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Phosphorus for Bearing Cranberries in North America

Teryl Roper
Utah State University, teryl.roper@usu.edu

Joan Davenport
Washington State University, jdavenp@wsu.edu

Carolyn J. DeMoranville
University of Massachusetts - Amherst, carolynd@umext.umass.edu

Sebastien Marchand

Art Poole

See next page for additional authors

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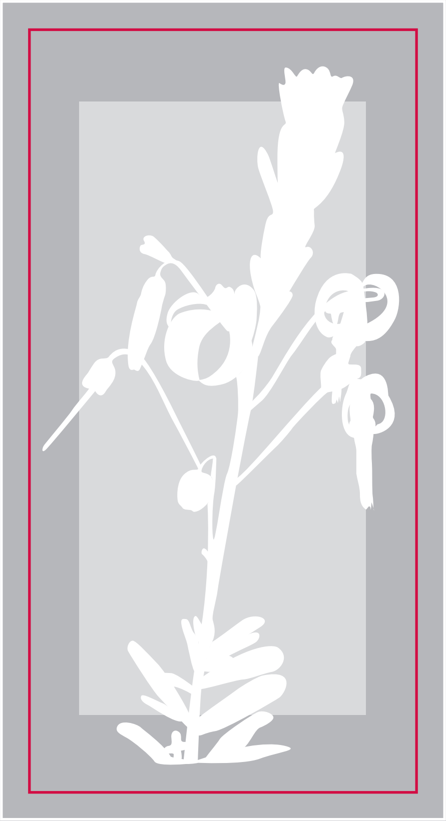

Phosphorus
For Bearing Cranberries
In North America

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For Bearing Cranberries In North America

Authors: Teryl Roper[1], Joan Davenport[2], Carolyn DeMoranville[3],
Sébastien Marchand[4], Art Poole[5], and Kim Patten[6]

Phosphorus is one of 13 essential mineral nutrients required for cranberry vines to grow and produce fruit. Cranberry growers apply phosphorus containing fertilizers to optimize growth and fruiting. While phosphorus is a required mineral element for plant growth, it can also be an environmental contaminant. Phosphorus is typically the limiting factor for the growth of algae in surface waters. When phosphorus is provided in such systems, algal blooms (eutrophication) can result. As the algal population peaks and the algae die, oxygen in the water is depleted, often resulting in fish kills.

The purpose of this publication is to help cranberry growers understand how phosphorus is used by cranberry vines, how phosphorus reacts in soils, sources of phosphate as fertilizer, and how to determine the need for phosphorus fertilizer.

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Phosphorus and water quality

Nutrients are necessary for aquatic ecosystems to support plant growth and the rest of the food web. However, excessive availability of nutrients is detrimental. The principle adverse impact of nutrient enrichment is to change the trophic state of a waterbody. Trophic state refers to the overall level of nutrients that support plant and animal life in a community. Water bodies are usually referred to as oligotrophic (low nutrients), mesotrophic (moderate nutrients), or eutrophic (high nutrients). Some increases in trophic levels occur naturally. Others are encouraged by the actions of people.

Phosphorus is usually the limiting factor that prevents the growth of substantial amounts of algae and other plants in water bodies. Phosphorus in freshwater in excess of 0.1 milligram per liter is sufficient to encourage growth of algae and aquatic plants. These plants consume both oxygen and carbon dioxide from the water. Reduced oxygen may lead to fish kills. Consumption of carbon dioxide can alter water pH, thus changing the species a water body can support.

Since it takes so little phosphorus in water to cause such dramatic results, it is incumbent on growers to do all they can to reduce the amount of phosphorus fertilizer into the environment. Since cranberry production is so intimately tied to surface waters, the opportunity for water contamination from cranberry beds is enormous.

