to 0.2	Cu	4 to 10
K	0.4 to 0.75	Mn[2]	Above 10
Ca	0.3 to 0.8	Fe[2]	Above 20
Mg	0.15 to 0.25	Zn	15 to 30
S	0.08 to 0.25		

[1]Based on samples taken between August 15 and September 15.

[2]No sufficient range has been identified for Mn or Fe.

North America, and *How to Take a Cranberry Tissue Sample*, from the University of Wisconsin (see "For more information," page 35).

Do not separate leaves and stems or wash them before submitting the sample to the laboratory. Remove any fruit that might be present.

Have cranberry tissue analyzed for total N, P, K, Ca, Mg, S, B, Zn, Cu, and Mn. Compare the results to the values in Table 5 to determine whether sufficient nutrients were supplied by the soil and your fertilizer program. See the individual nutrient sections below for fertilizer recommendations based on soil and tissue test results.

Many laboratories provide analyses for other micronutrients. These analyses may be helpful in problem or "troubleshooting" situations, but are difficult to interpret from routine sampling.

Interpreting tissue analyses

Tissue tests alone will not tell you how much fertilizer to apply. When interpreting tissue test results, you must also take into account factors such as trends over time; soil test results; bed management; weather; upright growth; yield; and past fertilizer application rates, timing, and materials. The examples and

Teryl Roper

Figure 10.—Clip current-season growth from a mixture of fruit-bearing and nonflowering uprights.

scenarios below illustrate how some of these factors can be used with tissue test results to decide whether nutrient application is needed. For additional guidance and recommended application rates, see the individual sections on pages 15–31.

Normal fluctuations versus trends. Tissue test results can change 10 percent from year to year even if management does not change. This fluctuation is normal. Understanding whether changes represent a trend or normal yearly variation is facilitated by creating a trend line of results over time, as shown for P in Figure 11.

In Figure 11, tissue concentration is within the sufficient range (0.1 to 0.2 percent) and is stable, as shown by the relatively flat trend line. If no P has been added, soil supply is adequate. If you have been regularly adding P fertilizer, consider whether the amount can be reduced. A 250 bbl/a cranberry crop removes about 5 lb P_2O_5/a. New growth requires about 20 lb P_2O_5/a, half of which is recycled from old growth. Therefore, if you are applying more than 20 lb P_2O_5/a/year, reduce the application rate. See pages 23–25 and Appendix D (page 41) for more information on P management.

When tissue values decline (as shown for K in Figure 12) and are approaching the lower threshold of sufficient (0.4 percent in Figure 12), monitor tissue values annually. If this trend continued in 2009, it would suggest a need for K fertilizer.

Yield and soil test results. When interpreting K tissue test results, take yield into account. Typically, a heavy crop is associated with lower tissue K concentration than is a light crop. Thus, a year with high yield can cause a single-year decline in tissue K concentration. Tissue K can be expected to increase the following year, assuming that tissue and soil K were not marginal before the high yield occurred.

Given the scenario of declining but sufficient tissue K shown in Figure 12, a review of soil test results, yield, and fertilizer application records might show one of the following scenarios.
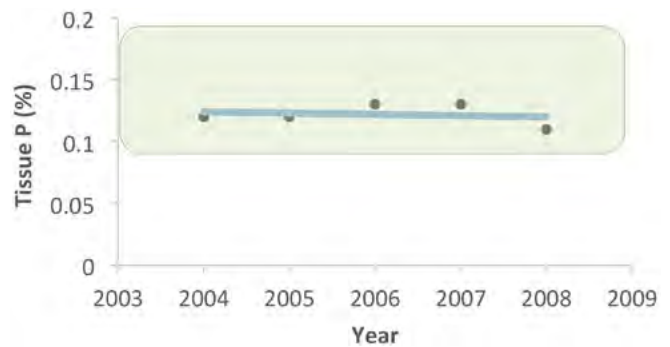

Figure 11.—Cranberry tissue P concentration from the same bed for 5 years. The light green highlighted area is the P sufficiency range. Figure by John Hart.
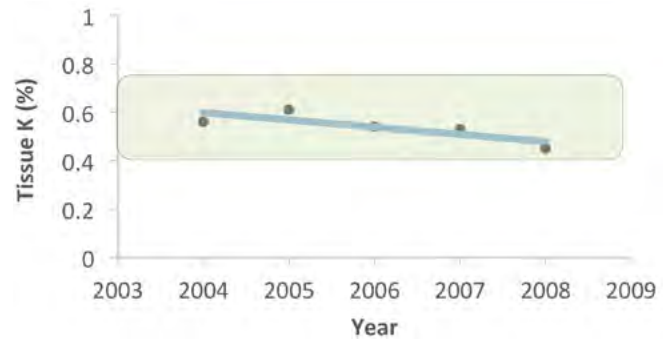

Figure 12—Cranberry tissue K concentration from the same bed for 5 years. The light green highlighted area is the K sufficiency range. Figure by John Hart.

- No K fertilizer has been applied for several years, and soil test K is above 60 ppm and not declining: No K addition is needed. Collect and analyze tissue samples this year.

- A large crop was harvested last year: No K addition is needed. Collect and analyze tissue samples this year.

- Soil test K is below 60 ppm and declining: Apply K.

- Soil test K is below 60 ppm, and the previous crop was normal or smaller than usual: Apply K.

See the "Potassium" section (pages 25–28) and Appendix E (page 45) for information on K application rates.

Yield and current-season upright growth. Nitrogen can be managed using the same approach as K. However, annual N application is required. As part of N management, include evaluation of previous yield and new upright growth.
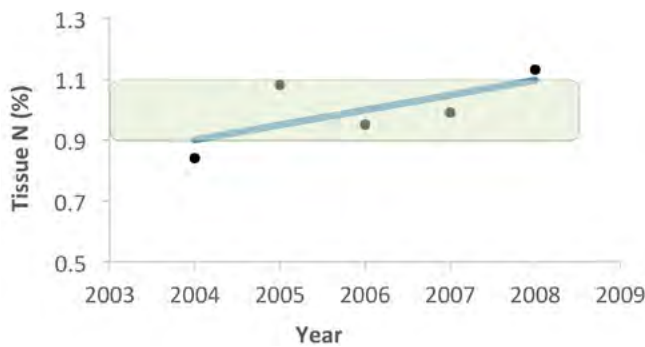
Figure 13.—Cranberry tissue N concentration from the same bed for 5 years. Figure by John Hart.

The sufficient range for N concentration in cranberry tissue from producing beds is 0.9 to 1.1 percent. Figure 13 represents tissue N within a producing bed. Tissue N was within the sufficient range from 2005 through 2007. It was below the sufficient range in 2004 and above in 2008.

Figure 13 shows a clearly increasing trend of tissue N. If the N rate was increased in 2005 in response to the low tissue N seen in 2004, assess the current rate. It may now be higher than necessary. A decision about changing the N rate should be made in conjunction with assessment of current-year plant growth, as well as the previous year's yield. Consider the following scenarios.

- If total annual growth is normal (2 to 4 inches), continue with last year's N rate. Wait until berries are pea sized to begin N application. Continue to monitor upright growth.

- If most upright growth is more than 4 inches, reduce the N rate.

- If upright growth is 2 to 3 inches and the bed produced a heavy crop last year, continue with the same rate as last year.

Why does last year's yield matter? A light crop will use slightly less N for fruit production. The N not used for fruit production can be stored in the leaves and roots. The plant can then use it to meet next year's early-season N need. Thus, early-season N application following a light yield has the potential to promote excessive vegetative growth. See the sidebar "What happens to N when yield is low?" for more information.

Yield and last year's upright growth. In some cases, both yield and tissue N are low. If the crop is light and the plant uses less N for berry

What happens to N when yield is low?

In years when cranberry yield is 30 to 50 percent below normal but beds were fertilized as usual, growers expect late-summer tissue N concentration to be high. However, this is not the case. What happened to the excess N?

The excess N is likely distributed throughout the plant, in the leaves, roots, and stems. Most of the N in a cranberry plant is in the leaves. However, if yield is reduced by 30 to 50 percent, only 5 to 10 lb of N would be excess. This amount of N would change leaf N concentration only slightly.

For example, an acre of cranberries contains about 5,000 lb (dry weight) of new uprights (see Table 1, page 6). A yield reduction of 30 to 50 percent reduces fruit N use by only 5 to 10 lb/a. This amount of N would increase leaf N concentration by only 0.1 percent (5 ÷ 5,000 x 100).

production, it can use the excess for vegetative growth. With increased vegetative growth, the N in sampled uprights is diluted. For this reason, any review of tissue analysis should take into account the amount of plant growth during the year the sample was taken.

See the "Nitrogen" section for more information on N application rates, timing, and materials.

Nitrogen (N)

Nitrogen in the ammonium form (NH_4^+) is essential for cranberry growth. It is used to create amino acids, which are then assembled into proteins. Proteins are essential for photosynthesis. The carbon captured through photosynthesis is used for leaf growth and berry development.

Dried cranberry leaves contain approximately 1 percent N, while dried cranberry fruit contains about 0.5 percent N. A concentration of 1 percent may seem small, but it makes N the most abundant nutrient in cranberry plants. For a bed producing 250 bbl/a, these concentrations represent about 15 lb N/a in fruit and approximately 50 lb N/a in new shoot growth each year.

New upright growth and berries obtain N from two sources: older plant tissue and the soil. Soil N includes naturally occurring N (including N

from decaying cranberry plant tissues) as well as fertilizer N.

For sustained yield, cranberries require annual N application. *Nitrogen fertilizer is not used primarily for current-year berry production, but rather to build plant tissue for photosynthesis, which translates into carbohydrates for future fruit production.* In Massachusetts research, N increased current-year yield only 10 to 15 percent of the time. In contrast, N applied the previous 1 or 2 years significantly correlated with yield.

Research and observation provide evidence of considerable N recycling within the plant. In Oregon research conducted with 'Stevens' cranberries, a naturally occurring isotope of N (^{15}N) was used to prepare N fertilizer so that it could be distinguished from nonfertilizer N. Only about 20 percent of the N found in the plant came from the fertilizer. The rest came from N recycled within the plant or from other soil sources of N.

Application of fertilizer N increases tissue N concentration. When N is deficient, N application also increases yield. When N is already sufficient, N fertilizer application decreases yield (Figure 14). The N rate at which yield begins to decline is determined by soil characteristics, variety, upright length, and previous adequacy of tissue N.

For the commonly planted varieties, a flowering upright supports on average two berries. The higher yield from hybrid varieties primarily results from larger berries and a higher proportion of uprights bearing fruit, although the highest
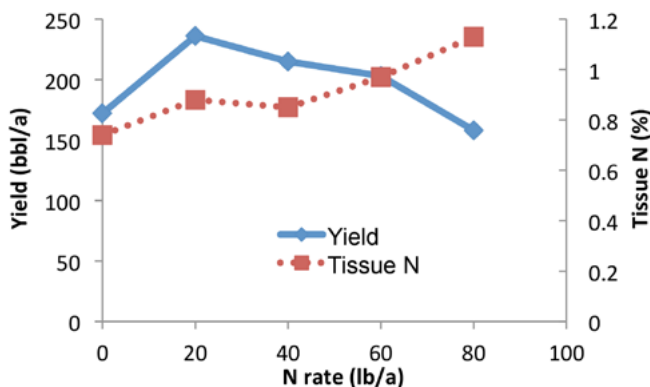
yielding hybrids seem to support more than two berries on some uprights. Berry size (weight) and proportion of total uprights that flower are primarily genetically controlled, and neither is affected by N fertilizer when plant N is sufficient.

The larger berries of hybrid varieties may result from increased photosynthesis made possible by larger leaves. Flowering uprights on 'Stevens' are more likely to flower a second year than those on native varieties. Thus, a greater proportion of uprights flower annually. The same likely is true for newer hybrids. See Appendix B, "Nitrogen Fertilization and Yield Components" (page 38), for more information about the effect of N application on berry size and other yield components.

To ensure that adequate, but not excess, N is supplied, growers must determine four things:

- How much N to apply (rate)
- When to apply N (timing)
- N source
- Method of application

The following sections address these decisions for south coastal Oregon cranberry production. See the sidebar "A note about choosing fertilizer rates" before making decisions about application rates for N or other nutrients.

N rate

In general, 40 to 60 lb N/a of applied N is adequate for producing cranberry beds in south coastal Oregon. In some circumstances, such as when frost prevents fruit set or when excess growth occurred the previous year, the N rate may be as low as zero.

Figure 14.—Fertilizer N steadily increased tissue N in 'Stevens' cranberry, but increased yield only with the lowest rate of N. This example is from the U.S. east coast. Data from Davenport and DeMoranville (2004); figure by Carolyn DeMoranville.

A note about choosing fertilizer rates

Each of the nutrient sections in this publication provides guidance for selecting fertilizer rates based on tissue analyses. Better decisions result when you consider trends in tissue test results and/or combine the results with soil analyses and information about upright growth, previous fertilizer application, and yield. See "Interpreting tissue analyses" (pages 13–15) for more information about how to use this more comprehensive approach.

Nitrogen requirement differs slightly among the varieties grown in Oregon. Varieties with larger leaves may require slightly more N than those with smaller leaves.

One approach used to determine N application rate is to estimate the amount removed with harvest and pruning and then apply N to "replace" this N. For example, with a harvest of 250 bbl fruit/a and pruning of 500 lb vines/a, approximately 35 lb N/a is removed. This amount is slightly less than the low end of N application recommendations (40 lb N/a). The values are reasonably close, however, considering variation in the amount of N removed and the fact that not all applied N will be used by the crop.

The removal-replacement approach is supported by calculations of annual N utilization. Cranberries recycle substantial amounts of N from old to new growth before the 1-year-old leaves drop, reducing the amount of N fertilizer needed. When a credit for recycled N (30 lb/a) is subtracted from N needed for new growth and fruit production (66 lb/a), the result again indicates need for application of approximately 35 lb N/a (Table 1, page 6).

Another approach is to begin with a base N rate for a given variety and then adjust it based on current-year upright growth, multiyear trends in tissue N concentration, and last year's yield, as discussed in the section "Interpreting tissue analyses." Begin with the following base rates:

- **'Crowley', 'McFarlin', similar older varieties, and 'Crimson Queen':** 40 lb N/a. Early-season N readily causes excessive vegetative growth on 'Crimson Queen'.

- **'Stevens', 'Pilgrim', and 'Mullica Queen':** 45 to 50 lb N/a

- **Demoranville and HyRed:** 55 to 60 lb N/a

Now consider growth of flowering uprights before bloom. Upright growth before bloom is well correlated with yield. Although it varies (by location, yield, variety, etc.), a range of length provides acceptable yield. Recommendations for 'Stevens' from Massachusetts indicate that 2¼ to 2¾ inches of growth before early bloom is adequate. Figure 5 (page 6) shows upright length and yield from Wisconsin.

Consider new upright growth in conjunction with last year's tissue N analysis. If plants produce 2 to 4 inches of new upright growth and last year's N concentration was 0.9 to 1.1 percent, you hit the "bull's eye" with last year's N rate and can continue with the same rate.

If needed, adjust N rate based on multiyear tissue concentration trends and current-season upright growth (Table 6). See page 15 for more information.

As discussed under "Interpreting tissue analyses," the previous year's yield is another factor to consider when choosing an N rate. For example:

- If upright growth is 2 to 3 inches and the bed produced a heavy crop last year, continue with the same rate as last year.

- Be very careful of early-season N application following a light yield, as it could promote excessive vegetative growth.

Growers often are tempted to apply "insurance" N, as often is done with other nutrients. This

Table 6.—Nitrogen rate adjustments based on upright growth and tissue N concentration.

