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CRANBERRY FRUIT ROT PLAYERS IN 2005

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Cranberry fruit rot is caused by a complex of at least 12 and perhaps as many as 15 to 20 different species of fungi in Wisconsin. In 2005 two fungi were especially important: species of *Colletotrichum*, which causes bitter rot, and *Phyllosticta vaccinii*, which causes early rot.

Colletotrichum (bitter rot)

Various species of this fungus have gained importance in Wisconsin in recent years. For example, in a survey of cranberry marshes in central Wisconsin in 1998 through 2000, we rarely encountered it, but since about 2002 it has affected 15 to 40 percent of fruit in some plantings, including Stevens beds. The reasons behind this are not known but may be related to a series of relatively warm winters that allow the pathogen to overwinter at high levels. Bitter rot tends to show up late in the season (mid September or later), but once the rot is detected, the decline in fruit quality is rapid. Beds can look good one week, and have 15% or more rot just a week or so later.

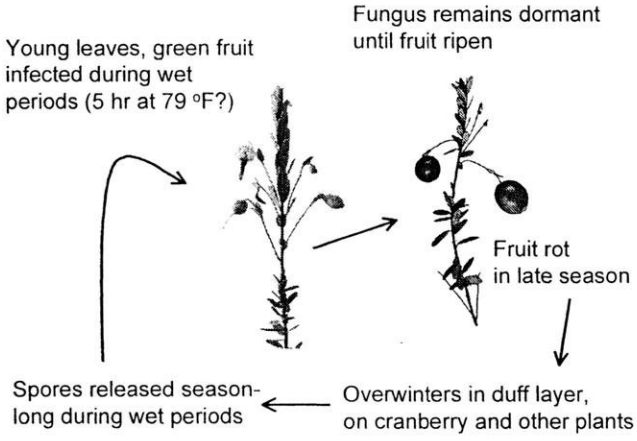

Figure 1. Proposed disease cycle for bitter rot, caused by species of *Colletotrichum.*

Disease cycle for bitter rot. Details of the disease cycle are not well understood, but are proposed in Figure 1 and as follows. The fungus overwinters in the duff layer, and on cranberry vines and other plants. This pathogen is not specific to cranberry, but rather affects many woody plants and weeds. Spores are released starting when shoot growth resumes in the spring and continue to be released season-long during rainy periods. Wind-driven rain and splashing rain spread spores. Young leaves and young, green fruit are most susceptible. Studies have not been done on cranberry, but on apple, species of *Colletotrichum* can infect after five consecutive hours of leaf wetness at 79 °F. Infection

would take a longer duration of wetness at higher or lower temperatures. Rather than rotting green fruit shortly after infection, the fungus goes dormant or "latent" for several weeks. Then, when fruit begin to ripen, the fungus comes to life again, growing quickly and rotting fruit.

***Phyllosticta vaccinii* (early rot)**

Early rot is a cranberry disease that causes leaf spots, blossom blast, premature leaf drop, and fruit rot. Early rot is caused by the fungus *Phyllosticta vaccinii.* A related fungus, *Phyllosticta elongata*, causes a minor berry speckle symptom and is common in healthy cranberry plants. Early rot is so named because the disease starts rotting fruit relatively early compared to other fungal pathogens (e.g., in August vs. September). By late August, early rot appears on a berry as a soft, watery spot, usually with a distinct margin. The spot is often lighter in color than the healthy tissue surrounding it. Sometimes, but not always, dark concentric rings give the spot a bull's eye appearance.

Historically, early rot has been very important in New Jersey, moderately important in Massachusetts, and rare in Wisconsin. In August and September of 2005, however, early rot was found at four sites on the variety HyRed and in established plantings adjacent to HyRed. It was also detected at one site on vines from an out-of-state breeding program. *P. vaccinii* thrives at temperatures of 84 °F or greater. The unusually warm summer of 2005 probably favored growth of this fungus and also stressed cranberry plants. Plantings with a sparse canopy or with pockets of poor growth are especially susceptible to early rot, because the temperature within the canopy is high.