(Footnotes)

[1] Professor, University of Wisconsin-Madison

[2] Associate Professor, Washington State University

[3] Director, Cranberry Experiment Station, University of Massachusetts

[4] Agronomist, Club Evironnemental et Technique Atocas Québec

[5] County Educator, Coos County Oregon, Oregon State University

[6] Associate Professor, Washington State University

sources of phosphate as fertilizer, and how to determine the need for phosphorus fertilizer.

Phosphorus: How is it used in plants?

While phosphorus is certainly critical for normal plant growth, development and reproduction, it comprises only about 0.2% of plant dry weight. Compared to the 94% of plant dry weight consisting of carbon, hydrogen and oxygen, phosphorus could be considered minor. However, without sufficient phosphorus the 94% doesn't happen. Developmentally, phosphorus is critical in root development and flowering. Phosphorus is involved in three important structural and metabolic aspects of plants (and animals as well).

Membranes. Cell membranes are composed primarily of phospholipids. A phospholipid usually consists of two long fatty acid chains (groups of 14-18 carbons connected together) attached to a phosphate ion. Frequently another chemical group is attached near the phosphate. Phospholipids have a hydrophobic portion (the fatty acid chain) and a hydrophilic end (the phosphate). Phospholipids naturally arrange themselves in bilayers with the fatty acids in the middle and the phosphates to the outside. You can visualize what a phospholipid looks like by thinking about old-fashioned non-spring type wooden clothespins.

In addition to lipids, membranes also contain proteins. Phosphorus is an essential component of some proteins. Some proteins attach to a membrane exterior, while others can be embedded partially or completely through membranes.

Membranes are important as they define "inside" and "outside" of cells and organelles within cells. They keep things "in" that need to be in, and keep out materials that might be damaging to the cell.

Membranes are also active in energy transformation and use in cells. When one side of a membrane has a net negative charge and the other a positive charge, there is a charge separation across the membrane that can be used to do "work". This is exactly what happens in photosynthesis and respiration.

Energy currency. Phosphorus is an important component of ATP, the energy currency in cells. In photosynthesis a phosphate ion is attached to an ADP molecule making ATP (energy is stored). In respiration a phosphate is removed from ATP to make ADP (energy is used). ATP can be moved from one place to another in a cell, thus moving energy.

Phosphate is also involved in moving energy from chloroplasts into other portions of cells. Sugars are made via photosynthesis in the chloroplast and are then moved out of the chloroplast as a three carbon sugar with a phosphate attached. When phosphorus is in short supply sugars can't leave the chloroplast and the carbon is stored in the chloroplast as starch.

Genetic code. Phosphorus is the "glue" that holds the base pairs together to form DNA and RNA. DNA contains the genetic code that determines the form and function of an organism. The DNA in different cranberry cultivars is slightly different. Using various techniques of molecular biology scientists can tell different cultivars apart based on analysis of their DNA.

So we see that phosphorus is extremely important to plants. Without sufficient phosphorus, plants can't carry on their vital functions. However, new phosphorus doesn't need to be taken up by plants for every cell function each time. Phosphorus that exists in plant cells is recycled over and over. Further, a substantial amount of phosphorus is retained in perennial portions of the vines from year to year, so even within a given year not all phosphorus must come directly from the soil.

While phosphorus is essential for plant metabolism, carbon, hydrogen, and oxygen are still the most abundant minerals in plants. Keeping plant phosphorus needs in balance with other nutrient needs is the basis for good fertilizer decisions.

How Phosphorus Reacts in Soil

Each year growers make applications of phosphorus-containing fertilizers to supply plants with nutrients they require. The need to add phosphorus fertilizer arises from the inability of soils to supply adequate amounts of orthophosphate ($H_2PO_4^-$ and HPO_4^{2-}) for satisfactory crop growth. The reactions that phosphorus undergoes in soils are fundamentally different than for N or K and result in poor (25% or less) efficiency of recovery in a given year. In contrast uptake of N or K fertilizer may be as high as 80%.

Fertilizers used by cranberry growers can contain phosphorus in one of four different formulations: Triple superphosphate, regular superphosphate, monoammonium phosphate, or diammonium phosphate. In order for a plant root to take up a phosphate ion it must be in the soil solution (liquid fraction of the soil). It cannot be bonded to any other ion.