Current-season upright growth	Tissue N concentration[1]	Action
Less than 2 inches	Low	Increase the N rate.
Less than 2 inches	High	Look for stress from pests, drainage, drought, frost, or other factors limiting growth.
2 to 4 inches	Sufficient and stable	Continue with your current fertilizer program.
2 to 4 inches	Sufficient and increasing or high	Continue with the current N rate. Begin application when berries are pea sized. Continue to monitor upright growth.
More than 4 inches	Low	Review N rate and timing. You may need to reduce the N rate and avoid early N application.
More than 4 inches	Sufficient or high	Reduce the N rate.

[1]Tissue analysis performed in August–September of the previous year. Tissue N concentration of 0.9 to 1.1 percent is considered sufficient.

approach seems logical since (1) no soil or tissue test provides a definitive N rate, (2) growers want to ensure that all plant nutrient requirements are met, and (3) supplying extra nutrients seems preferable to underapplication.

However, caution is required when choosing an N application rate. The negative consequences of overapplication (excessive vine growth, decreased yield, and reduced fruit quality) can outweigh any potential yield loss caused by a marginally low rate. See Figures 5 (page 6) and 15 and "Fruit quality and N rate," below.

Fruit quality and N rate

In addition to promoting unwanted vegetative growth and reducing yield, excess N reduces fruit quality at harvest and during fresh berry storage.

To measure the influence of N on fresh and stored fruit quality, we applied N at 30, 50, and 70 lb/a to a mature 'Stevens' bed for 2 years. We then simulated a wet harvest on five dates from late September to late November. Fruit was stored for 3 weeks after harvest. Yield, fruit quality at harvest, and storage quality were measured.

Application of the lowest N rate, 30 lb/a, produced the highest berry weight and yield. The firmest fruit was also found with 30 lb N/a. Berry firmness decreased with increasing N rate for all harvest dates except the first. Berry quality (°Brix, percent sound or marketable fruit, and color) was reduced with application of 70 lb N/a. Research with 'Stevens' in Massachusetts found similar results; fruit rot (both at harvest and after 30 days of storage) increased linearly with added N fertilizer. See the sidebar "Harvest date and storage interactions" for more information.

N timing

Nitrogen supply must be managed so that carbohydrates and other plant resources are used to produce fruit rather than excessive vegetative growth. Cranberry plants utilize N during three periods: early growth, fruit set, and bud set.

Nitrogen applied from bud through early fruit sizing will begin to be assimilated and used within 24 hours. However, use continues for weeks after N application. For details about N assimilation,
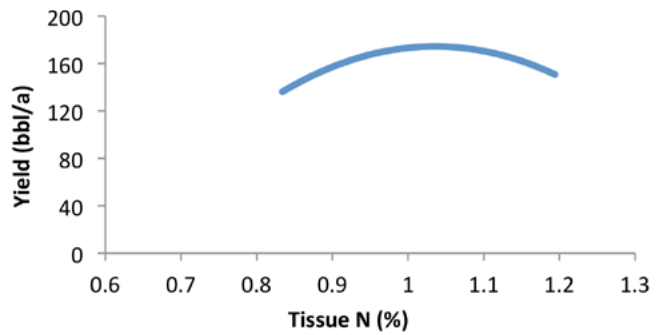

Figure 15.—Cranberry yield from an Oregon bed decreased as tissue N increased from 1 to 1.2 percent. Figure by John Hart.

Harvest date and storage interactions

Delaying harvest from late September or early October to mid-November increased berry weight, °Brix (percent soluble solids), anthocyanin content, and yield. Waiting until late November to harvest fruit reduced berry weight and yield, while increasing the incidence of fruit rot.

For most harvest dates, °Brix increased after 3 weeks of storage. Increased °Brix was not related to desiccation, as berry weight did not decline during this time. Storage did not change anthocyanin content for most harvest dates. Physiological damage and rot increased after storage, particularly in the latest harvested fruit (Figure 16) and in fruit stored at room temperature.

Bernadine Strik, © Oregon State University

Figure 16.—'Stevens' cranberries held for late harvest. Photo taken in early November For late-harvested cranberries, careful N management is required to ensure fruit quality during storage.

see the sidebar "How fast do cranberries use fertilizer?"

To measure the use of N from fertilizer applied throughout the season, a naturally occurring isotope of N (^{15}N) was used to prepare ammonium sulfate. Adding a small amount of ^{15}N to the predominant ^{14}N allowed the fertilizer N to be followed in the plant. Nitrogen was applied at 40 lb/a split into five applications of 8 lb/a each.

Results of this research highlight three points.

- Substantially more fertilizer N was measured in new growth when labeled N was applied at popcorn and hook stage, compared to application at later developmental stages (Figure 18). This additional N fertilizer uptake creates the potential for excess vegetative growth following early-season N application. Nitrogen applied between bud break and early bloom often produces

How fast do cranberries use fertilizer?

Fertilizer application sometimes is called "feeding" plants. Do plants process fertilizer as fast as we process food? Let's compare the time needed for the food you eat to be usable to that needed for cranberries to use fertilizer.

Suppose you apply fertilizer to a cranberry bed on a warm, sunny spring day. After working hard, you are tired and thirsty. You find some shade and sip an "energy" beverage. In about 15 to 20 minutes, you feel refreshed. The sugar (and possibly caffeine) from the beverage is entering your blood. No digestion was necessary to make the sugar available to your body.

Your cranberries will use the fertilizer you applied in much the same way. When nutrients are applied in an available form, such as NH_4-N or PO_4-P, and the cranberry plant has begun spring growth or is blooming (cabbage head to bloom), the nutrients are used quickly.

Research using ^{15}N-enriched fertilizer in Oregon supports this concept. A bed of south coastal Oregon 'Stevens' cranberries received labeled N in ammonium sulfate solution during mid-May (roughneck to hook development stage; ½ to ¾ inch new growth). Rain was falling during application. Nitrogen from the fertilizer was found in cranberry uprights 24 hours after application. The amount of N from fertilizer increased rapidly for a week after application and gradually for the next 2 weeks (Figure 17). The rate of fertilizer use is governed by temperature and varies from year to year.

If "dry" or granular fertilizer application is not followed by irrigation or rainfall, it will not be used as quickly as the material in the example above. However, granular fertilizer application followed by more than ¼ inch of irrigation water or rain should provide immediately available N for cranberry plants.

Phosphorus shows a similar pattern. Labeled P was applied to rooted cuttings of 'Howes' cranberries grown in a Wisconsin greenhouse. A small amount of labeled P was detected in the plant after 8 hours, with

the amount steadily increasing during the week of sampling.

To ensure rapid nutrient use by cranberry plants, keep the following points in mind.

- For rapid use, the nutrients must be in a form the cranberry plant can use (known as an available form).

- Nutrients in commercial granular or liquid fertilizer usually are in an available form.

- Nutrients (especially N) in many organic fertilizer materials must first be converted to an available form by microbes.

- Controlled-release materials usually supply nutrients in an available form and gradually make them available to plants. The key to their use is matching release to plant demand.

- To use nutrients rapidly, the cranberry plant must be in a period of high nutrient use. Maximum nutrient use occurs from cabbage head to early fruit set.

- During this phase of rapid nutrient use, cranberries begin using available nutrients within a day of application and assimilate a substantial amount of fertilizer within a week.
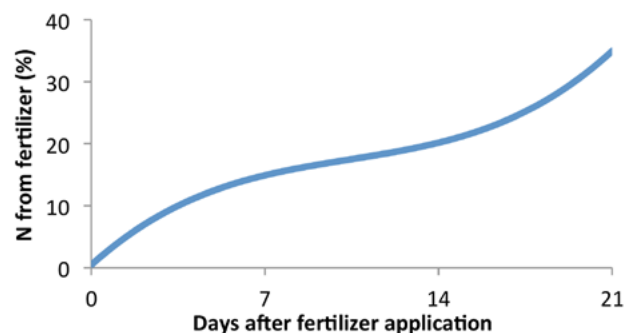

Figure 17.—Fertilizer N from a mid-May application is rapidly used by cranberry plants. Figure by John Hart.

excessive growth, especially during cloudy or rainy periods.

- Plants flower and set fruit for a period of several weeks, and N demand is high throughout this period. Peak use by fruit occurs as seeds and first flesh form. Nitrogen use drops substantially about 3 weeks after fruit set.

- Less fertilizer N was used when N was supplied after fruit set than when N was applied during or before fruit set (Figure 19).

The above data and grower experience show that, for most beds, optimum timing of N for fruit set, berry size, and bud initiation seems to be from the time the first pea-sized berries are observed until the last flower falls, a period of 3 to 4 weeks.

Supply most of the N during the fruit set/ development stage. Wait until the first pea-sized berries are observed before beginning N fertilization (Figure 20). Apply 10 to 20 lb N/a every 7 to 14 days until the last petals fall. Make no more than three applications, with the third being lighter than the first two.

An alternative approach is to use two applications of 20 lb N/a at 2-week intervals during the same period. A single application during this period is another option. However, multiple or "split" N application can result in more even fertilizer distribution, especially if you vary the application pattern.

Reduce N fertilization after fruit is sized, since little N is used at that time (Figures 18 and 19). Use bee activity during bloom to help determine the timing of the final N application. Make the final application 1 to 3 weeks after bee activity stops.

During fruit set and sizing, terminal leaves on flowering uprights should turn from a healthy green color to a pale yellowish-green. Terminal leaf margins turn red, while leaf bases and midribs remain green. These signals of stress indicate *normal* nutrient flow from current-season growth to developing fruit. Recent research supports these observations.
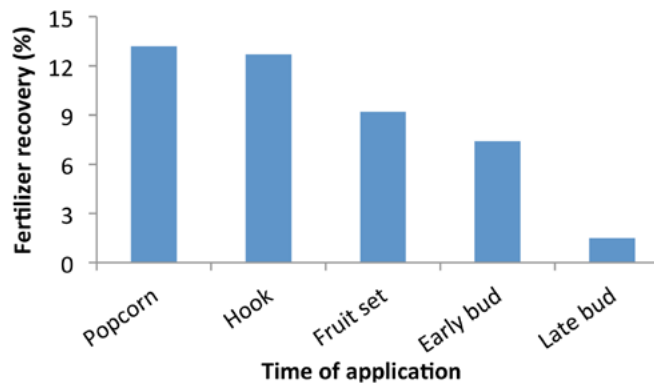

Figure 18.—Fertilizer N use by new growth decreases as the growing season progresses. Fertilizer recovery represents the proportion of fertilizer N measured in new upright growth compared to the amount applied, as determined by using labeled fertilizer. Figure by John Hart.
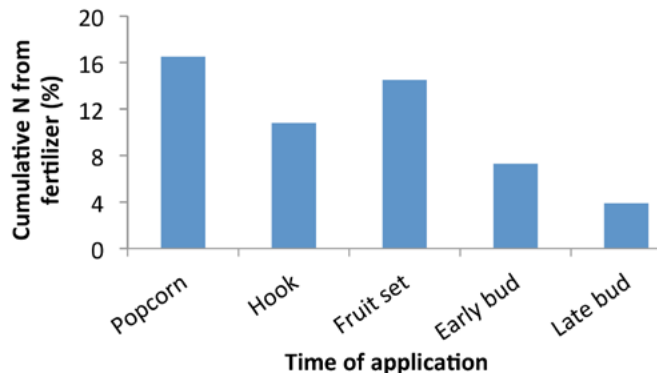

Figure 19.—Fertilizer N use by cranberry plants decreases as the growing season progresses. Nitrogen from fertilizer was calculated from measurements of labeled fertilizer N and total N in cranberry tissue. Cumulative N from fertilizer is the sum of N recovered from old growth, new growth, fruit, and roots. Figure by John Hart.

Bernadine Strik, © Oregon State University

Figure 20.—Begin N application when the first pea-sized berries are observed.

Growers often wonder whether they should apply N in the fall to enhance bud set. Application of N after September 15 is not recommended or usually needed.

Another common question is, "After fertilizer application, how much time is needed for the N to move to the young fruit?" In reality, little current-season N moves to the fruit; only about 5 percent of the total N in the fruit is from current-year N application. Most of the N in the fruit has been remobilized from the leaves. Movement of current-season fertilizer N into fruit is not desired. N should remain in leaves, where it will be used to make sugars that will cause the fruit to grow.

N source

Cranberries efficiently utilize ammonium-N (NH_4). This form of N is supplied by ammonium sulfate (21-0-0-24), ammonium phosphate (11-55-0), ammonium phosphate-sulfate (16-20-0-14), and blends created with these materials. Urea is often included in fertilizer blends (Figure 21) and is readily converted to ammonium-N after application.

All of these materials are suitable and of equal efficacy for cranberry production. Urea alone is as effective as multiple-source materials or blends with K or other nutrients. See the sidebar "Effectiveness of blended fertilizers" for more information.

Nutrients, especially N, are equally available to cranberry plants when applied in liquid or dry forms. Most liquid or fluid fertilizer materials are made from the same ingredients as dry material.

Nitrate-N (NO_3) is not a suitable N source for cranberries; do not use fertilizers containing NO_3-N. Cranberries' very limited ability to utilize nitrate is advantageous, as NO_3-N is easily leached, especially in irrigated sandy soils, such as those used for south coastal Oregon cranberry production. See the sidebar "Soil pH and nitrate leaching" (page 5) for related information. In contrast, the ammonium form of N is not leached.

Effectiveness of blended fertilizers

Blended fertilizer is as effective as granulated fertilizer with the same analysis.

One concern about blended materials is the possibility of uneven nutrient application. Centrifugal force from a spin spreader or pneumatic applicator propels particles with differing densities unequal distances, resulting in nonuniform application of nutrients. For example, urea weighs only about 45 lb/cu ft, while potassium chloride (0-0-60) weighs 60 to 65 lb/cu ft. Even so, the difference in distribution between these two materials is not sufficient to prevent cranberry roots from obtaining needed nutrients.

One way to assure more even distribution is a split application at right angles. Unfortunately, this option is not always feasible in cranberry beds.

Another concern is the need for N, P, and K in every granule. Cranberry roots in a producing bed thoroughly cover the upper soil layer. Fertilizer materials are soluble, especially those containing N and K. When dissolved in irrigation water, the nutrients will move to the roots.

Research in Wisconsin confirmed the efficiency of cranberry roots at finding nutrients. A solution of ^{15}N was applied to a square meter of cranberry bed. A week later, cranberry tissue was collected at various distances from the application area. The N was found well outside the square along the direction of vine growth. It also extended to the sides of the vines and "backward" along the vines about 6 to 12 inches.

John Hart, © Oregon State University

Figure 21.—Urea ammonium sulfate, 40-0-0-6, is a popular source of N and S.

In Wisconsin, two inorganic N sources were compared with two organic sources, Milorganite and composted chicken manure. The inorganic N sources tested were ammonium sulfate and sulfur-coated urea (SCU, a controlled-release material). All treatments were adjusted to provide the same amount of N, P, and K. None of the other products performed as well as ammonium sulfate. Similar results have been measured repeatedly.

Traditional fertilizer, such as urea, may be coated with a polymer (plastic-like material) or chemical to reduce the rate at which the fertilizer becomes available to plants or to reduce its rate of microbial change. The potential benefit of a polymer-coated material, especially for new beds, is the ability to apply the entire year's supply of N in a single application. However, before recommending polymer-coated products, we must compare their efficacy to single and split applications of the same material without the coating.

Polymer-coated urea (ESN) and urea coated with a maleic-itaconic organic acid combination (NSN) have been tested in Oregon on wheat, grass seed, and sweet corn. No yield advantage was measured from the use of these materials on those crops.