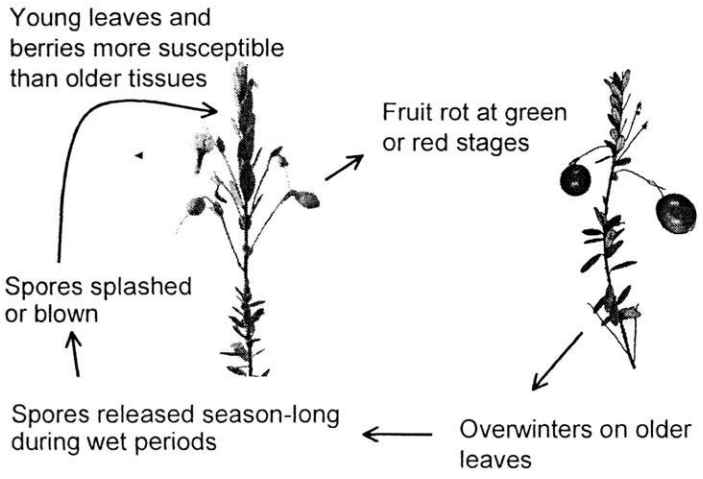

Figure 2. Proposed disease cycle for early rot, caused by *Phyllosticta vaccinii.*

Disease cycle for early rot. Details are not well understood, but a proposed disease cycle is illustrated in Figure 2. *Phyllosticta vaccinii* probably overwinters on living cranberry plants rather than in the duff layer or soil. Spores are released beginning in spring and continuing season-long during wet periods. Wind-driven rain and splashing rain droplets spread spores. Young leaves and berries are more susceptible to infection

than older tissues. Unlike *Colletotrichum*, which undergoes a long latent period, *Phyllosticta vaccinii* starts rotting fruit while they are green and continues until harvest. In addition to cranberry, *Phyllosticta vaccinii* infects blueberry and possibly related plants in the genus *Vaccinium*; however, it is not known to infect weeds common in Wisconsin cranberry beds. Transfer of spores on feet or machinery is possible if vines are wet. However, spread of the disease requires not just movement of spores but also that the plants are susceptible. Therefore, the risk of spreading the disease is probably greatest when there are young, susceptible tissues present. Movement of cranberry vines for propagation can spread the disease among beds on a marsh and over greater distances (e.g., between states).

Control of bitter rot and early rot

Cultural practices

- Since the pathogens that cause bitter rot and early rot overwinter and persist on vines, do not establish plantings with vines from beds with a history of rot problems.
- On hot summer days, vines might benefit from sprinkling to reduce heat stress. It is not known how long vines must remain wet in order for fruit rot pathogens to infect. However, sprinkling for 15- to 20-minute intervals on hot, breezy, sunny days does not provide a long enough period of wetness for most fungi to infect.
- Do not irrigate in the evening, as vines will remain wet for several hours. The prolonged wetness will increase fungal infection.
- Clean vines from beaters and other equipment before moving between beds.
- Wear washable boots if walking in a bed known to have rot problems, and disinfect boots with dilute bleach (1:10 dilution) or other disinfectant before entering other beds.
- Avoid excessive nitrogen fertilization. Nitrogen causes tissues to be succulent and soft, thereby making them more susceptible to infection. Over-fertilization also increases canopy density and causes foliage to stay wet for longer periods.

Chemical control

- Most research on fruit rot control with fungicides has looked at the fruit rot complex rather than individual pathogens such as *Colletotrichum* or *Phyllosticta vaccinii*. Nevertheless, the following practices are effective in the eastern U.S. where fungicides are used every year to manage fruit rot. The available fungicides and relevant comments:

  Bravo: Effective but can be phytotoxic in low spray volume and/or if applied on days when the canopy temperature reaches 90 °F. Phytotoxicity includes browning of petals and red flecks on fruit. The fruit flecks become almost invisible once the fruit turn red. In some trials Bravo has reduced yields, presumably from burning flowers. Pre-harvest interval of 50 days.
  Mancozeb (e.g., Dithane): Moderately effective; reduces fruit color if applied during bloom or to fruit. Pre-harvest interval of 30 days.
  Abound: Reduced-risk fungicide; inconsistent performance in fruit rot trials. Effective against cottonball, however, and does not appear to be phytotoxic even when applied to flowers. Pre-harvest interval of 3 days.

Copper: Marginally effective at best. Some formulations are accepted by organic certification programs. Exempt from pre-harvest interval.

- Timing of fungicide applications dramatically affects results! Fungicides should be applied during bloom and/or early fruit set stages for best results. The fungi that lead to fruit rot infect when fruit are small and green.
- At a site where early rot is a problem, it might be desirable to protect new, non-bearing vines. If leaf infection is prevented, *Phyllosticta vaccinii* will not be able to produce spores that infect fruit. The only fungicides allowed for application before bloom are some copper compounds (which probably do not provide much benefit) and chlorothalonil (available by 2ee or 24C special labels). Bravo (chlorothalonil), may be applied a maximum of three times per season.