What happens to that fertilizer once it reaches the soil surface? When fertilizer containing phosphorus is applied to soil, it goes through a sequence of reactions that can be generalized into three components: 1) dissolution of the phosphorus fertilizer particle, 2) precipitation reactions, and 3) adsorption reactions.

Dissolution of the particle. Dry granular fertilizers must react with water to dissolve. Because the granules are concentrated salts, they attract water from the surrounding environment, including the air. As water reacts with the granules they dissolve and create a concentrated solution of the fertilizer that moves into the surrounding soil. Irrigation or rainfall hastens dissolution of the granules and movement into the soil.

Precipitation reactions. As the phosphorus dissolves from the fertilizer granule it is present as a negatively charged phosphate ion ($H_2PO_4^-$). This negatively charged ion (anion) is very reactive with positively charged ions (cations) such as iron (Fe^{++}/Fe^{+++}), aluminum (Al^{++}), manganese (Mn^{++}/Mn^{+++}), or magnesium (Mg^{++}). Dissolved phosphate reacts almost immediately with cations to form relatively insoluble compounds. These compounds are not completely insoluble in water, but they are poorly soluble. Acid soils fix more phosphorus than neutral soils because as soil pH drops iron and aluminum ions become more available to react with phosphate. Cranberry soils are low in pH and often are high in iron, so phosphorus precipitates readily.

Notice that in the description above, both iron and manganese are listed with different numbers of positive charges. Iron and manganese are transition elements. Depending on how wet or dry the soil is for prolonged periods of time, iron and manganese will have different charges. Under wet soil conditions, after winter or harvest floods, iron and manganese will have a smaller positive charge and can tie up less phosphorus. When soils are dry during the growing season, both metals are able to tie up more phosphorus due to higher charges. This increases the soils ability to render phosphorus unavailable to cranberry vines. These reactions are unique to cranberry soils.

The reactions of phosphate with cations in soil solution are called precipitation reactions because the compounds formed aggregate and will settle out of solution (precipitate).

As plant uptake or other reactions remove ‘free’ phosphorus from the soil solution, phosphorus is released from these compounds until equilibrium is reached. Unfortunately, phosphorus is not released into the soil solution nearly as quickly as plants can take phosphorus out of the soil solution.

Adsorption reactions. The relatively insoluble phosphorus compounds formed in precipitation reactions can also react with the mineral fraction of the soil, a process known as adsorption. Once the phosphorus combines with iron, aluminum, manganese, etc. and adsorbs to the soil minerals, its solubility declines even further. This is important as only soluble phosphorus can be taken up by plants.

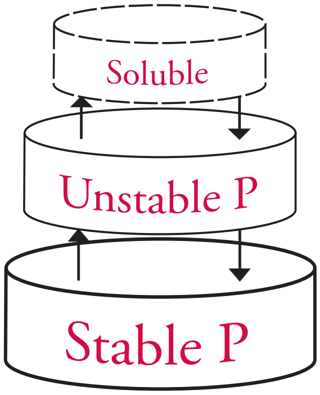
As a result of these reactions phosphorus fertilizer that is applied to soils becomes plant unavailable fairly quickly—in a few hours to a few days. While the total amount of phosphorus in the soil may increase over time, plant available phosphorus tends to remain low and relatively constant.

Is all soil P available to plants? The simple answer is no. Inorganic phosphorus in soils is found in three fractions: in soil solution, exchangeable (unstable), and insoluble (stable). Only the phosphorus in solution is plant available. As this phosphorus is taken up from the soil solution, it is replaced by phosphorus coming from the exchangeable pool of phosphorus (Fig. 1).