In some Oregon field crop situations, yield was reduced following use of a coated material or one with a nitrification inhibitor, especially materials containing DCD (dicyandiamide). Super U is one product containing DCD. In contrast, a urease inhibitor, Agrotain, reduces N loss from volatilization of top-dressed urea on some Oregon field crops.

Osmocote, a controlled-release fertilizer, tends to work well in cranberry production, but is quite expensive.

Before using these materials, ask yourself, "What is the problem I'm trying to solve?" Problems with N loss often can be solved with split N applications and/or irrigation within 24 hours following application. Carefully compare application cost to the higher cost for coated or other specialty material.

Thunderstorms can supply a substantial amount of N. In rural Wisconsin, annual precipitation contains about 10 to 15 lb N/a. However, this N is primarily NO_3-N, not NH-N, and therefore is poorly used by cranberries. Furthermore, since precipitation falls on all treatments at a research site, any N from precipitation should not be counted as part of N application.

In Oregon, very little N is provided by rain, probably about 1 lb/a annually at most. In 2006, between 1 and 2 lb N/a (ammonium-N and nitrate-N) was deposited at the Alsea Ranger Station.

Method of application

Broadcast applications of dry materials (Figure 22) usually result in more even distribution than do applications made through sprinkler systems. To avoid plant injury, apply materials to dry vines, then rinse with irrigation.

Liquid fertilizer materials applied through the sprinkler system are often called "leaf feeds." This term is misleading, as most of the fertilizer reaches the bed surface rather than remaining on the leaves. From the bed surface, it is washed

Bob Donaldson

Figure 22.—Three common methods of fertilizer application: "belly grinder" or hand-held spin spreader (left), pneumatic boom applicator (center), and self-propelled spin spreader (right).

into the soil with irrigation and is moved into the cranberry plant through the roots. In contrast, a true "leaf feed" or foliar fertilizer is applied at a low rate and volume with a sprayer. The goal is to cover leaves with little or no runoff, so that the nutrient can be absorbed by the foliage. See the sidebar "Foliar nutrient application" for more information.

Phosphorus (P)

Phosphorus is important for plant metabolism, especially energy transfer. Plants use a P-based molecule to carry energy from one molecule to another. This system is important for the transport of sugars created through photosynthesis. These sugars are used for metabolism or growth, or are exported to other plant parts such as fruit. Therefore, one symptom of P deficiency is stunted growth and reduced yield. In addition, P is a primary constituent of genetic material (DNA).

In other growing areas, P creates environmental concerns, as it can contribute to water quality degradation. Phosphorus that moves into fresh

water bodies can stimulate aquatic weed and algae growth. Thus, P transport via runoff can be a problem if a significant rain event closely follows fertilizer application. For more information, see *Phosphorus for Bearing Cranberries in North America* (see "For more information," page 35).

Phosphorus does not leach, even in sandy soils (see Appendix C, "Considerations for Interpretation of Soil Analyses," page 40). Repeated top-dress P application increases soil test P in the surface soil layers rather than throughout the soil, resulting in stratification. Soil test results for P are difficult to interpret when stratification occurs.

Some data suggest that P can leach from uprights when a bed is flooded (as for harvest). However, recent work in Massachusetts suggests that the P sometimes found in harvest flood water more likely comes from the soil. The mechanism for this movement is under investigation. Three possible explanations have been suggested: (1) P dissolved in the soil water moves into the flood water, (2) P bound to Fe in the soil is released as soil oxygen is depleted during the flood, and (3) loosely bound forms of P in the soil are released into the flood water. The answer may be some combination of these three mechanisms. High levels of P in the upper soil layer could provide the reservoir of P that is mobilized by one of these mechanisms.

P rate

Most bearing cranberry beds do not require annual P application for four reasons.

- Ample P is supplied during bed establishment and subsequent years.

- Annual P use by cranberry plants is low.

- Little P is removed with harvest and pruning. A yield of 250 bbl/a contains approximately 2 lb P, and 500 lb vines/a removed by pruning contains about ½ lb P.

- Cranberry plants are very efficient at recycling P from old to new growth.

Unlike N, no differences exist among varieties in their need for P.

Foliar nutrient application

Nutrient uptake through leaves is less efficient than it is through roots. Cranberry uprights cannot absorb sufficient N, P, K, or most other nutrients solely through the leaves to meet their full requirement.

Foliar N applications do have their place. They are most effective when uprights are growing poorly or look pale. Foliar applications are expensive, but can cause vines to "green" in a short time.

Before applying a foliar nutrient, carefully consider whether it is needed. If your cranberries are growing well and tissue nutrient levels are adequate, foliar application is not necessary.

For foliar N applications, use urea. It readily moves from leaf surfaces into plants. Other materials sold for foliar application are more expensive than urea. They also may contain other forms of N and usually contain more nutrients than needed.

Urea utilization by cranberries was decreased when a spreader sticker was added to a foliar urea application.

Tissue analysis is the first step in determining whether P application is needed (Table 7). A concentration of 0.1 to 0.2 percent P is sufficient. Soil analysis is less useful. Soil test P below 15 ppm most likely will produce tissue P below 0.1 percent. However, soil test P above 15 ppm does not ensure tissue P above 0.1 percent.

Use Table 7 to determine your P application rate. If tissue P was between 0.1 and 0.2 percent and stable in last year's analysis, you may not need to apply any P (see "Interpreting tissue analyses," pages 13–15). A year or two without P fertilizer typically will not result in P deficiency, a decline in tissue P concentration, or reduction in yield. If you are not comfortable eliminating P from your nutrient program, reduce the amount applied and monitor tissue P. For more information, see Appendix D, "The Nutrient Detective: Looking for an Increase in Cranberry Yield from Fertilizer P Application" (page 41).

Table 7.—Cranberry P sufficiency and fertilizer recommendations based on tissue tests.

Tissue P (%)[1]	Status	Apply this amount of P_2O_5 (lb/a)[2]
Below 0.1	Low	20 to 45
0.1 to 0.2	Sufficient	0 to 20
Above 0.2	High	0

[1] Tissue analysis performed in August–September of the previous year.
[2] Broadcast application.

In two Oregon trials, no P was added for 3 years. Tissue analysis showed that the vines still contained sufficient P. With sufficient P in the leaves, no yield reduction was expected, and none occurred. Similar results were seen in Massachusetts and Wisconsin. For more information, see Appendix D.

When P is needed, research shows no yield increase from applying more than 20 lb P/a (about 45 lb P_2O_5/a). Plot-scale work in established P-deficient bogs in Massachusetts showed equal results from P applications ranging from 40 to 120 lb P_2O_5/a. More recent work with Massachusetts growers on a whole-bed scale has shown no yield decline, and in some cases yield increase, after 10 years of applying no more than 10 lb P/a (about 22 lb P_2O_5/a).

P timing

The P in fertilizer reacts quickly with Fe and Al in acidic soils to form insoluble compounds. Thus, P application should occur when cranberries are using nutrients. Frequent, light applications likely are preferable to one or two large doses.

When P fertilizer is applied to bearing beds with sufficient tissue P concentration, exact timing is not critical.

When P is deficient, no definitive data exist to indicate whether single or multiple applications are superior. If making a single application, do so at or before the roughneck development stage. Alternatively, wait until late spring (after frost protection has stopped), and then apply P in two or three doses. Cranberry research and extension workers from other areas recommend three applications, coinciding with the timing for N. These applications usually use materials containing both N and P.

P source

The primary P material used in blends is ammonium phosphate, typically monoammonium phosphate (Table 8). Phosphoric acid can be used as a foliar P source, but should not be applied

Table 8.—Concentration and solubility of common P fertilizer materials.

Fertilizer	Chemical formula	Analysis (P_2O_5)	Solubility (%)
Triple superphosphate	$Ca(H_2PO_4)_2$	0-46-0	87
Diammonium phosphate	$(NH_4)_2HPO_4$	18-46-0	100
Monoammonium phosphate	$NH_4H_2PO_4$	11-48-0 to 11-55-0	100
Ammonium polyphosphate (dry)	$NH_4H_2PO_4 + (NH_4)_3HP_2O_7$	10-34-0	100
Ammonium polyphosphate (liquid)	$NH_4H_2PO_4 + (NH_4)_3HP_2O_7$	15-62-0	100
Ordinary superphosphate	$Ca(H_2PO_4)_3 + CaSO_4$	0-20-0	85
Phosphoric acid	H_3PO_4	—	100
Rock phosphate	—	varies	varies

during flowering or on plantings harvested for fresh fruit. Rock phosphate can be used for organic beds, although this material varies greatly in the amount of P_2O_5 supplied. Some of the rock phosphate from western U.S. mines is almost insoluble, while material from Florida supplies P at about the same rate as does single super phosphate, an old (and likely now unavailable) fertilizer.

Many growers overapply P by using fertilizers such as 6-24-24. Materials such as 16-16-16 are preferable when P is needed. If you choose fertilizer blends based on nutrient ratio, use a 1:1:1 ratio or, even better, 2:1:2 or 2:1:1. Do *not* use blends with a 1:2:1 or 1:4:4 ratio. In Massachusetts, many growers have adopted an 18-8-18 fertilizer in order to supply less P (5 to 10 lb P/a) when applying fertilizer to satisfy N requirements.

Some fertilizer additives or coatings are designed to increase P availability. Little is known about their performance in cranberry production, especially in Oregon. See the sidebar "Would Avail be beneficial?" for more information.

Potassium (K)

The amount of K in cranberry leaves is second only to N, and K is the most abundant nutrient in cranberry fruit. Cranberries are marketed for their health benefits, including K content.

K is not readily metabolized by cranberry plants. This trait contributes to its mobility within plants and to the fact that it is easily removed from fallen leaves by water.

The ease of K movement within the plant makes K important in plant water movement and retention. Many enzymes rely on K for activation. Potassium also functions in protein synthesis, photosynthesis, cell extension, opening and closing of stomata, and movement of sugar.

The K in cranberry fruit must be supplied from the soil or fertilizer. Soil K is naturally low in the sand-based beds used for Oregon cranberry production. Native or unamended sand used for bed construction typically contains between only 10 and 15 ppm K. Many decades ago, cranberry producers recognized the need for K fertilizer. Application of about 15 lb K_2O/a is needed to

Would Avail be beneficial?

Avail is the same material as Nutri-sphere (a combination of maleic-itaconic organic acids). However, it is applied to P fertilizer rather than to N sources. When applied to N sources to reduce nitrification, N fertilizer requirement, or urea volatilization, it performs poorly or at least unpredictably.

When applied to P fertilizer, this material is intended to prevent Al and other elements from making fertilizer P unavailable. When P is needed, our current recommendation is to apply P in multiple applications. If Avail performs as advertised, it could allow a single application of P, thus reducing labor cost. However, you would need to compare the added cost of the material to the savings in labor cost to determine whether it is economically beneficial.

To date, we know of no tests of Avail's effectiveness in cranberries. Tests with other crops have given mixed results.

Bernadine Strik, © Oregon State University

Figure 23.—Substantial amounts of K are removed with harvest, so a higher yielding bed requires more K than one with lower yields.

increase soil test K by 1 ppm in 3 inches of sand. After many years of K application, most south coastal Oregon cranberry beds now supply sufficient K without the addition of fertilizer K.

In many crops, especially grasses, tissue K increases with K application or with increasing soil test K. This relationship has not been found in cranberries.

We are unaware of any differences in K requirement among cranberry varieties. However, substantial amounts of K are removed in the crop

(Figure 23, page 25), so a bed producing 300 bbl/a requires more K than a bed producing 150 bbl/a.

K rate

Tissue analysis is the first step in deciding whether K is needed and, if so, how much. The sufficient range for cranberry tissue collected mid-August to mid-September is 0.4 to 0.75 percent K.

If last year's tissue test results were below 0.4 percent K, apply 60 to 100 lb K$_2$O/a (Table 9).

Table 9.—Cranberry K sufficiency and fertilizer recommendations based on tissue analysis.

Tissue K (%)[1]	Status	Apply this amount of K$_2$O (lb/a)[2]
Below 0.4	Low	60 to 100
0.4 to 0.75	Sufficient	0 to 60
Above 0.75	High	0

[1]Tissue analysis performed in August–September of the previous year.
[2]Broadcast application.

Tissue K between 0.4 and 0.75 percent is considered sufficient. When tissue K is within this range, K applications are optional; routine maintenance or replacement applications are not needed. Rather, K application is appropriate under certain circumstances to ensure sufficient supply for future plant growth and fruit production. Decisions about the need for K can be aided by consideration of previous fertilizer records, soil test results, and yield. The following examples provide recommendations for some possible scenarios.

- If tissue K is above 0.4 percent, no K application is needed, even if no K fertilizer has been applied for several years. In two Oregon trials with tissue K above 0.4 percent, no K was added for 3 years, and no yield reduction occurred (see Appendix E, "Reducing K for Cranberry Production," page 45). In Wisconsin, application of 0 to 800 lb K$_2$O/a over 3 years did not change cranberry yield. In addition, plots receiving no K fertilizer for 3 years did not fall below 0.4 percent tissue K.

- If soil test K is below 60 ppm, apply K if soil test K is declining *or* the crop is normal or smaller than usual.

- Previous-year yield can affect the need for K application (see page 14). If a large crop was harvested last year and tissue K is sufficient, no K is needed, even if tissue K has declined. The decline in tissue K likely is a result of the large crop, and tissue K can be expected to increase when yield returns to normal (Figure 24). Collect tissue samples for analysis in August or September to guide next year's decision making.

If these guidelines indicate that no K application is needed, but you are uncomfortable eliminating K from your nutrient program, reduce the amount applied and monitor tissue K.

One approach is to apply a maintenance K rate to replace the amount removed by the crop. A 300 bbl/a crop removes 30 to 35 lb K/a (34 to 40 lb K$_2$O/a). Based on monitoring of a grower bed, an annual application of 30 to 40 lb K$_2$O/a should be adequate to maintain soil test K between 40 and 60 ppm. This soil test range will provide sufficient K for a tissue concentration of about 0.45 percent.

K timing

For maintenance applications to producing beds with sufficient tissue K concentration, application timing is not critical. Apply K at the same time as N. When applying both nutrients, use a material containing both.

Figure 24.—Previous-year yield can affect the need for K application. Tissue K can decline following a heavy yield, but increase again when yield returns to normal.

Lynn Ketchum, © Oregon State University

26

Where tissue analysis indicates a need for K application, apply K between bud break and fruit development. During this period, the plant is actively growing and using nutrients.

If making a single application of K, do so at or before the roughneck development stage. However, multiple applications are recommended, especially for higher rates. Sandy soils are not able to hold much K. Therefore, if more than 40 lb K_2O/a is applied at one time, some of the K can be leached from the root zone. If making multiple applications, wait until late spring (after frost protection has stopped), and then apply K in two or three doses.

Growers often ask whether K is needed earlier or later in the season. *No data support the idea that early application of K produces better fruit set or higher yield. Likewise, no benefit of routine August K application has been found.* If adequate K is supplied earlier in the growing season, cranberries will not need additional K.

Late K application has been claimed to improve fruit anthocyanin concentration at harvest. Research in Wisconsin showed no influence of K rate or timing on fruit color at harvest. Therefore, late or high applications of K to improve fruit color are not justified.

Likewise, August K application has not been shown to improve bud set (Figure 25). Any K application is made for general plant health, growth, and yield. Early-season growth relies on stored nutrients. Thus, an August K application will be used by the plant next season, not just for bud development.

Figure 25.—Late K application has **not** been shown to improve bud set and normally is unnecessary.

Under certain circumstances, an August K application may be beneficial. If tissue K is marginal, little early-season K was applied, the frost season was long, and the crop is heavy, consider an August K application.

Research in British Columbia showed K use until mid-December, so K fertilizer applied in August can be used by cranberries. Application should be complete by early August.