MANAGING CRANBERRY TIPWORM, WITH REFERENCE TO 2005 INSECTICIDE TRIALS

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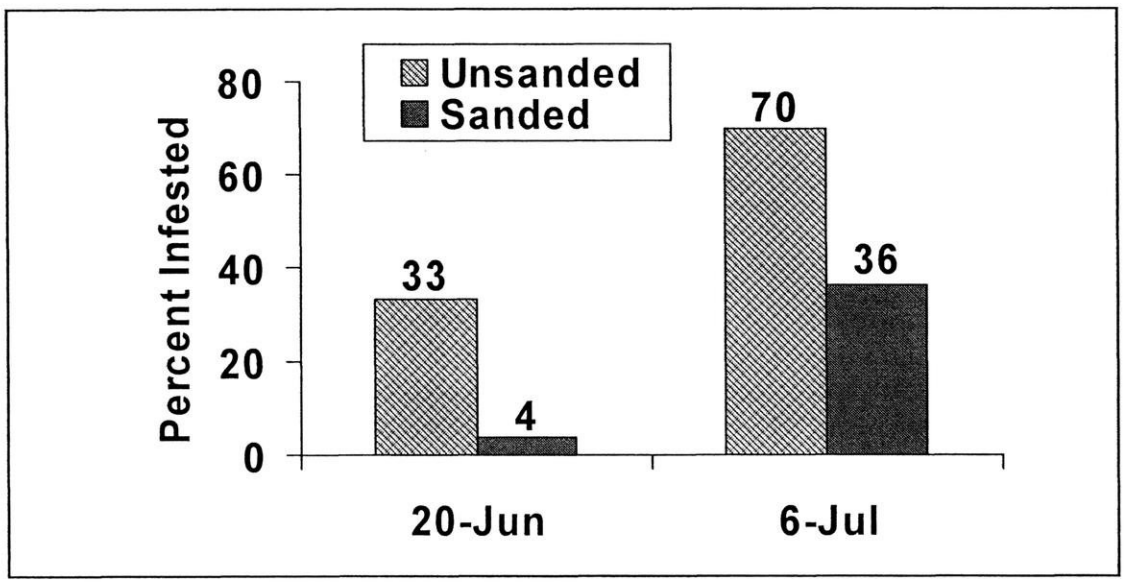
Introduction. Cranberry tipworm has long been considered a pest of commercial cranberry production. The significance of its injury varies with location. In areas with a long, warm growing season, plants often compensate for damage without loss of yield. In more northern growing areas with a shorter growing season, plants are less able to compensate, resulting in yield loss the subsequent year. Insecticides registered for tipworm control include the organophosphates azinphosmethyl (such as Guthion®), diazinon, and phosmet (Imidan®). The first two of these products are the standards used by the industry. We have not previously had data regarding the efficacy of phosmet. The effectiveness of other products is unknown. Uses of azinphosmethyl and diazinon are likely both soon to be cancelled. The purpose of this paper is to give a brief overview of life cycle and damage of tipworm, summarize current control recommendations, and discuss results of our 2005 insecticide trials.

Life Cycle and Damage. Cranberry tipworm is a tiny midge, about 2mm long (about 1/10 the size of a mosquito). There are generally 5 generations per year, with the first three being the most important and most abundant. Females lay eggs in the tips of actively growing vegetative stems, usually avoiding stem tips with flower buds. They are very abundant in recently-mowed beds, as well as in over-fertilized beds with rampant vegetative growth. The tiny larvae feed at the apical meristem, eventually killing it. This results in secondary branching and these secondary stems can be reinfested by subsequent generations. Late-season damage results in secondary stems that are vegetative rather than fruitful in the following growing season, thus reducing yield. Although tipworm is common in Massachusetts, researchers there have concluded that it does not cause economic losses. However, further north in Maine, losses attributed to tipworm can be substantial. Many growers in central Wisconsin do not consider it a significant pest because of new stem production by injured plants. However, growers in northern Wisconsin have attributed significant yield losses to this insect. Our research conducted in the late 1990s confirmed yield losses in the Manitowish Waters area, where only 9% of damaged terminals flowered and fruited the following year. In such cases, controls are warranted.