The rate of release from the insoluble pool is very slow, too slow to contribute significantly to crop growth over a single growing season. Thus, the phosphorus available to a crop is that which is capable of dissolution during the growing season. This is usually only a small fraction of the total phosphorus in the soil. Soil scientists estimate that generally only about 1% of soil phosphorus is in solution (readily available) and as much as 80-90% is in the stable pool. Fertilizer phosphorus is generally more available for crop growth than is soil phosphorus.

One of the unique characteristics of phosphorus is its immobility in soil. Phosphate ions do not leach, as do nitrate or potassium ions, even in sandy soils. Thus phosphorus moves very slowly in soils and it is difficult to move phosphorus into the root zone without some sort of tillage. In perennial cropping situations, like cranberry, it is extremely important to add phosphorus fertilizer to the soil during bed establishment.

Figure 1.— Relative amounts of phosphorus in the three pools available in soils. Phosphorus can move from one pool to another, but moves very slowly.



So what does this mean for cranberry producers? Because phosphorus in the soil becomes plant unavailable relatively quickly, frequency of phosphorus application may be more important than the total amount of phosphorus applied.

Chemical soil testing is supposed to extract only the phosphorus that is the soil solution and, therefore, plant available. We have found that existing soil tests extract too much phosphorus from sandy, acidic cranberry soils, thus overestimating the plant available phosphorus. That is why your soil test may show that the soil has excessive phosphorus, but your vines may be low to barely sufficient. This underscores the importance of tissue testing when managing cranberry phosphorus.

Soil Characteristics that Can Affect Phosphorus Availability and Uptake

Since phosphorus fertilizer applied to cranberries is held in the soil, it is important to understand how soil affects plant uptake of phosphorus. Soil affects plant uptake of phosphorus in at least three ways: 1) the amount of soil phosphorus (quantity), 2) the concentration of soil solution phosphorus (concentration), and 3) the movement of phosphorus to roots (diffusion).

While soils may have substantial quantities of total phosphorus, this is different than plant available phosphorus. Total phosphorus includes phosphorus held in the mineral fraction of the soil that only becomes available as the soil minerals weather or break down. This fraction also includes phosphorus held in relatively insoluble compounds with iron, aluminum, and manganese. In other words, total soil phosphorus includes the

80-90% of phosphorus that is very poorly available or stable.

The concentration of phosphorus in the soil solution is a much more important parameter in relation to plant uptake. Plants can't absorb phosphorus from the mineral or structural portion of the soil directly. Phosphorus must be in water and must not be attached to any other ions in order for the roots to take it up. Phosphorus in the soil solution is in equilibrium with phosphorus adsorbed to the soil particles. When a plant takes up a phosphate ion, for example, another phosphate ion will slowly de-sorb from the soil and go into solution. This is what is meant by equilibrium.

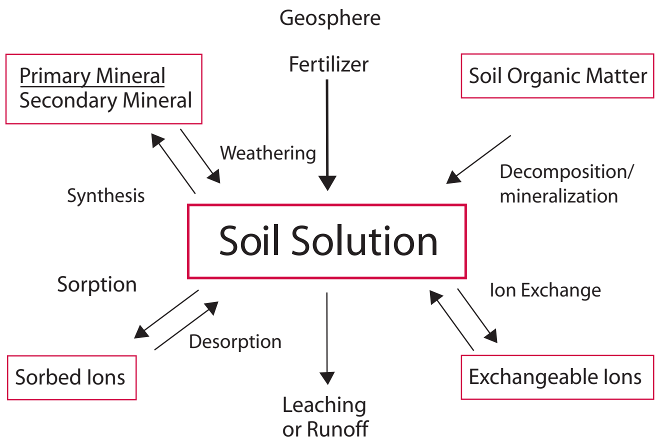
Soil water is a repository for dissolved solids and gases and for this reason it is commonly referred to as the soil solution. Soil solution is defined as the aqueous liquid phase of soil and its solutes consisting of ions dissociated from the surfaces of the soil particles and of other soluble materials. The soil solution moves through the soil through macropores (infiltration, percolation, and drainage), micropores (retained water), and water films around soil particles (capillary movement).