K source

Three materials that supply K are commonly available:

- Potassium sulfate, 0-0-50 (K_2SO_4)
- Potassium chloride, 0-0-60 (muriate of potash, KCl)
- Potassium-magnesium sulfate (approximately 22 percent K_2O, 11 percent Mg, and 22 percent S)

Any of these materials may be a component of blended N-P-K fertilizers. All supply K in the same form, as the ion K^+. None is superior from the aspect of K supply, regardless of soil type or bed age. No yield difference was measured when sources were compared at the same K application rate.

Sources differ only in solubility and in the accompanying material (sulfate, chloride, or Mg). Although cranberries have been shown to be sensitive to Cl, application of K as KCl should not be a problem at the rates recommended in Table 9.

Potassium-magnesium sulfate is marketed as Sul-Po-Mag or K-Mag. Use of this material does not alleviate "crunchy" vines.

Method of application

K can be applied as a dry blended (complete) fertilizer or as K alone, as in 0-0-60. It also can be applied as a liquid through the irrigation system.

After applying dry K fertilizer, rinse the material from the foliage with irrigation to prevent fertilizer burn. Application of liquid material through the irrigation system is not a foliar application. This method of applying K is no different than supplying K with dry fertilizer.

27

Potassium from either material will enter the plant through the roots.

Calcium (Ca)

Cranberries require Ca for holding cell walls together, cell elongation and division, and membrane function. Calcium moves with water through plant roots and into shoots and leaves. Therefore, as long as plants are using water, they are accumulating Ca from the soil. Cyclic wet/dry soil moisture supply interrupts Ca uptake, especially Ca supply to fruit.

Cranberries require at most half as much Ca as do other woody perennial fruit crops such as cherries and plums. Approximately 2 lb Ca/a is removed in cranberry fruit at harvest.

Unlike most nutrients, Ca accumulates throughout the growing season. This trait is important, since Ca is necessary for new growth but becomes immobile once it is incorporated into leaf or fruit tissue.

Because Ca is accumulated throughout the year, application of Ca during bloom is unlikely to increase fruit set or yield. We know of no research to support this idea. One research project in the eastern U.S. showed increased yield with applications of Ca and B at fruit set. However, the Ca and B were applied together, so we can't tell which nutrient caused the yield increase. Boron is needed for flower development, pollen germination, and growth, so it likely was the limiting nutrient.

Figure 26.—Lime (left) and gypsum (right) traditionally were available as flour-like, powdery materials. New processes compress and bind the tiny particles into pellets that can be applied with a spin spreader. Note the similarity in appearance of the materials. Check labels carefully before applying either material.

Not only are Ca applications unlikely to increase yield, evidence that they change Ca levels in cranberry fruit is lacking.

The soil in most south coastal Oregon cranberry beds supplies sufficient Ca without the addition of fertilizer Ca. In Oregon research, plots that received no gypsum for 2 years maintained sufficient tissue Ca and yield. The small amount of Ca removed at harvest is the primary reason no change in yield or tissue Ca concentration was measured. These results suggest that cranberries obtain adequate Ca from the soil.

Ca rate, timing, and source

Calcium may be applied for maintenance, i.e., to replace Ca removed with harvest and pruning. When tissue Ca levels are sufficient, we recommend applying 0 to 50 lb gypsum/a (Table 10). Application of 50 lb gypsum/a supplies 10 lb Ca/a. Do not exceed the rates in Table 10.

Table 10.—Cranberry Ca sufficiency and fertilizer recommendations based on tissue analysis.

Tissue Ca (%)[1]	Status	Apply this amount of gypsum (lb/a)[2]
Below 0.3	Low	50 to 100
0.3 to 0.8	Sufficient	0 to 50
Above 0.8	High	0

[1]Tissue analysis performed in August–September of the previous year.

[2]Broadcast application.

For maintenance applications, apply Ca between bud break and fruit development. If tissue Ca is low, apply Ca between bud break and roughneck.

The commonly used source of Ca is gypsum (calcium sulfate), which contains about 20 percent Ca (Figure 26). In addition to applying Ca to meet cranberry nutritional needs, growers routinely apply Ca as gypsum to alleviate poor drainage. Gypsum will *not* improve drainage in typical sand-based south coastal Oregon cranberry beds.

Nor does gypsum alleviate crunchy vines. Beds are crunchy when the proportion of exposed wood is large relative to leaf biomass. This situation usually indicates an N management problem or an event that led to leaf fall, such as Casoron

Gale Gingrich, © Oregon State University

application. In a recent Oregon investigation, addition of gypsum did not reduce Casoron crunch when cranberry tissue Ca was sufficient.

For more information about gypsum application, tissue Ca, and Casoron application, see Appendix F, "Effects of Gypsum Application on Cranberry Growth" (page 49).

Magnesium (Mg)

Magnesium is essential for chlorophyll production and is involved in several other important plant enzyme systems. Compared to N, P, or K, small amounts of Mg are required.

Little is known about Mg nutrition of cranberries. According to Eck (1990), no reports of yield or growth increases in response to Mg applications have been published.

Eck reports that blueberries grown on the same soils as cranberries sometimes exhibit Mg deficiency symptoms. The limited growth of cranberries compared to blueberries may be one factor in cranberries' lower Mg requirement. Also, the evergreen growth habit of cranberries may allow Mg to be moved from old to new growth.

The choice of 0.15 percent as a sufficient level of tissue Mg in a late-summer sample is supported by tissue analysis summaries throughout North American growing regions. Analyses of Oregon cranberry tissue from 1974 to 1988 showed that most samples contained between 0.17 and 0.24 percent Mg. Only 2 percent of the samples were below 0.17 percent. In 2014, Mg tissue concentration was sufficient in 30 samples collected from south coastal Oregon beds. Cranberries in this region routinely receive Mg as a component of commonly used K and S sources. If Mg deficiency were common, greater variation in tissue Mg concentration would be expected.

If tissue Mg is low, the cause may be Ca or K fertilization. In this case, Ca and/or K tissue concentrations should be high. If they are, reduce applications of these nutrients.

Mg rate, timing, and source

If tissue analysis indicates a need for Mg, apply Mg at cabbage head/bud break according to Table 11. Epsom salts ($MgSO_4 \cdot 7H_2O$) or potassium-magnesium sulfate (SulPoMag) are acceptable Mg sources.

Table 11.—Cranberry Mg sufficiency and fertilizer recommendations based on tissue analysis.

Tissue Mg (%)[1]	Status	Apply this amount of Mg (lb/a)[2]
Below 0.15	Low	20
0.15 to 0.25	Sufficient	0 to 20
Above 0.25	High	0

[1]Tissue analysis performed in August–September of the previous year.
[2]Broadcast application.

Sulfur (S)

Little S is required for cranberry production. Fruit in a 250 bbl/a harvest removes only about 3 lb S/a. About 1 lb S/a is removed in harvest trash and the same amount in pruned vines.

The small amount of S required by cranberries usually is supplied with application of fertilizer materials such as ammonium sulfate, urea-sul, gypsum, K-Mag, Epsom salts, or potassium sulfate (0-0-50-18). Therefore, separate applications of S are not recommended unless tissue analysis indicates deficiency.

Support for the premise that cranberries receive sufficient S from fertilizer materials was found in a 2008–2009 research project. After 2 years with application of 300 lb gypsum/a (30 lb S/a), cranberry tissue S concentration was similar
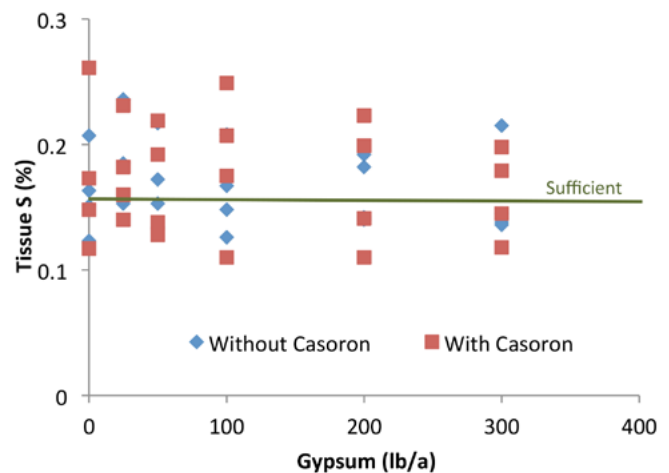

Figure 27.—Cranberry tissue S concentration was unchanged after 2 years of gypsum application. Unpublished data and figure by Linda White.

29

to that in plants where no gypsum was applied (Figure 27, page 29). All treatments received equal amounts of other S-containing fertilizer. See Appendix F for details.

Tissue analysis is used for prediction of cranberry S needs (Table 12). Soil tests for S, even preplant, are unreliable.

Table 12.—Cranberry S sufficiency and fertilizer recommendations based on tissue analysis.

Tissue S (%)[1]	Status	Apply this amount of S (lb/a)[2]
Below 0.08	Low	10 to 20
0.08 to 0.25	Sufficient	0 to 10
Above 0.25	High	0

[1]Tissue analysis performed in August–September of the previous year.

[2]Broadcast application.

When S is needed, use the sulfate (SO_4) form. Ammonium sulfate, potassium sulfate, gypsum, epsom salts, and Sulpo-Mag/K-Mag include the sulfate form of S. Apply at the same time as N.

Micronutrients

Very little field research with micronutrients has been performed on cranberries. Such research is difficult and must be replicated many times, as the effects of micronutrient application are usually too small to distinguish from natural variability.

Cranberries use only small quantities of the micronutrients Fe, Mn, Cu, Zn, Cl, B, and Mo. The majority of micronutrients are retained in the perennial portions of the vines, and little is harvested with the crop (Table 13).

Laboratory work has determined the critical tissue values for these nutrients. Deficiencies are not common, although low Cu and Zn tissue levels are sometimes seen in New Jersey.

Micronutrient application is not recommended for south coastal Oregon cranberry production unless tissue concentration is low or dropping. The metallic micronutrients Fe, Mn, Cu, and Zn are readily available in the acidic soil on which cranberries are produced. Sea spray provides deposition of B. No data support addition of Mo to cranberry beds.

Toxicity of these elements has been measured in solution culture. However, the concentrations that affect vegetative growth are 100-fold higher than those normally found in cranberry tissue tests.

Boron (B)

Boron is needed for pollen tube growth (a part of the pollination process), so B application sometimes can be helpful for fruit set.

Apply B only when need is indicated by tissue analysis (Table 14). A single annual low rate is sufficient. *Boron can be toxic to cranberries if applied in excess.* When B is applied, monitor tissue B at least every other year and discontinue application if tissue B exceeds 60 ppm.

Apply B between roughneck and early bloom. Use a soluble form of B broadcast by sprayer or sprinkler. Do not mix it with copper materials.

Table 14.—Cranberry B sufficiency and fertilizer recommendations based on tissue analysis.

Tissue B (ppm)[1]	Status	Apply this amount of B (lb/a)[2]
Below 15	Low	1
15 to 60	Sufficient	0 to 1
Above 60	High	0

[1]Tissue analysis performed in August–September of the previous year.

[2]Broadcast application.

Table 13.—Micronutrient concentration and content for a 250 bbl/a cranberry crop (Cu, B, and Zn).[1]

Plant component	Cranberry plant weight (lb/a)		Cu		B		Zn	
	Wet ("as is")	Dry	(%)	(lb/a)	(%)	(lb/a)	(%)	(lb/a)
Fruit	25,000	3,000	0.0004	0.01	0.004	0.1	0.002	—
New shoots	9,000	5,200	0.0006	0.03	0.004	0.2	0.002	—
Total	—	8,200	—	0.04	—	0.3	—	0.2

[1]Data from DeMoranville (1992).

Copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn)

Copper concentration in south coastal Oregon cranberry tissue usually is sufficient. In addition, Cu is contained in many commonly used fungicides. Therefore, addition of Cu is not necessary. Excess Cu is toxic to plants, producing short, stubby roots that lead to reduced growth.

Interpretation of tissue tests for Fe is complicated by the presence of dust on leaves. Since Fe is a constituent of soil, dust adds Fe to the leaf surface. Distinguishing between Fe *in* the leaf and Fe *on* the leaf is impossible, so Fe analysis is not recommended.

High levels of manganese (Mn) are common in cranberry tissue. If Mn-containing fungicides have not been used and tissue Mn concentration exceeds 300 ppm, soil drainage may be inadequate or soil pH may be low.

Apply Zn only when need is shown by tissue analysis (Table 15). Apply Zn between roughneck and early bloom. Soluble forms of Zn, such as zinc sulfate or chelate, can be applied by sprayer or sprinkler.

Table 15.—Cranberry Zn sufficiency and fertilizer recommendations based on tissue analysis.

Tissue Zn (ppm)[1]	Status	Apply this amount of Zn (lb/a)[2]
Below 15	Low	1 to 2
15 to 30	Sufficient	0 to 1
Above 30	High	0

[1] Tissue analysis performed in August–September of the previous year.

[2] Broadcast application.

Soil pH

pH is a convenient way to express the amount of hydrogen (H^+) ion in solution. The more H^+ ion in solution, the more acidic the soil. The numbering system used to express H^+ ion concentration is reversed, so a soil with pH of 4 has a greater concentration of H^+ ion in solution than a soil with pH of 6. A pH of 7 is neutral, less than 7 is acidic, and greater than 7 is basic, or alkaline.

The scale used for pH is logarithmic. In other words, each unit change represents a 10-fold difference. Thus, pH of 5.0 is 10 times more acidic than pH of 6.0.

From a management viewpoint, soil pH determines whether a soil is suited to a particular crop. We don't usually choose a crop based on soil pH; rather we adjust pH for the crop we wish to grow. Lime is added to acidic soil to raise pH. Amendments such as elemental S are added to reduce soil pH.

See the sidebar "The soil acidification process" for more information.

John Hart, © Oregon State University

Figure 28.—Cranberries are less sensitive to low soil pH than are most other crops.

The soil acidification process

Soil acidification occurs naturally, with rainfall, over thousands of years. As rain falls through the atmosphere, it reacts with carbon dioxide. This process produces dilute carbonic acid, resulting in rainfall with a pH of approximately 5.5.

The carbonic acid in rainwater adds H^+ ions to the soil. These H^+ ions replace the cations Ca, Mg, and K, which are held on the surface of soil particles. Subsequent leaching of these cations to groundwater not only contributes to soil acidification but also makes groundwater "hard."

Plant growth is also acidifying. Plant roots excrete organic acids, add carbon dioxide to the air in the soil, and exchange H^+ for nutrients such as NH_4-N and K. NH_4-N is often applied to cranberry beds in N fertilizer and its use by plants is an important acidifying process in cranberry soil.

Humans accelerate soil acidification by harvesting plant parts containing bases (Ca, Mg, and K). This effect is small in cranberry production since only a small portion of the plant biomass is removed via harvest, pruning, and harvest trash. Even so, routine management of cranberry beds is acidifying.

Why is soil pH important?

Soil pH plays a major role in regulating solubility of nutrients and toxic elements in soil solution. Greater solubility makes a nutrient or toxic element more available to plants. A change in solubility may create growth-limiting soil conditions. Acidic soils can limit growth in several ways.

- Aluminum availability increases. Even small concentrations of Al in soil solution can be toxic to roots of sensitive plants. A reduction in root growth limits the ability of a plant to obtain water and nutrients. Fortunately, cranberries tolerate Al better than most other plants when soil pH is within the recommended range of 4.5 to 5.5.

- Plant-available Mn can increase to levels that inhibit shoot growth.

- Exchangeable cations—Ca, Mg, and K—decline, as exchange sites are occupied by H^+ and Al. The displaced nutrients, especially Mg, can become deficient.