More detailed information, including color pictures, on tipworm biology and damage can be seen at the website
http://www.hort.wisc.edu/cran/mgt_articles/articles_pest_mgt/insects/profiles_insects/TIPWORM.pdf

Control Options. Winter sanding is an effective method of controlling tipworm. Tipworm pupae overwinter in the debris beneath cranberry vines, and a layer of sand 2-:" deep covers the tiny insects and the fragile adults are not able to dig through this layer in spring. Results of one of our sanding studies are shown in the following graph.



In this study, sanded and unsanded plots were arranged in broad strips the length of the bed. Populations rose quickly because of the adjacent unsanded strips. This demonstrates the importance of sanding adjacent blocks of beds in the same year, to reduce the rate of reinfestation from unsanded beds. Regardless, tipworm is an abundant insect on cranberry farms, and reinfestation will begin to occur the year after sanding.

Azinphosmethyl and diazinon are both labeled and efficacious for controlling tipworm. The use of both products on cranberry is soon to be discontinued. Phosmet is labeled for tipworm control, but no previous trials had been conducted in Wisconsin. No other products are known to be effective. Because of tipworm's high reproductive capacity and short generation time, reinfestation of treated beds can occur quite quickly. It is recommended that growers target the first generation when the entire population is roughly in the same stage. The first application should be targeted toward the egg-laying period as both adults and young larvae are killed by the currently-available organophosphates. A second and even third application may be necessary to reduce large populations. These should be timed for the second and third flights (if the bed is not in bloom), respectively.

2005 Insecticide Trials. In light of the impending loss of the two primary insecticides used for tipworm control, in 2005 we conducted preliminary small-plot screenings of 17 insecticidal products, representing seven insecticide classes. Some of these products currently have cranberry registration; others do not. All products tested were known to be effective against one or more pests in the insect order Diptera (the flies and their relatives), which includes cranberry tipworm.

The trials were conducted on a bed of Ben Lear in the southern growing region. The bed was mowed for vines during the third week of April 2005. Our grower-cooperator applied Guthion to the entire bed on July 7, followed by an application of diazinon (but not to our plot area) on July 14. Plot size was 6x6 ft and each treatment was replicated four times. Materials were applied at high-end label rates with a CO_2 sprayer.

Three applications were made at 10 day intervals, on 19 and 29 July and 8 August. Terminals taken for evaluation were transported to our lab in Madison on ice and kept refrigerated until counted. Twenty terminals per plot were dissected under a microscope and the condition of the terminal and life stages of tipworm present were recorded. Insecticides evaluated are shown in the following table.

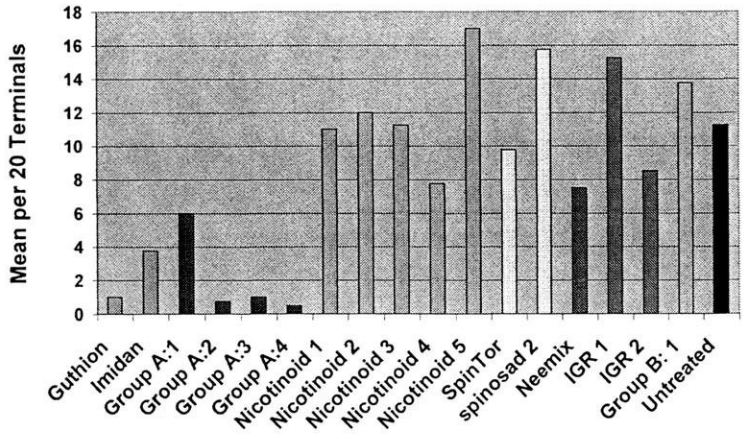
Insecticide Class*	Common Name*	Brand Name*
Organophosphate	azinphosmethyl	Guthion
	phosmet	Imidan
Group A	A:1	
	A:2	
	A:3	
	A:4	
Neonicotinoid	neonicotinoid 1	
	neonicotinoid 2	
	neonicotinoid 3	
	neonicotinoid 4	
	neonicotinoid 5	
Spinosad	spinosad	SpinTor
	spinosad	formulation 2*
Botanical (neem)	azadirachtin	Neemix
Insect Growth Regulator	IGR 1	
	IGR 2	
Group B	B:1	
Untreated control		

* In accordance with an agreement with the Wisconsin State Cranberry Growers Association, names of unregistered insecticides and unregistered pesticide classes are not provided.