In order for nutrient uptake to occur, nutrients in the soil solution must come in contact with the surface of plant roots. Movement of ions within the soil solution is thought to primarily occur via diffusion. Diffusion is the process of ions moving from an area of higher concentration to an area of lower concentration until the concentration of that ion is uniform (equilibrium is reached). Practically, diffusion in soils usually occurs for only short distances (<½ inch). Diffusion increases with soil temperature.

Soil texture is an important determinant of the ability of a soil to retain phosphorus. The maximum amount of phosphorus adsorbed for a group of acid soils was 18, 104, and 342 ppm P for sand, fine sandy loam, and silty clay loam textures, respectively. The coarse soils typically used for cranberries are the soils least able to retain phosphorus. However, phosphorus fertilizer applied to coarse soils results in a greater increase in soil solution phosphorus than occurs with applications to finer textured soils. So while cranberry soil has relatively poor capacity to store phosphorus, adding fertilizer can increase phosphorus in the soil solution.

In review, soil may hold substantial amounts of phosphorus in or adsorbed to the mineral fraction, but this phosphorus is not available for plant growth. Only phosphorus that is in the soil solution and in close proximity to plant roots can be taken up by plants. Slowly, over time, phosphorus may move from the mineral fraction to the soil solution. All of these processes are important to plants getting sufficient phosphorus. The Figure 2 illustrates the complexity of the system.

Figure 2.— Simplified soil phosphorus cycle.



Sources of phosphorus

Pure phosphorus is never found free in nature, but it is widely found in combination with other minerals. Apatite is an impure tri-calcium phosphate and is an important source of industrial phosphorus. The ultimate source of most phosphate fertilizer is phosphate rock. These are lime-rich sedimentary rocks that became enriched in phosphorus under shallow marine conditions. Currently U.S. phosphate mining takes place in Florida, North Carolina, Idaho and Utah. Some phosphate mining is underway in Ontario, Canada.

Mined phosphate rock is almost insoluble. To make a fertilizer in which the phosphorus is available, the phosphate rock is finely ground and then treated with acid. Treating with sulfuric acid produces superphosphate. Treating with phosphoric acid produces triple superphosphate. Reacting phosphoric acid with ammonia produces ammonium phosphate.

Phosphorus or phosphate?

In fertilizer, phosphorus exists as the phosphate ion ($H_2PO_4^-$ or $HPO_4^=$). By historic convention, the middle number on the fertilizer bag is the percent of available phosphate represented as P_2O_5, even though no P_2O_5 exists in the bag. It would be simpler and less confusing to express phosphorus on an elemental basis (as actual P), but the oxide analysis has become so entrenched in the fertilizer industry that it would be difficult to change.

To convert between phosphate and phosphorus, use the following conversion factors:

Phosphorus (P) = phosphate (P_2O_5) x 0.44
Phosphate (P_2O_5) = phosphorus (P) x 2.29

Phosphate fertilizers

Fertilizers used by cranberry growers can contain phosphorus in one of four different formulations: triple superphosphate, regular superphosphate, monoammonium phosphate, or diammonium phosphate. In order for a plant root to take up a phosphate ion it must be in the soil solution (liquid fraction of the soil). It cannot be bonded to any other ion. In other words, the fertilizer must be dissolved in the soil water. Properties of phosphate fertilizers are shown in Table 1.

Water solubility. The amount of water soluble phosphorus in the different sources of phosphate varies considerably (Table 1). When phosphorus is broadcast and incorporated or topdressed, minor differences in water solubility makes little or no difference. Most commonly used phosphorus fertilizers presently sold for use on cranberries (except rock phosphate, which is not generally recommended) contain at least 85% water soluble phosphorus.

Orthophosphate versus polyphosphate. Sources of phosphorus containing the $H_2PO_4^-$ or $HPO_4^=$ ions are called orthophosphates. The superphosphates and ammonium phosphates are also orthophosphates. Polyphosphates contain a mixture of orthophosphate and some long-chain phosphate ions such as pyrophosphate, $(HP_2O_7)_3^-$. Commercially produced polyphosphate contains about

Table 1. Agricultural phosphate fertilizers.