Plants vary in sensitivity or tolerance to acidic soil conditions. Because cranberries evolved in acid soils, they are adapted to life in a nutrient-poor environment. To a large extent, pH effects that would be negative for other plants are not a problem for cranberries (Figure 28, page 31).

Monitoring soil pH

Soil pH was monitored monthly from mid-April to mid-September in six south coastal Oregon cranberry beds. Significant variability existed within a bed, indicating the need to collect multiple samples to reflect a bed average.

Where crop growth and productivity vary noticeably, divide the bed into areas that reflect differences in growth and previous soil test pH. Collect samples from each area and thoroughly mix the samples before submitting a composite sample to the laboratory.

Soil pH in Oregon cranberry beds also varied throughout the year. Soil pH was highest in April and generally declined 0.5 unit through July, before stabilizing in August and September (Figure 29). Thus, soil sampling for pH should be conducted either early in the spring or just prior to harvest, but not during the active growing season when pH is changing rapidly.

Cranberry tissue samples are collected between mid-August and mid-September. The same time period is appropriate for collecting soil samples for soil pH determination.

When soil pH is between 4.5 and 5.5, annual monitoring is not needed. When soil pH is being raised with lime or lowered with elemental S, annual monitoring is recommended for 3 years to ensure that pH has changed sufficiently and become stable.

Tissue analysis as an indicator of soil pH

Soil and seasonal variability make measurement of small pH changes difficult. Especially in woody perennial crops, plant tissue analysis can detect soil pH changes more easily than can soil sampling.

Tissue Mn increases as soil pH decreases. Monitor tissue Mn and measure soil pH if tissue Mn increases more than 50 ppm in 3 years.

Adjusting soil pH

The ideal soil pH for cranberry production is between 4.0 and 5.5. Soil pH below 4.0 is detrimental to cranberry growth and, therefore, yield. In soils high in organic matter, such as peat, however, pH can be as low as 3.5 without adversely affecting cranberry plants.
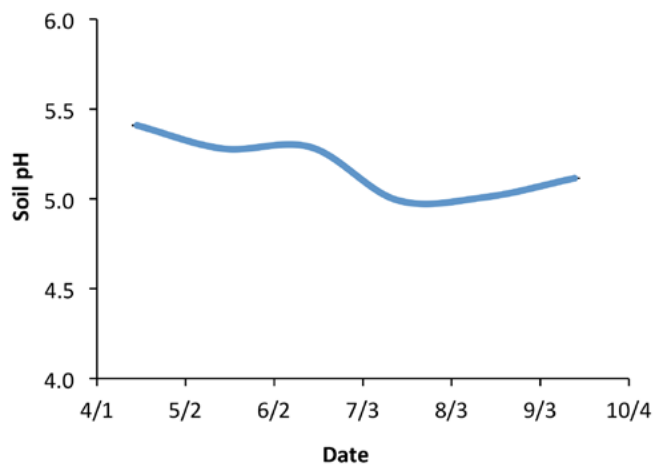

Figure 29.—Average seasonal soil pH change in the upper 6 inches of soil from six south coastal Oregon cranberry beds. Data from Davenport, et al. (2003); figure by Joan Davenport.

The mineral-based soils, sandy soils, and layered sand and organic matter typical of south coastal Oregon cranberry production areas rarely have a soil pH lower than 4.0. The recommended soil pH range for south coastal Oregon cranberry production is 4.5 to 5.5.

Raising soil pH

Raising soil pH is justified *only* when soil pH is below 4.0 and plant growth is reduced.

Since cranberry soils, in general, have low buffering capacity, very little lime is needed to increase soil pH. Apply no more than 100 to 150 lb lime/a. Fall application is recommended so that lime can react over the winter. Lime is not mobile in soil, so pH will increase only in the surface few inches (possibly as little as 2 inches) of soil.

After a lime application, collect soil samples about a year later and measure soil pH to determine whether it increased as desired. Collect separate samples from each 2-inch soil depth to a depth of 6 inches. Do not mix the samples before submitting them to a laboratory.

If soil pH hasn't increased sufficiently, a second application can be made. Reduce the rate by 50 lb/a.

Lowering soil pH

Organic growers sometimes lower soil pH. They feel this practice discourages weed growth, especially lotus (birdsfoot trefoil). Soil pH reduction requires prudence and should never produce a pH below 4.0.

Soil pH is lowered through the use of elemental S (S_0), not the sulfate (SO_4^{-2}) form. Soil microorganisms convert elemental S to sulfate. A by-product of this process is sulfuric acid (H_2SO_4). The hydrogen from sulfuric acid lowers soil pH. Addition of sulfate-containing materials (e.g., potassium sulfate or gypsum) does not lower pH because these materials supply no hydrogen.

Use extreme caution when applying elemental S (Figure 30). In sandy soils, a small amount of S can produce a large reduction in pH. Research in cranberry beds has shown that it takes about 1,000 lb of granular S/a to reduce pH by 1 unit. Overapplication likely will reduce pH more than

desired. Raising pH to correct this problem can be difficult, as lime is not mobile in soil.

A second reason for caution is that in very wet conditions elemental S is converted to hydrogen sulfide gas rather than to sulfuric acid. Hydrogen sulfide is toxic to plants.

Apply no more than 100 to 500 lb granular elemental S/a annually. If you have never used the material before, use a low rate, 100 to 200 lb/a. If your experience shows that higher rates are needed and do not lower soil pH too much, use a maximum of 500 lb/a.

Apply elemental S at any time during the growing season. Spring or early summer application is typical. Split the total into two or three applications.

Avoid elemental S application when soil is saturated. Do not apply when standing water is present on the soil surface for a day or more.

Lowering soil pH is a microbial process that is affected by moisture and temperature. It requires months for completion. When elemental S is applied in the fall, little pH change will be measured until the following spring. When elemental S is applied in the spring, soil pH will decrease within 1 to 3 months.

Figure 30.—When attempting to lower soil pH with elemental S application, proceed with caution and sample soil the following year. It is easy to lower soil pH too much, but difficult to correct the problem.

Lynn Ketchum, © Oregon State University

33

Gypsum and soil pH

Availability of information, coupled with the ease of communication and travel, allows growers to discuss management practices. One practice discussed and unfortunately not well understood is the use of gypsum. Both gypsum ($CaSO_3$) and lime ($CaCO_4$) contain Ca; therefore, both materials add Ca to the soil.

Unlike lime, gypsum does not raise soil pH. Both materials can, however, offset the Al toxicity that can occur in very acidic soils. Gypsum is about 100 times more soluble than lime. This greater solubility allows gypsum to move into the subsoil over the course of several years.

Field trials on acidic soils with low cation exchange capacity (CEC) demonstrated that gypsum reduces Al toxicity when applied at high rates, usually 8 to 10 t/a. Most of these studies were conducted on highly weathered (low CEC) soils in the southeastern United States, Hawaii, and other warm climates. Treating subsoil Al toxicity with gypsum is not needed for Oregon cranberry production.

For more information about soil pH in Oregon, see OSU Extension publications EM 9061 *Soil Acidity in Oregon: Understanding and Using Concepts for Crop Production*, and EM 9057, *Applying Lime to Raise Soil pH for Crop Production (Western Oregon)*.

Nutrition for cranberry bed establishment

See Appendix G, "Fertilizer and Irrigation Recommendations for Bed Establishment" (page 51), for information on this topic.

For more information (Extension publications)

Applying Lime to Raise Soil pH for Crop Production (Western Oregon), EM 9057. http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/38531/em9057.pdf

Cranberry Production in the Pacific Northwest, PNW 247. http://extension.oregonstate.edu/catalog/pdf/pnw/pnw247.pdf

Cranberry Tissue Testing for Producing Beds in North America, EM 8610. http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/14789/em8610.pdf

How to Take a Cranberry Tissue Sample. http://documents.crinet.com/AgSource-Cooperative-Services/Agronomy/How-to-Take-a-Cranberry-Tissue-Sample.pdf

Nitrogen for Bearing Cranberries in North America, EM 8741. http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20088/em8741.pdf

Phosphorus for Bearing Cranberries in North America. http://scholarworks.umass.edu/cranberry_factsheets/11/

The Physiology of Cranberry Yield. http://scholarworks.umass.edu/cranberry_factsheets/16/

Soil Acidity in Oregon: *Understanding and Using Concepts for Crop Production*, EM 9061. http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/41199/em9061.pdf

References

Birrenkott, B., C. Henson, and E. Stang. 1991. Carbohydrate levels and the development of fruit in cranberry. J. Amer. Soc. Hort. Sci. 116(2):174–178.

Birrenkott, B. and E. Stang. 1990. Selective flower removal increases cranberry fruit set. HortScience 25(10):1226–1228.

Chaplin, M. and L. Martin. 1979. Seasonal changes in leaf element content of cranberry, *Vaccinium macrocarpon* Ait. Commun. in Soil Sci. and Plant Analysis 10(6):895–902.

Christensen, N. and J. Hart. 2008. *Combating Take-all of Winter Wheat in Western Oregon*. EC 1423-E. Oregon State University Extension Service, Corvallis, OR.

Davenport, J. and C. DeMoranville. 2004. Temperature influences nitrogen release rates in cranberry soils. HortScience 39(1):80–83.

Davenport, J., C. DeMoranville, J. Hart, S. Kumidini, K. Patten, A. Poole, and T. Roper. 2003. Spatial and temporal variability of cranberry soil pH. Acta Hort. (ISHS) 626:323–336. http://www.actahort.org/books/626/626_44.htm

DeMoranville, C. 1992. Cranberry nutrients, phenology, and N-P-K fertilization. Ph.D. dissertation, University of Massachusetts.

DeMoranville, C. 2010. Nutrient management in cranberry production. In: *Cranberry Station Best Management Practices Guide*. Revised 2010. University of Massachusetts. http://scholarworks.umass.edu/cranberrybmp2010/19/

DeMoranville, C. 2014. *Massachusetts Cranberry Chart Book Management Guide*. A joint publication of the Massachusetts Agricultural Experiment Station and Cooperative Extension, East Wareham, MA. http://scholarworks.umass.edu/cranchart/186/

DeMoranville, C. and J. Davenport. 1997. Phosphorus forms, rates, and timing in Massachusetts cranberry production. Acta Hort. 446:381–388.

DeMoranville, C., J. Davenport, K. Patten, T. Roper, B. Strik, N. Vorsa, and A. Poole. 1996. Fruit mass development in three cranberry cultivars and five production regions. J. Amer. Soc. Hort. Sci. 121(4):680–685.

Eaton, G. 1971. Effect of N, P, and K fertilizer applications on cranberry leaf nutrient composition, fruit color and yield in a mature bog. J. Amer. Soc. Hort. Sci 96(4):430–433.

Eck, P. 1971. Cranberry growth and composition as influenced by nitrogen treatment. HortScience 6(1):38–39.

Eck, P. 1990. *The American Cranberry*. Rutgers University Press, New Brunswick, NJ.

Galletta, G., D. Himelrick, and L. Chandler. 1990. *Small Fruit Crop Management*. Prentice Hall, Englewood Cliffs, NJ.

Hagidimitriou, M. and T. Roper. 1994. Seasonal changes in non-structural carbohydrates in cranberry. J. Amer. Soc. Hort. Sci. 119(5):1029–1033.

Hanson, E. and S. Berkheimer. 2004. Effect of soil calcium applications on blueberry yield and quality. Small Fruits Review 3:133–139.

Hart, J., A. Poole, B. Strik, and N. Christensen. 1994. Nitrogen fertilizer rate and timing trials in Oregon. In: *Proceedings of the 1994 Wisconsin Cranberry School* 5:18–22. March 16–17, Stevens Point, WI.

Lampinen, B. and C. DeMoranville. 2003. Effect of irrigation and sand application on cranberry growth and yield. HortScience 38(3):493. Abstr.

Patten, K. and J. Wang. 1994. Leaf removal and terminal bud size affect the fruiting habits of cranberry. HortScience 29:997–998.

Roper, T. 1992. Cranberry soil and tissue analysis: Diagnostic tools. The Wisconsin Cranberry IPM Newsletter 6(7):1–2. A joint publication of the University of Wisconsin, Ocean Spray Cranberries, Inc., The Wisconsin Cranberry Board, Inc., Cliffstar Corporation, and private crop consulting services, Madison, WI.

Roper, T. and S. Coombs. 1992. Nutrient status of Wisconsin cranberries. Cranberries: The National Cranberry Magazine 15(2):11–15.

Roper, T. and J. Klueh. 1994. Removing new growth reduced fruiting in cranberry. HortScience 29(3):199–201.

Roper, T., A. Krueger, C. DeMoranville, N. Vorsa, J. Hart, and A. Poole. 2004. Rate of ammonium uptake by cranberry (*Vaccinium macrocarpon* Ait.) vines in the field is affected by temperature. HortScience 39(3):588–590.

Roper, T., K. Patten, C. DeMoranville, J. Davenport, B. Strik, and A. Poole. 1993. Fruiting of cranberry uprights reduces fruiting the following year. HortScience 28(3):228.

Roper, T., E. Stang, and G. Hawker. 1992. Early season leaf removal reduces fruit set and size in cranberry. HortScience 27(1):75.

Smith, J. 1994. Nitrogen fertilization of cranberries: What type should I use, how should I apply it, and where is my nitrogen from last season? In: *Proceedings of the 1994 Wisconsin Cranberry School* 5:23–30. March 16–17, Stevens Point, WI.

Strik, B. and A. Poole. 1991. Time and severity of pruning effects on cranberry yield components and fruit anthocyanin content. HortScience 26(12):1462–1464.

Strik, B. and A. Poole. 1992. Alternate year pruning recommended for cranberry. HortScience 27(12):1327.

Strik, B. and A. Poole. 1995. Does sand application to soil surface benefit cranberry production? HortScience 30(1):47–49.

Strik, B., T. Roper, C. DeMoranville, J. Davenport, and A. Poole. 1991. Cultivar and growing region influence return bloom of cranberry uprights. HortScience 26(11):1366–1367.

Torio, J. and P. Eck. 1969. Nitrogen, phosphorus, potassium and sulfur nutrition of the cranberry in sand culture. J. Amer. Soc. Hort. Sci. 94(6):622–625.

Vanden Heuvel, J. and J. Davenport. 2005. Effects of light, temperature, defoliation, and fruiting on carbon assimilation and partitioning in potted cranberry. HortScience 40(6):1699–1704.

Wood, J., L. Warner, and W. Powers. 1950. Preliminary Report, Water and Nutrient Relations for Cranberries. Oregon State College Extension Service, Experiment Station Soils Department (now Oregon State University), Corvallis, OR.

Acknowledgments

Appendix A. Estimating Cranberry Yield

During August, growers begin to think seriously about current-year yield. Yield estimates are helpful for planning harvest and marketing activities and for assessing results of management changes.

Yield estimates are made by collecting all berries from a measured area and either counting or weighing them. Choose an area that represents the bed as a whole; don't select a particularly healthy area. Remember that estimates are approximations, and harvested yield may differ significantly from the estimate if the bed is not uniform or if you can't recover all of the fruit (due to the presence of weeds, rot, etc.).

Two methods of yield estimation are presented below. Both are based on the fact that, in general, each gram of fruit within a 1-square-foot area equals approximately 1 bbl/a of cranberries. Thus, if the total fruit weight from a 1-square-foot area is 150 g, the estimated yield is 150 bbl/a.

Oregon cranberries usually weigh 0.9 to 1.1 g in mid-August and between 1.2 and 1.4 g at harvest. Thus, yield should increase by about 20 percent over an August estimate (Figure 31). Older varieties such as 'McFarlin' have smaller fruit than newer varieties such as 'Pilgrim'.