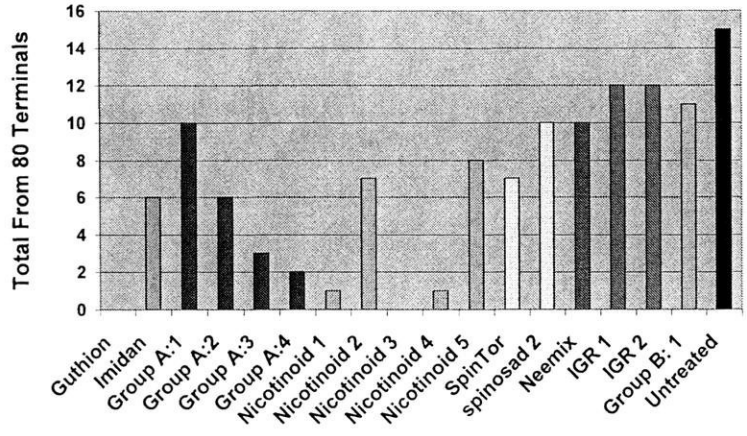
There was a heavy infestation of tipworm in the experimental bed. In our first (pre-treatment) sample, 1139 of 1440 terminals (79%) were damaged or infested. In our second sample, 78% of control terminals were infested or recently damaged, and 100% of control terminals had been injured during the season.

Representative results are presented in the following three graphs.

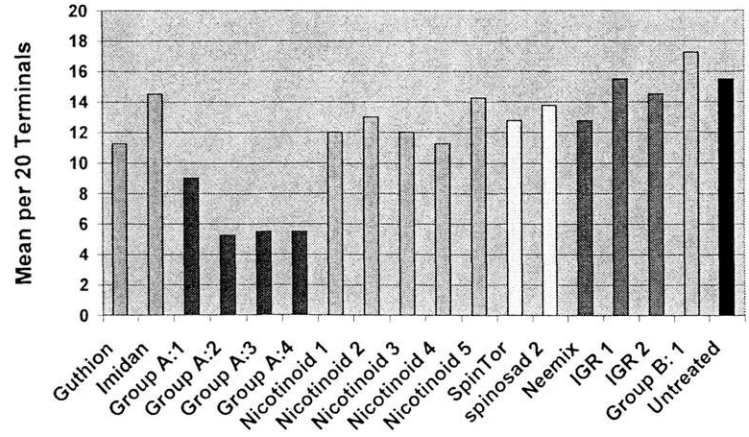
Number Eggs Per Sample - 17 August Sample



Total Live Larvae and Pupae - 17 August Sample



Damaged Terminals - 17 August Sample



In summary, Guthion performed well. Imidan performed less well. Several Group A products performed well, but registrants of these materials have thus far been unwilling to register their products on cranberry. Neonicotinoids had high egg counts but low larval counts (comparatively, but not statistically), suggesting that they do not control adults but may kill larvae. These results may relate to our small plot size, especially if the materials do not control the flying adults. The spinosads, insect growth regulators, Neemix, and Group B material all performed poorly.

In 2006, we hope to continue these trials. In particular, we will evaluate additional registered organophosphates and carbaryl, and re-evaluate the neonicotinoids using larger plots.

OPTIMIZING GLYPHOSATE WICK-WIPING IN CRANBERRY PRODUCTION

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Glyphosate, sold as Roundup and several other trade names (not all registered on cranberry), is one of few herbicides in cranberry production that will control perennial weeds. However, growers report that weed control when wick-wiping can be quite variable. Several factors should be considered to optimize the use of glyphosate in wick-wiping, including water source and condition, application timing relative to weed growth stage, and adequate weed coverage, uptake, and translocation. Additionally, glyphosate-resistant weeds have been observed in some cropping systems. The factors that favor resistance development in cranberry production should be considered so that this valuable tool will be viable well into the future.

Glyphosate mode of action

The first step in efficiently using any herbicide is to gain a basic understanding of how the herbicide works. Glyphosate is rapidly taken up by shoots, stems, and leaves of emerged plants. The herbicide binds to soil, and therefore will not control weeds prior to emergence. Once the herbicide is absorbed by the above-ground tissue, glyphosate is translocated or moved in the plants "piping system" with carbohydrates. The "piping system" transports carbohydrates from roots to the above-ground growth in the spring and from the green tissue to the roots in the late summer and early fall.