Name of Fertilizer	Chemical Formula	Fertilizer Analysis	Water Solubility
		%	%
Ammonium Polyphosphate	$NH_4H_2PO_4+(NH_4)_3HP_2O_7$		
Liquid		10-34-0	100
Dry		15-62-0	100
Diammonium Phosphate	$(NH_4)_2HPO_4$	18-46-0	>95
Monoammonium Phosphate	$NH_4H_2PO_4$	11-48-0	92
Triple Superphosphate	$Ca(H_2PO_4)_2$	0-46-0	87
Ordinary	$Ca(H_2PO_4)_2 + CaSO_4$	0-20-0	85
Rock Phosphate	$3Ca_3(PO_4)_2 \cdot CaF_2$	0-32-0	<1

50% orthophosphate and 50% long-chain phosphate compounds.

Claims that polyphosphates are superior to orthophosphates exaggerate their ability to partially chelate or combine with certain micronutrients and hold them in an available form. Research has not shown that this difference increases yield or nutrient uptake in most soils. Polyphosphate ions react with soil moisture to form orthophosphates relatively rapidly (1-2 weeks). On almost all soils orthophosphate and polyphosphate fertilizers are equally effective.

Liquid versus dry. Compared to conventional dry fertilizers, liquid fertilizers are easier to handle, mix, and apply. However, despite claims to the contrary, research has shown that liquid phosphate does not improve fertilizer phosphorus availability or recovery when applied to the soil. It is the soil interactions that control phosphorus uptake, not the physical form of the fertilizer applied. Liquid formulations used as foliar applications are designed to deliver phosphorus directly to the plant. However, unpublished studies evaluating foliar phosphorus sources for cranberry have found no increase in tissue phosphorus in low tissue phosphorus fields with their use.

Determining the need for phosphorus fertilizer

Cranberry producers have to decide how much phosphorus fertilizer to apply each year. Apply too little and the vines won't be as healthy, resulting in poor growth and reduced yields. Applying too much costs time and money and may result in phosphorus leaving beds. While phosphorus is critical to cranberry growth and production, it is typically also the limiting factor for algae growth in surface waters. When phosphorus leaves cranberry farms it can be a substantial environmental pollutant. Being conservative in applications of phosphorus fertilizer will save input costs and will help to protect the environment. What information should a manager use to make the decision about how much phosphorus to apply?

Soil testing

Since phosphorus fertilizer is applied to the soil and is taken up by roots from the soil, it makes sense to test the soil to see how much phosphorus is there and available for cranberry roots to absorb. In theory this is a good idea. In practice there are problems.

Chemical soil testing is done by mixing the soil with an extractant solution, filtering out the soil, and then analyzing the aqueous solution for phosphorus. Chemical extractants used in soil testing are not designed to remove all of the phosphorus from the soil since not all the phosphorus in the soil is plant available. Instead they remove a fraction of the total phosphorus that is supposed to roughly equal the phosphorus that is plant available. In actuality there can be huge discrepancies between extractable phosphorus (an estimate of plant available phosphorus) and actual plant available phosphorus. Usually these tests are calibrated for annual agronomic crops such as corn and soybeans. They are best used on mineral soils.

Chemical soil tests were developed for annual cropping systems where all the nutrients required for plant growth must come from the soil each year. Cranberries are perennial. Substantial amounts of mineral nutrients remain in the dormant vines over the winter. These minerals are re-mobilized in the spring to support plant growth so that not all nutrients have to come from the soil anew each year.

In different parts of the world different materials are used to extract phosphorus from the soil. Many labs use the Bray-1 protocol. This dilute strong-acid extractant (a mixture of dilute hydrochloric acid and ammonium fluoride) dissolves and extracts phosphorus minerals including Ca-P, Al-P and Fe-P. In the field, these minerals do not readily dissolve in the soil solution. So cranberry soils can test high for Bray-1 phosphorus due to the large bound phosphorus pool. Despite this result, the vines are often phosphorus deficient.