How to estimate yield

The first step in estimating yield is to collect and weigh a few individual berries in mid- to late August. If berry weight averages between 0.9 and 1.1 g, you can use Method 1 below. If the weight is outside this range, use Method 2.

Method 1

Harvest and count berries from a 12 inch x 12 inch area. The estimated current yield in bbl/a is the number of berries counted. Multiply by 1.2 to estimate yield at harvest.

Example: You pick all fruit from a 12 inch x 12 inch area and count 135 berries. The estimated current yield is 135 bbl/a. The estimated harvest yield is 162 bbl/a (135 x 1.2).

This approach assumes berries weigh 1 g on average. By weighing individual berries from your

Figure 31.—Cranberry weight in August can be used to estimate final yield at harvest. Fruit weight should increase by about 20 percent between August and harvest.

Lynn Ketchum, © Oregon State University

beds for several years, you can make more accurate yield estimates. For example, if the average fruit weight is 1.2 g, your yield (bbl/a) will be 1.2 times the number of berries. Multiply the berry number by the average berry weight (135 x 1.2 = 162 bbl/a). Then multiply by 1.2 to find the estimated harvest yield (162 x 1.2 = 194 bbl/a).

Method 2

Harvest all berries from a 12 inch x 12 inch area and weigh the total (in grams). Multiply the berry weight by 0.96 to find the estimated yield in bbl/a. Multiply by 1.2 to estimate final yield at harvest.

Example: You pick and weigh all fruit from a 12 inch x 12 inch area of your cranberry bed. The weight is 135 g. Estimated current yield is 130 bbl/a (135 g x 0.96). The estimated harvest yield is 156 bbl/a (130 x 1.2).

Notes

- Use the following conversions if you sample from an area smaller than 1 square foot.

  — For a 12 inch x 6 inch area (½ square foot), multiply the final result (bbl/a) by 2.

  — For a 6 inch x 6 inch area (¼ square foot), multiply the final result by 4.

  — For a 6-inch circle (0.196 square foot), multiply the final result by 5.09.

- To create your own method for estimating yield, use the following equivalent measures.

1 lb = 454 g	1 bbl cranberries = 100 lb
1 a = 43,560 sq ft	1 g = 0.0022 lb

Appendix B. Nitrogen Fertilization and Yield Components

Nitrogen fertilizer is applied to achieve and maintain tissue sufficiency. When vines have sufficient N concentration, N will not limit yields. Understanding how N affects yield components should help growers manage N application.

Oregon research in the late 1980s and 1990s helped us understand the relationship between N fertilization and yield. We identified a cranberry bed in south coastal Oregon that was severely N-deficient. For 3 years, plots in this bed were given 0, 20, 40, or 60 lb N/a. Cranberry yield components were measured after 3 years of fertilizer application. Yield components, yield component ratios, and yield are given in Table 16.

Table 16 shows that in this N-deficient bed, N application increased total upright number, flowering upright number, flower number, number of berries, and total berry weight (lines 1–5). It also increased tissue N concentration (data not shown).

Based on prior research, we know that the two important ratios that affect yield are floral induction (line 6—proportion of flowering uprights) and fruit set (line 8—fruit number per flower number). Addition of N to a deficient cranberry bed did not change floral induction (line 6), which averaged about one-third of the total uprights regardless of the N rate. However, fruit set increased from 28 to 48 percent when sufficient N was supplied (line 8).

When 60 lb N/a was applied, 3.9 flowers per flowering upright were counted (line 7). Fruit was formed on about half of these flowers (line 8). Each flowering upright produced two berries, the theoretical maximum based on the amount of carbon each upright can transform into carbohydrates and the amount of carbon in a mature fruit.

Such a large increase in fruit set indicates a change in the cranberry plant. Most likely, N application allowed production of additional leaves to transform carbon from the atmosphere (CO_2) into plant energy (carbohydrates) for growth and storage. Average upright length, known to correlate with total leaf area, increased from 2 inches to 2¾ inches as N rate increased from 0 to 60 lb/a. This upright length is consistent with recommendations for cranberry fertilization.

Table 16.—Influence of N application rate on cranberry yield and yield components.[1]

Line	Yield component	N application rate (lb/a)			
		0	20	40	60
1	Total uprights (number/sq ft)	274	334	378	443
2	Flowering uprights (number/sq ft)	74	110	126	143
3	Flowers (number/sq ft)	282	369	400	555
4	Berries (number/sq ft)	76	128	191	264
5	Total berry weight (g/sq ft)	113	202	315	485
6	Floral induction (proportion of flowering uprights) (%)	27	31.0	33	32
7	Flowers per flowering upright (number)	3.8	3.6	3.2	3.9
8	Fruit set (%) [(berries ÷ flowers) x 100]	28	35	48	48
9	Average berry weight (g)	1.5	1.6	1.6	1.8
10	Effect of N application on berry number (%)[2]	—	168	251	347
11	Effect of N application on berry weight (%)[3]	—	107	107	120

[1]'Stevens' cranberries grown in south coastal Oregon. Measurements were taken after 3 years of treatment.

[2]Ratio of berry number at each N rate compared to 76 berries in the 0 lb N/a treatment, expressed as a percentage. For example, berry number at the 20 lb N/a rate is 168 percent of berry number at the 0 lb N/a rate (128 ÷ 76 = 1.68 x 100 = 168%).

[3]Ratio of average berry weight at each N rate compared to 1.5 g in the 0 lb N/a treatment, expressed as a percentage. For example, berry weight at the 20 lb N/a rate is 107 percent of berry weight at the 0 lb N/a rate (1.6 ÷ 1.5 = 1.07 x 100 = 107%).

Appendix B—*continued*. Nitrogen Fertilization and Yield Components

What components most affect yield?

If we extrapolate the increase in yield from our small samples to an acre, we see a large increase resulting from the increased number of berries (line 10). This change was caused by increased fruit set and by a slight increase in the number of flowering uprights.

Let's examine the limitation to berry number. If each flowering upright can produce two berries, and the ratio of flowering uprights to total uprights is constant (line 6), then the total upright number (density) and length of uprights are critical (Figure 32). Upright density determines the number of flowering uprights and flowers, while the length of uprights determines how much carbon is available to produce berries.

Some growers focus on increasing berry size (weight). After fruit set, they want to "pump up" berries with fertilizer. However, as N fertilizer rate increased, berry weight increased only slightly. If we extrapolate to yield per acre, the yield increase resulting from larger berries (line 11) was much less than that from more berries (line 10).

The results shown in Table 16 strongly suggest that after upright number has been maximized, yield can be increased more by increasing berry number (either through greater floral induction or fruit set) than by increasing fruit size. Berry size rarely changes yield significantly.

Figure 32.—Research has found that yield increases are primarily a result of increased fruit set. Nitrogen fertilization at appropriate timing and rates can increase fruit set by encouraging optimal upright number and length.

Management implications

While N from fertilizer and plant recycling plays a role in both upright density and length, that role occurs well before fruit set. In addition, most nutrients, including N, are moved into the fruit within the first 2 to 3 weeks after fruit set. After that development stage, all changes are in water content and carbohydrates. Thus, adding N fertilizer at fruit set or later is too late to influence the key yield components in the current year.

Appendix C. Considerations for Interpretation of Soil Analyses

When collecting soil samples and interpreting soil test results, keep in mind the changes that occur as a cranberry bed ages (Figure 33). Top-dress fertilizer application creates layers with substantial differences in nutrients and soil pH (stratification). As the bed ages, P and K soil test values increase and pH decreases in the surface inch or two of sand.

Soil was collected from either the top 3 inches (surface) or top 6 inches (entire soil) of beds from 4 to 20 years old. After only 4 years of top-dress fertilizer application, a difference in soil test P was measured between these two depths (Figure 34). The difference increased with bed age.

The small increase in soil test P seen in "entire soil" samples is likely due to increased P near the surface rather than to movement of P throughout the 6-inch sample. Soil analyses from a 10-year-old bed support this hypothesis. Each year the bed received 100 lb/a of gypsum, K-Mag (potassium-magnesium sulfate), and 0-23-25. Soil test P in the surface 2 inches of the bed was about double the amount measured at 4 and 8 inches (Figure 35).

Management implications

No research has correlated soil analysis values by sample collection depth with cranberry yield. Even so, you need to realize that soil test levels for nutrients not mobile in soil (P, K, and Mg) increase rapidly with fertilizer top-dressing in the top 2 to 3 inches of cranberry beds, resulting in stratification of nutrients. Soil tests are difficult to interpret when nutrient stratification occurs.

When a soil sample is taken to a depth of 6 inches after years or decades of top-dress fertilizer application, the analysis will underestimate the amount of nutrients available to plants, as cranberry roots will readily use the material concentrated near the surface.

Linda White, © Oregon State University

Figure 33.—Soil from a new bed (left) and a mature bed (right). Newly planted beds do not have the duff layer evident in older bed soil.
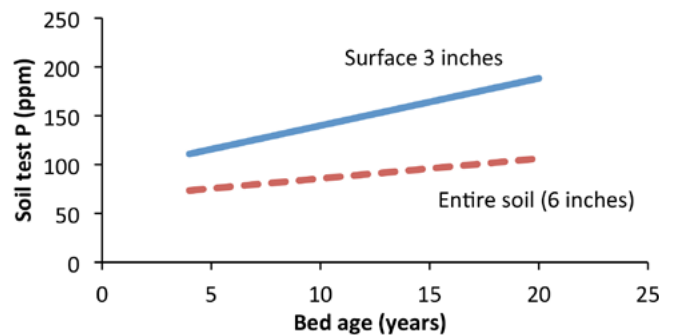
Figure 34.—Soil test P increased in the top 3 inches of soil with increasing cranberry bed age. Figure by John Hart.
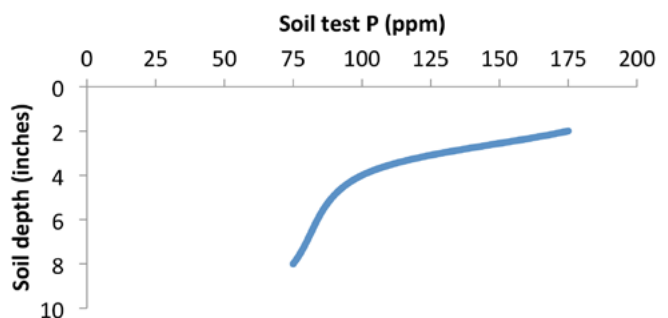

Figure 35.—Soil test P decreased with sampling depth in a 10-year-old cranberry bed. Figure by John Hart.

Appendix D. The Nutrient Detective: Looking for an Increase in Yield from P Fertilizer Application

South coastal Oregon cranberry growers routinely apply 6-24-24 to their beds. However, the amount of P needed by cranberry plants is modest compared to N. Only about 1 lb P is contained in each 100 bbl of berries, compared to as much as 6 lb N. Likewise, tissue concentration of 0.1 percent P is sufficient, compared to 1 percent N, a tenfold larger amount. Thus, repeated use of 6-24-24 likely oversupplies P.

To investigate the need for P fertilizer application, two beds were supplied with 0, 40, and 80 lb P_2O_5/a for 3 years. One bed was in Curry County, and the second in Coos County. The beds were chosen for contrasting management. The Curry County site routinely received P fertilizer substantially in excess of crop needs. In contrast, P application at the Coos County site was only slightly more than crop need.

Site differences are seen in soil test results after the first year of P application (Figure 36). Soil test P at the Curry County site was double that at the Coos County site. It also was about double the threshold above which no fertilizer P is recommended for new plantings (30 ppm).

Even with the high soil test P value at the Curry County site, fertilizer P application increased soil test P. At the Coos County site, soil test P increased only when 80 lb P_2O_5/a was applied.

Was P application needed?

For fertilizer application to be recommended, it must do four things: (1) increase tissue nutrient concentration or content, (2) increase growth, (3) positively influence yield components, and (4) increase yield sufficiently to be economically logical. We'll explore whether fertilizer P application met these criteria at the two south coastal Oregon sites.

Tissue nutrient concentration

Phosphorus application usually increased tissue test P values. Although values fluctuated annually, they always were within the recommended range for cranberry. Each increment of P fertilizer

increased tissue P in the Coos County bed (Figure 37). With 80 lb P_2O_5/a, tissue P in the Coos County bed increased to about the same concentration as that in the Curry County bed.

In contrast, results were mixed at the Curry County site (Figure 38). This result is not surprising, as tissue P was about 25 percent higher there than in the Coos County bed.
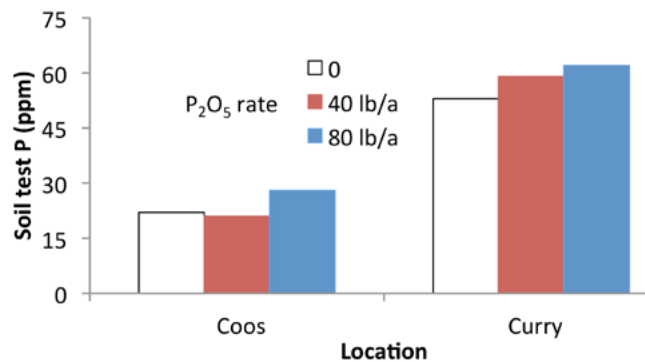

Figure 36.—Soil test P change with P fertilizer application (6-inch sample collection depth) in two south coastal Oregon cranberry beds. Figure by John Hart.
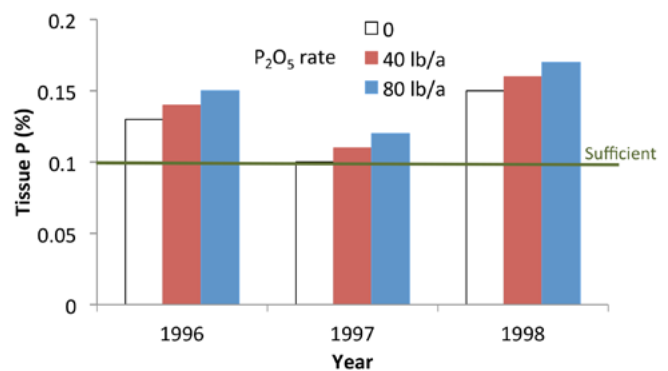

Figure 37.—Cranberry tissue P increased with P fertilizer application at the Coos County site. Figure by John Hart.
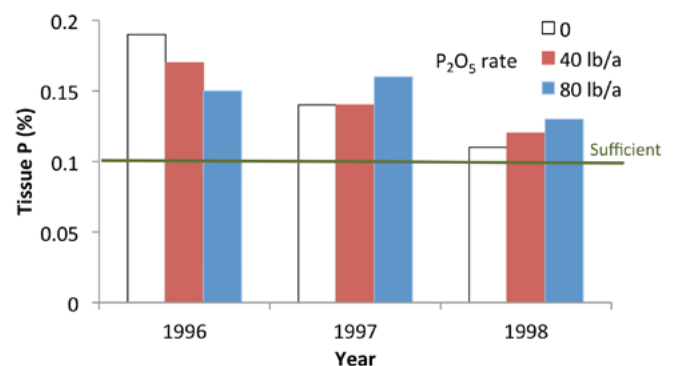

Figure 38.—Cranberry tissue P changed unpredictably with P fertilizer application at the Curry County site. Figure by John Hart.

41

Appendix D—*continued*. The Nutrient Detective: Looking for an Increase in Yield from P Fertilizer Application

Soil test P at the Coos County site was low enough that most growers would apply P fertilizer. Even so, after withholding P fertilizer for 3 years, tissue P concentration was above the minimum sufficient value of 0.1 percent (Figure 37).

Data also showed that tissue P did not increase as soil test P increased (Figure 39).

From these data we conclude the following.

- Tissue P fluctuates yearly.

- The annual change can be larger than would be explained by P fertilizer application.

- When tissue P is slightly above the sufficient value (0.12 percent), P fertilizer can increase tissue P concentration.

- When tissue P is 50 percent above the sufficient value (0.15 percent), P fertilizer is unlikely to increase tissue P concentration.

- When soil test P is above 20 ppm, tissue P and soil test P are independent.

Growth

Since P application increased tissue P in many cases, we need to determine whether it also increased growth. Neither flowering nor vegetative upright length was increased by P fertilizer application at either site in 1997 (Figure 40). Nonetheless, the data from this research provide some valuable information.

- Flowering uprights are longer than vegetative uprights.

- Annual upright growth was normal—2 to 3 inches.

- When tissue P is adequate, addition of P fertilizer does not change upright length.

Yield components

Next, we will examine whether P application changed yield components (upright number, berry number, and berry size). See Appendix C for information about the role of various yield components in increasing yield.

Between 100 and 200 flowering uprights/sq ft and 400 to 500 total uprights/sq foot are needed for good cranberry production. All P treatments in both beds produced a sufficient number of flowering uprights (Figure 41).

Phosphorus application did not significantly change upright number in either bed (Figure 41).
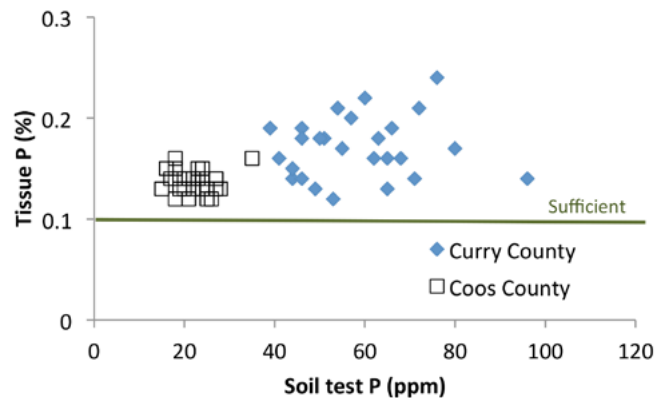

Figure 39.—Cranberry tissue P concentration did not increase as soil test P increased, 1996. Figure by John Hart.
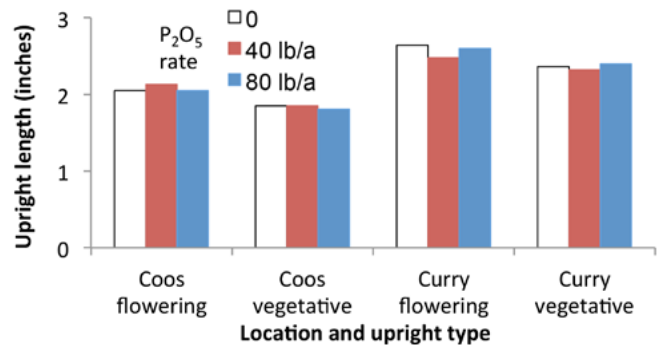

Figure 40.—Upright length was not changed by P fertilizer application at either location, 1997. Figure by John Hart.
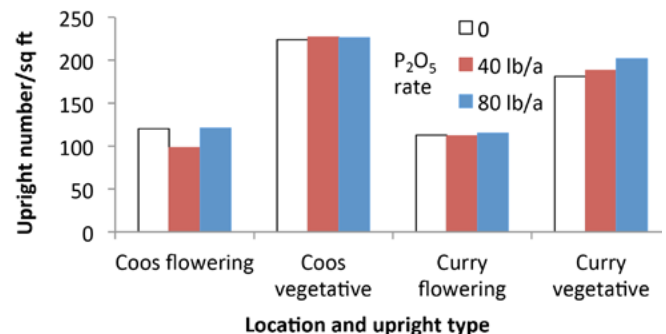

Figure 41.—Phosphorus fertilizer did not change upright number or the proportion of flowering uprights at either site, 1997. Figure by John Hart.

Appendix D—*continued*. The Nutrient Detective: Looking for an Increase in Yield from P Fertilizer Application

The proportion of flowering uprights was 45 to 60 percent in all treatments.

Phosphorus fertilizer application did not change berry number at either site in 1997 or 1998 (Figure 42).

The lack of response by cranberry plants to P application is not surprising, as cranberries are adapted to acidic environments with low P solubility. Other plant species may not be able to assimilate adequate P in this situation.

After berries have set, growers often apply fertilizer in an effort to make the berries larger. However, carbon from photosynthesis is what creates larger berries, not nutrient addition. In fact, increasing the P rate produced a trend for lower individual berry weight at both sites in both 1997 and 1998. The reduction in berry weight was statistically significant at the Coos County site in 1997 and at the Curry County site in 1998 (Figure 43).

Figure 43 provides evidence that nutrient application after berry set does not increase berry size. Similar results have been seen following N application. Fertilizer application is made to supply nutrients to the plant rather than to increase berry size.

Yield

The figures in this appendix show that when P soil supply and tissue concentration are sufficient, cranberry plants neither grow more nor produce more or larger berries with P application. As might be expected, therefore, yield was not changed by P fertilizer application (Figure 44).

Management implications

When tissue and soil test P are sufficient, no P fertilizer is needed. If you are routinely applying P in this situation, you can reduce production costs without reducing yield. If you find it difficult to eliminate fertilizer application, you might try reducing the P rate by 20 to 25 percent each year.
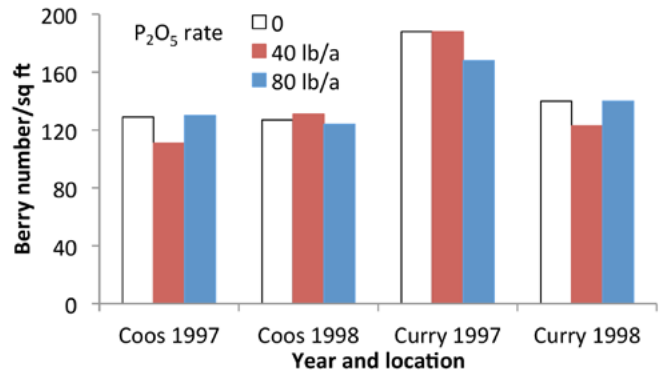

Figure 42.—Phosphorus fertilizer application did not change berry number at either site. Figure by John Hart.
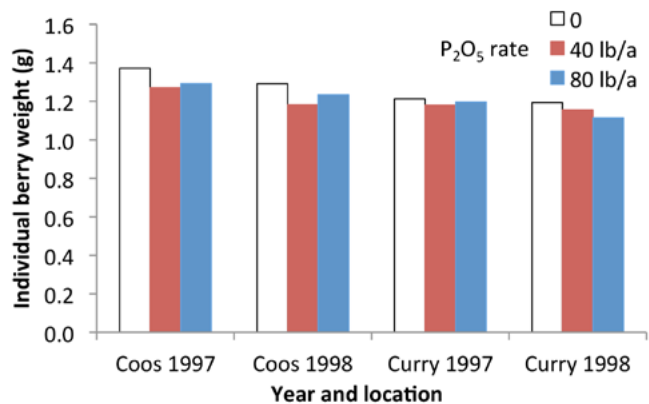

Figure 43.—Individual berry weight tended to decrease as P application rate increased. Figure by John Hart.
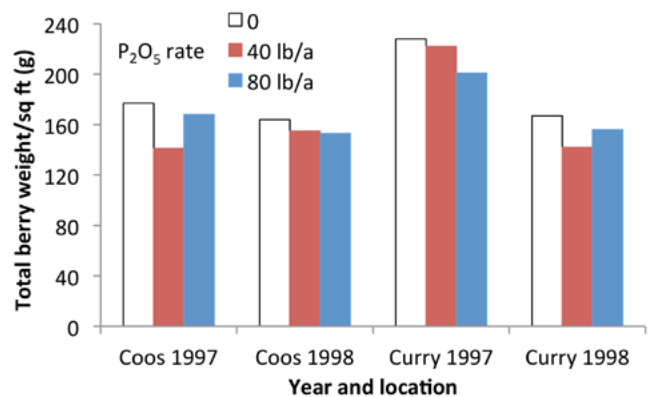

Figure 44.—Phosphorus fertilizer application did not change total berry weight harvested from a 12-inch diameter area at either site. Berry weight in grams from a 12-inch-diameter ring corresponds to yield in barrels per acre. See Appendix A, "Estimating Cranberry Yield," for more information. Figure by John Hart.

Appendix D—*continued*. The Nutrient Detective: Looking for an Increase in Yield from P Fertilizer Application

Monitor tissue P annually when reducing the P rate. Tissue P is influenced by year as well as by P application. If tissue P decreases following a reduction in P application, but remains sufficient (above 0.1 percent), typical yearly variability may be the cause. In this situation, you have several options.

- Continue reducing the P application rate. This option is reasonable even with declining tissue P, as tissue P changes yearly even when P is applied.

- Apply the same rate as the previous year. If tissue P is still sufficient the following year, you can feel more confident about reducing or eliminating P application when tissue P is sufficient.

- Use a maintenance application of P to replace P removed in fruit, harvest trash, and pruned vines (see page 24).

- Conduct an experiment on 25 percent of your acreage. Reduce annual P application on this land, while maintaining the higher rate on the bulk of your acreage. Compare tissue test results and yield over 3 to 5 years and look for trends. Calculate savings in fertilizer and application costs (labor, fuel, depreciation, lubricants). Select the program that provides the greatest return on investment.

- Increase P application to the previous rate. This option is not recommended, as data show that P is not needed when cranberry tissue and soil test P are sufficient.

Appendix E. Reducing K for Cranberry Production

Many decades ago, cranberry producers recognized the need to supplement the natural K supply in the soil with fertilizers. Repeated application of fertilizer with low N and relatively high K analysis (typically 6-24-24) became routine.

This practice oversupplies K. Nonetheless, growers felt that it was an inexpensive way to ensure sufficient K. From 2004 to 2008, the cost of K doubled. Growers began to ask, "How can I reduce my fertilizer cost?"

On many cranberry beds, K application can be reduced without causing a reduction in yield. The key is knowing when and where to reduce. Answering these questions requires management and monitoring similar to that used for N.

Approach a reduction in K application gradually, much as you would approach a weight loss program. Don't make large or sudden changes. Make small reductions, while monitoring tissue K and building confidence that results are positive.

The first step is to set a goal. We'll use OSU recommendations for soil and tissue K. The target for soil test K is between 50 and 100 ppm. Tissue K should be between 0.4 and 0.75 percent. If soil and tissue K are within this range, K application is recommended at 0 to 60 lb K_2O/a.

Let's look at yield from two cranberry beds where soil and tissue K were within the recommended range and K was applied or withheld for 3 years.

Tale of two beds

Potassium chloride (0-0-60) was applied to two cranberry beds for 3 years beginning in 1996. One was a 5-year-old 'Stevens' bed in Coos County and the other a 6-year-old 'Stevens' bed in Curry County. Treatments supplied a total of 0, 60, 120, or 180 lb K_2O/a, split monthly from mid-April to mid-June. Results are discussed below.

Yield, soil test K, and tissue K

Yield was measured in 1998. Yield was the same where K had been applied for 3 years and where no K was supplied (Figure 45).

Soil and tissue data are helpful in explaining the unchanged yield. The initial K application did not significantly change soil test K in the fall of the first year, regardless of rate (Table 17). This result was expected, since soil test K was adequate and the fertilizer was top-dressed.

After 3 years of application, tissue K increased slightly with the higher K application rates at the Coos County site (Figure 46). All tissue values,

Table 17.—Potassium application rate and soil test K.[1]

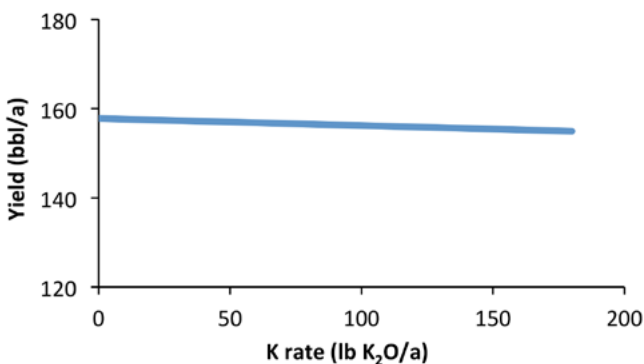| K application rate (lb K_2O/a)	Soil test K (ppm)	
	Coos	Curry
0	73	54
60	76	53
120	79	52
180	79	62

[1]September 1996.

Figure 45.—Cranberry yield was not influenced by K application after 3 years of K treatments, 1998. Yield from both sites was similar, so a single line is used to represent both beds. Figure by John Hart.
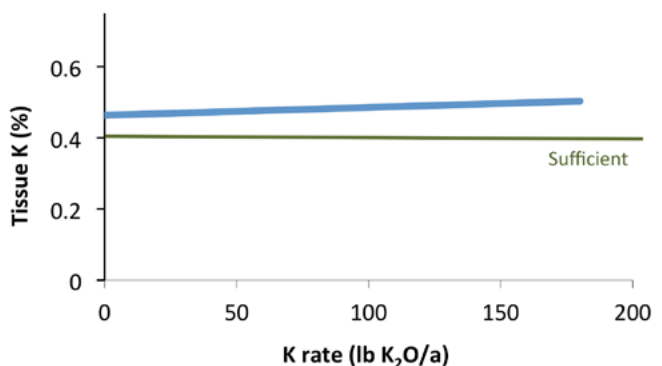

Figure 46.—Leaf K concentration and K fertilizer rate at the Coos County site. Tissue concentration is from 1998, the third year of fertilizer treatment. Figure by John Hart.

even from areas receiving no K fertilizer for 3 years, were within OSU's recommended range.

Since tissue K was adequate without K application, addition of K fertilizer was not expected to increase yield. Adding K when tissue K is sufficient may increase leaf K concentration, but does not alter yield (Figure 47).

Berry color

Cranberry color, as measured by total anthocyanin content (TAcy), was not changed by leaf K concentration (Figure 48, Curry County site). All TAcy measurements at the Coos County site were above 72 mg/g, the maximum measured by the test. Because leaf K was within OSU's sufficient range and changed only slightly with K application, K application was not expected to change TAcy.
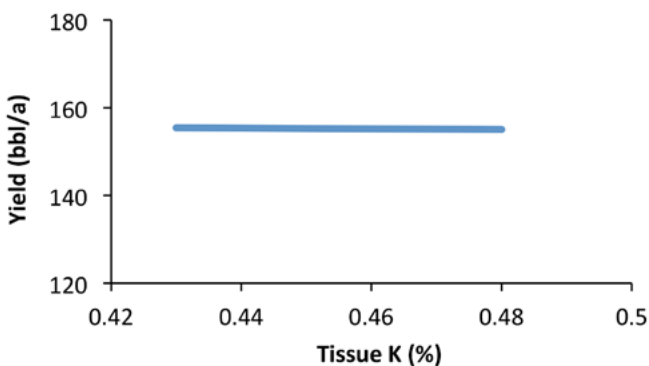
Berry weight

Figure 49 shows that berry weight did not change at either location after 2 years of K treatments. The line representing berry weight at the Coos County site shows a slight increase (from 1.32 g/berry with no K to 1.38 g/berry when 360 lb K_2O/a was applied). However, this change is not statistically significant.

Reduction in excess growth

Potassium application did not suppress growth (length) of either flowering or vegetative uprights (Figure 50). In fact, Figure 50 shows an opposite trend. Thus, we conclude that K fertilizer cannot be used as a growth-retarding treatment.