A further complication in cranberry

soils is their usually high concentrations of iron and aluminum, particularly iron. Soils that are high in iron release phosphorus to the Bray extractants too easily, thus overestimating the amount of phosphorus available to plants. Research has shown that chemical soil tests for phosphorus are inaccurate if soil iron exceeds 200 ppm. Cranberry soils in North America often exceed 200 ppm iron.

It is possible for the plant to be low in a nutrient while the soil tests high. This is often the case for phosphorus and cranberry vines. Most cranberry soils are high in extractable phosphorus, but low in plant available phosphorus.

For perennial crops, soil testing is an indirect means of determining the need for fertilizer applications. Tissue testing is a more direct means.

Tissue testing

Tissue testing is the primary means used by cranberry growers to determine 1) the need for fertilizer, and 2) the efficiency or efficacy of previous fertilizer applications. Guidelines are available for how to collect and interpret cranberry tissue tests (Davenport et al. 1995).

Some have questioned the timing recommended for tissue testing, indicating that it is then too late to make remedial fertilizer applications. Research determined that the August-September time period was best for stability of most nutrients. Cranberry tissue standards are therefore based on this sampling time for consistency. While this suggested timing is too late to modify fertilizer use for the current crop year, it is not too late for planning the coming crop year.

When you take a tissue sample in August or September of one year, the results will guide your spring fertilizer program for the next crop year. Generally, fertilizer applied in this year benefits next year's buds rather than this year's crop. This year's crop was fed last year. There is good evidence that fertilizer applied in the current year has most of its impact on the following year crop. The cycle for producing cranberries is a 16 month cycle, not a 5 month cycle.

The tissue test results don't tell you exactly how much fertilizer to apply. They tell you if the plants are in the deficient, low, sufficient, high, or excessive range. You must supplement this information with your knowledge of previous fertilizer applications, previous tissue test results, vine vigor, yield, age of the bed, cultivar, etc. When combined, this information can give you a pretty good idea if you need to alter your fertilizer program for the coming year.

Making the phosphorus choice

Choose the N-P-K ratio in your fertilizer depending on the phosphorus status of the plant and soil. If phosphorus is normal in the tissue test, a ratio of no more than 1N:2P is recommended. If soil and tissue phosphorus are low, increase the phosphorus in the material to a 1:3 or greater ratio with nitrogen. Foliar phosphorus may also be used pre-bloom if tissue tests are low but results are not assured.

Choose your fertilizer rate based on nitrogen needs but apply no more than 20 lb/A actual P per acre per season (≈45lb/A P_2O_5).

Phosphorus (P) Decision Guide

NO MORE than 20 lb/a P recommended (≈45 lb/a P_2O_5).

Make site specific decisions based on the information below.

Test results	*Action recommended*
Tissue test P normal (0.1-0.2%)	Apply P in your N-P-K fertilizer, no more than 1:2 ratio (N:P)
Soil and tissue test P low (tissue <0.1%, Bray soil <20 ppm)	Use an N-P-K fertilizer with higher P (1:3 or 4 ratio N:P)
Tissue P low, soil P ok (tissue <0.1%, Bray soil >20 ppm)	Add 2-4 lb/A foliar P (pre-bloom)
P excessive in soil (Bray soil >80 ppm)	Avoid N-P-K with high P (1:1 ratio recommended N:P)

For more information:

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Authors: *Teryl Roper*, Professor, University of Wisconsin-Madison; *Joan Davenport*, Associate Professor, Washington State University; *Carolyn DeMoranville*, Director Cranberry Experiment Station, University of Massachusettes; *Sebastien Marchand*, Quebec; *Art Poole*, County Educator, Coos County Oregon, Oregon State University; and *Kim Patten*, Associate Professor, Washington State University.