Figure 47.—Cranberry yield and leaf K concentration, 1998. Data from both sites are combined. Figure by John Hart.

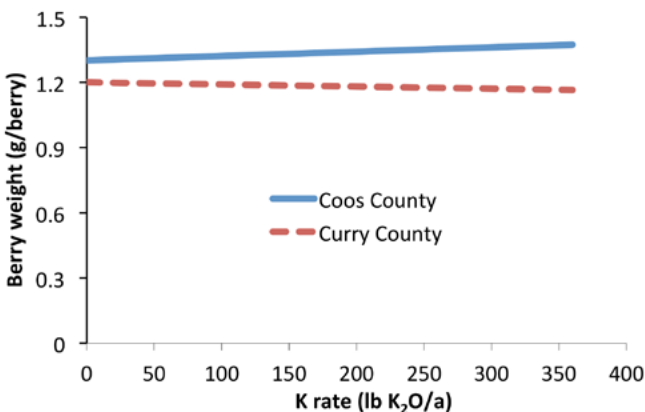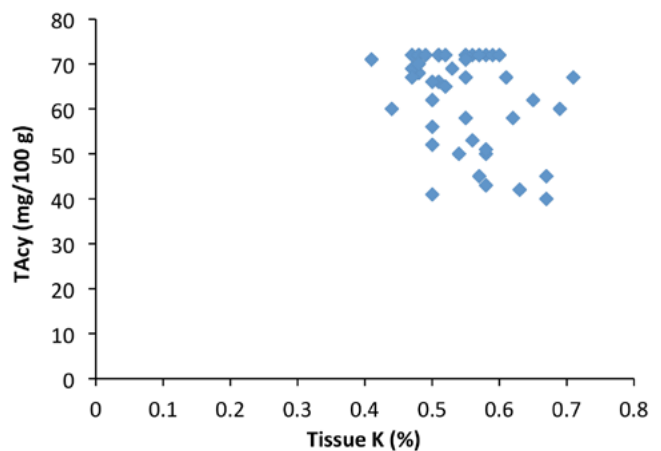Figure 48.—TAcy and leaf K concentration for the Curry County site, 1998. Figure by John Hart.

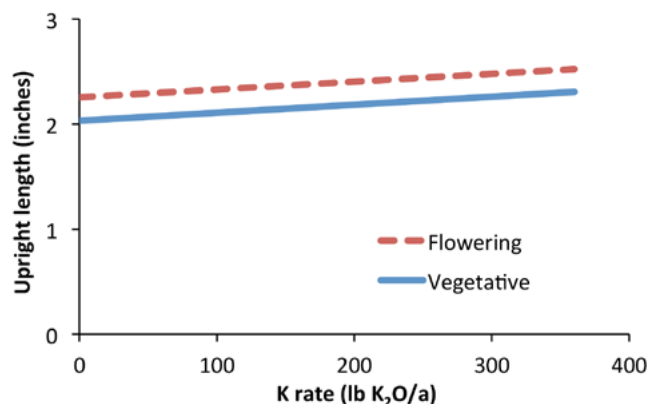Figure 49.—Berry weight and K fertilizer application rate. Data are from 1997 harvest. Figure by John Hart.

Figure 50.—Average upright length at harvest in 1997 with increasing K application rates. Data are an average for two sites. Figure by John Hart.

46

Appendix E—*continued*. Reducing K for Cranberry Production

Upright number and bud set

If bud set is influenced by K, upright number and yield should be changed by K application. However, when K was adequate, K treatments did not affect upright number (Figure 51) or yield (Figure 45).

Similar results from Wisconsin

Split applications of K were applied to two 'Stevens' cranberry beds in Wisconsin at rates between 0 and 800 lb K_2O/a. Treatments also compared potassium sulfate and potassium chloride at 200 and 400 lb K_2O /a. Fertilizer was applied at roughneck, bloom, fruit set, and in early August.

Potassium application increased both tissue K and soil test K, but not always significantly. The results were more pronounced in 2006 than in 2007. However, higher K rates did not increase yield or fruit size in either year.

An earlier trial in Wisconsin showed a 5 percent yield reduction following a single mid-July application of 180 lb K_2O/a. Yield decreased 10 percent when 270 lb K_2O/a was applied in mid-July.

Fruit was also analyzed for color. No effect of K fertilizer rate on fruit color was measured in either 2006 or 2007.

No reduction in tissue N, cold hardiness, or other growth-reducing factors was measured until the K application rate reached 1,440 lb K_2O/a. This amount of K burned and killed the vines.
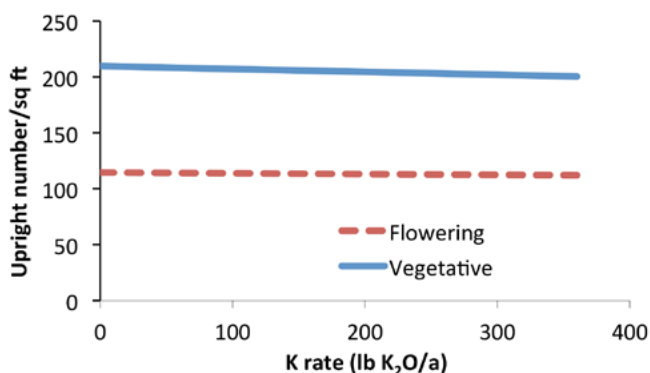

Figure 51.—Average upright number per square foot with increasing K application. Data are from 1997 harvest and are combined for two sites. Figure by John Hart.

Because some of the treatments were potassium sulfate and some were potassium chloride, it was possible to determine whether Cl in the rate range studied was detrimental to cranberries. No effect of Cl was seen.

Grower results from a low K "diet"

A south coastal Oregon cranberry grower was applying about 130 lb K_2O/a in various blends from spring through fruit set. The K application was gradually reduced beginning in 2004. In 2007 and 2008, only 70 lb K_2O/a was applied (20 lb/a in the spring and 50 lb/a during fruit set). The grower said, "This bed consistently produces 300 bbl/a. The range was from 295 to 330 bbl/a through those years, even with the reduction in potassium application."

The grower added, "The potassium tissue concentration did not change and was within the normal tissue concentration range of K for cranberries [0.4 to 0.75 percent] during the time K application was reduced" (Table 18).

Summary and management implications

When tissue K was between 0.4 and 0.75 percent and soil test K was between 50 and 100 ppm, K applications to Oregon cranberry beds had no effect on yield, berry color, upright length, or bud set. Likewise, Wisconsin research found no effect of K application on yield, fruit size, fruit color, or cold hardiness of plants.

These results show that when tissue and soil test K are within the sufficient range, K application can be reduced or eliminated for at least a year or two without reducing yield.

Table 18.—Annual tissue K concentration during years of K fertilizer reduction.

Year	Tissue K (%)
2004	0.56
2005	0.61
2006	0.54
2007	0.53

Appendix E—*continued*. Reducing K for Cranberry Production

Monitor K need through soil and tissue analysis. If tissue K is at the upper end of the sufficient range and you have been applying K regularly, you can reduce fertilizer cost by reducing the K rate. Don't make large or sudden changes.

Annual testing of cranberry uprights is necessary when K fertilizer is reduced. Changes in tissue concentration probably will not be noted for at least 3 years if soil and tissue K were sufficient and annual applications previously exceeded 80 lb K_2O/a.

Other ideas for saving money by reducing K

Reduce or eliminate foliar applications. When K is needed, dry fertilizer materials are usually a more economical choice.

Compare the cost of potassium chloride (muriate of potash; 0-0-60) and potassium sulfate. Usually, potassium chloride is less expensive per pound of K than is potassium sulfate. Application of 20 to 30 lb K_2O/a as potassium chloride three or four times a year allows leaching of Cl between applications and eliminates any potential for Cl toxicity.

Appendix F. Effects of Gypsum Application on Cranberry Growth

Calcium usually comprises more than 50 percent of the exchangeable cations in soil. Exchangeable Ca (and Mg) decreases as soil pH decreases from 8 to 4.

Soil textural class (the amount of sand, silt, and clay) and soil pH control the potential for exchangeable Ca. Exchangeable Ca is greater in soils with more than 40 percent clay, compared to sandy soils. Calcium typically is also low in acidic soils.

Thus, the sandy, acidic soils in which cranberries are grown likely contain low levels of Ca. It is easy to assume that Ca is required for cranberry production on these soils, so many growers annually apply gypsum ($CaSO_4$). It is believed that adding gypsum will increase yield, improve soil drainage, and alleviate crunchy vines caused by application of the herbicide Casoron. Typical gypsum application rates are 300 to 400 lb/a, substantially more than the maximum OSU recommendation of 100 lb/a.

Before 2008, little research on the effects of Ca on cranberries had been performed, and none in Oregon. The effects of Ca on fruit quality and size have not been studied. In highbush blueberries, a crop closely related to cranberries, the addition of 500 lb gypsum/a had no effect on berry size, yield, firmness, or incidence of fruit rot, compared to a nontreated control (Hanson and Berkheimer, 2004).

Oregon research

To measure how much, if any, applied Ca is needed for south coastal Oregon cranberry growth and fruit quality, two beds in Coos and Curry counties were chosen for study in 2008 and 2009. One bed was 'Stevens' and the other 'Stevens'/mixed varieties.

Beds received 50 lb Casoron/a or no Casoron. Gypsum was applied at 0, 25, 50, 100, 200, and 300 lb/a. Fruit was hand harvested from 1-square-foot areas. Yield, fruit rot, and °Brix (sugar content) were measured. In addition, five root samples per plot were collected to evaluate "crunchy vines" due to Casoron application.

Effect of Casoron application

In beds receiving no gypsum, leaf Ca concentration was higher where no Casoron was applied than in treatments receiving Casoron. This result indicates that Casoron likely damaged cranberry roots or impaired their growth. The same pattern was seen with other nutrients at both sites in 2009, supporting the idea of root damage from Casoron.

The conclusion that Casoron inhibits root growth was also supported by root observation tubes installed in the Curry County plots. Root growth was delayed where Casoron was applied. Roots first appeared in June in plots receiving no Casoron. In plots that received both Casoron and 200 lb gypsum/a, root appearance was delayed until late July or August.

Gypsum application did not affect leaf Ca concentration in treatments receiving no Casoron (Figure 52). However, Ca leaf concentration increased with increasing gypsum rate in treatments receiving Casoron.

Cranberry need for Ca

Cranberry plants seem to have a very low requirement for Ca. Calcium leaf concentration varies greatly among growing regions, but leaf Ca concentration between 0.3 and 0.8 percent generally is considered sufficient.
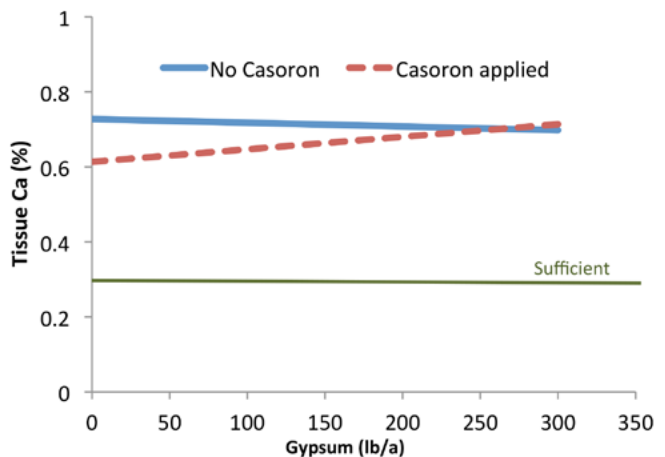

Figure 52.—Cranberry leaf Ca concentration increased with gypsum application only when Casoron was applied. All leaf Ca concentration values are within the sufficient range for cranberry. Unpublished data from Linda White; figure by John Hart.

49

Appendix F—*continued*. Effects of Gypsum Application on Cranberry Growth

All leaf Ca concentrations were within this range in samples from the Coos County bed during 2008 (Figure 52). Even with Casoron application and no gypsum application for 2 years, tissue Ca concentration was sufficient.

Management implications

No benefit was measured by adding Ca (as gypsum). Tissue Ca did not become deficient even with Casoron application and no Ca application. These results support the current recommendation of applying 0 to 50 lb gypsum/a (0 to 10 lb Ca/a) annually, so long as tissue Ca concentration is sufficient. This recommendation applies even where Casoron is used.

We should note that this research was limited to 2 years and two beds. Even so, similar results are expected if additional measurements are made.

Gypsum is an excellent source of Ca for cranberries if Ca additions are needed. However, need for Ca is indicated only when tissue Ca concentrations are low (below 0.3 percent).

Additional considerations

- In the Oregon research discussed above, gypsum did not increase or decrease cranberry yield or °Brix content in either year or at either farm.

- Gypsum will not raise or lower soil pH in cranberry beds.

- Gypsum will enhance soil drainage only under very specific conditions (in soils with high levels of sodium). The term for this condition is a sodic soil. Gypsum improves sodic soils by providing Ca^{++}, which is exchanged with Na^+ ions in the soil. This condition is not found in cranberry production; it is found only in arid and semiarid areas such as eastern Oregon and Washington.

- A potentially important negative consequence of gypsum application is its tendency to decrease soil test K and Mg values. In the research described above, soil K and Mg decreased as the rate of gypsum increased. The same effect is seen after application of high rates of Ca from other sources such as lime. If tissue K concentration is low or decreasing, the addition of 300 to 400 lb gypsum/a can further decrease K supply for cranberries.

Appendix G. Fertilizer and Irrigation Recommendations for Bed Establishment

Nitrogen (N)

Fertilization of new beds encourages rapid root growth and soil coverage by plants. Vigorous early growth decreases weed competition. For first-year plantings, apply 5 to 10 lb N/a when ¼ inch of growth is observed. Continue applying 10 lb N/a no more than every other week until September or until appropriate vigor and runner growth are achieved.

Establishment is achieved when runners generate new uprights and terminal buds. Once sufficient uprights and buds have formed, apply N according to recommendations for bearing beds.

Phosphorus (P)

Choose the P fertilizer rate based on soil test results (Table 19).

Efficient use of P fertilizer depends on fertilizer placement, as P is not mobile in soil. During bed preparation, lightly incorporate P to mix it with the surface 2 to 3 inches of the bed. The fibrous root system of cranberry develops in the top 1 to 3 inches of soil. Therefore, for new plantings, apply one-half to two-thirds of the P fertilizer just before vines are scattered and disked (Figure 53). Apply the remaining P at midseason. If vines have already been planted, split the P applications in the first year, applying half as growth starts and half at midseason.

Potassium (K)

Use Table 20 to determine the K rate based on soil test results. Like P, K is not mobile in soil, so it should be incorporated before planting.

Irrigation

Irrigate to maintain a moist, but not wet, soil environment. If water puddles consistently, adjust sprinklers, reduce irrigation amounts, or improve drainage. Cranberries may die or lose vigor if standing water is chronic.

Figure 53.—For new beds, incorporate P and K *before* scattering vines. Wait until ¼ inch of growth is observed before applying N.

Table 19.—Cranberry P sufficiency and fertilizer recommendations for new plantings based on soil analysis.

Soil test P (ppm)[1]	Status	Apply this amount of P_2O_5 (lb/a)[2]
0 to 15	Low	40 to 80
15 to 30	Sufficient	0 to 40
Above 30	High	0

[1]Bray method.

[2]Broadcast application.

Table 20.—Cranberry K sufficiency and fertilizer recommendations for new plantings based on soil analysis.

Soil test K (ppm)[1]	Status	Apply this amount of K_2O (lb/a)[2]
0 to 50	Low	60 to 100
50 to 100	Sufficient	0 to 60
Above 100	High	0

[1]Ammonium acetate extraction.

[2]Broadcast application.