The target site for glyphosate is the EPSP-synthase enzyme. This enzyme is involved in converting raw materials into amino acids that are the building blocks for protein. Seventy percent of the carbon captured by a plant flows through this one enzyme system. Glyphosate blocks the production of amino acids, and thus inhibits protein production. Glyphosate is considered a non-selective herbicide – it will severely injure or kill most plant species.

Optimizing herbicide performance relative to the seasons

The ability to control perennial weeds with glyphosate and other herbicides is based on the growth stage and time of year. In the spring, perennial plants export carbohydrates from roots to new shoots. During the summer, weeds assimilate energy by capturing sunlight with foliage. In the late summer, from about the first bloom on a perennial weed to the first hard frost, carbohydrates from the energy captured during summer are translocated to the root system for storage. The optimal general perennial control strategy takes advantage of this seasonal cycling of energy within the plant. In the spring, limit new vegetative growth and eliminate new seedlings. In the summer continue to prevent new energy capture by limiting vegetative ("green") growth. The late summer and early fall provide a time to attack the root storage system by "tagging along" an herbicide with the carbohydrates that are moved below-ground from foliage. **Keep in mind, though, that the application timing must coincide with the pre-harvest interval and other timing restrictions for the herbicide!**

Considerations of the target weed that affect glyphosate performance

There are several factors involving the target weed that will affect herbicide performance. Although glyphosate is a translocated herbicide that can be "piped" to the target site, adequate plant coverage when wick-wiping is necessary for optimum control. The use of an appropriate spray-tracer can improve and ensure coverage. Herbicide penetration through plant leaves is also affected by weather conditions. Weed control can be reduced when glyphosate is applied during prolonged hot, droughty weather. In these climates, plants develop a thick, waxy leaf cuticle and shut the stomata or leaf openings, thus decreasing herbicide uptake.

Considerations of the spray carrier water that affect glyphosate performance

Minerals, organic matter and other dissolved solids in carrier water sources can affect glyphosate performance. Hard water contains high concentrations of calcium, magnesium and other ions. These ions can bind to the salts of some herbicides, such as glyphosate, and reduce the effectiveness of the herbicide by limiting plant uptake. The additives that can be used to overcome hard water vary by pesticide label, so be sure to check your particular formulation prior to use. Ammonium sulfate is a common additive that adjusts pH and binds hard water ions.

Organic matter and other dissolved solids in the carrier water will rapidly bind glyphosate, thus reducing plant uptake and weed control. This often occurs with water drawn directly from ponds and streams. Choose a clean water source for your carrier water.

Glyphosate resistant weeds

Glyphosate has been used in several cropping systems for many years, and until recently, resistance was not observed. However, in the past few years, resistance has been confirmed in 9 weed species worldwide and is suspected in others. Resistance has been observed in Palmer amaranth, common ragweed, hairy fleabane, horseweed, goosegrass, Italian ryegrass, rigid ryegrass, and buckhorn plantain. While resistance is still fairly rare given the extent of glyphosate use, the recent increase warrants careful observation and consideration of the factors that increase risk for resistance.

Unfortunately, several of the factors that increase the risk for resistant weed selection are common in cranberry production. Herbicide resistance is observed where the use of an herbicide or herbicide mode of action is repeated often, such as in a perennial cropping system. Resistance is also favored by a heavy reliance on a single herbicide to control target weeds, such as perennial weed wiping in cranberry production. Weed species that reproduce prolifically (primarily through seed production) are more likely to become resistant. Also, application systems where the herbicide rate is difficult to control, such as in wick-wiping, increases the risk for resistance development.

With this increased risk in mind, it is important to recognize the signs of resistance development. Resistant weeds should be managed similar to a new invasive weed species; early detection and eradication of a localized infestation is more feasible than containing a widespread population. Herbicide resistance in weeds is often confused with other factors that affect herbicide performance, such as misapplication (poor timing

or rate) or weather conditions before, during or after application. Consider the following questions if herbicide resistance is suspected:

1. Is it only one weed species that survived herbicide application, or are other species that are normally susceptible to the applied herbicide also not controlled? Multiple species surviving an herbicide application often suggests reasons other than resistance for poor control.
2. Is there an obvious pattern, such as a sprayer skip or poor herbicide coverage that could explain weed control failure? Weed resistance often occurs in irregular patches where seed spread from a plant that survived a previous herbicide application.
3. Are there herbicide symptoms on the surviving plants? Resistant plants often, but not always, show no symptoms related to the herbicide application.
4. Is there a record of repeated use of the herbicide mode of action, and has the rate required for adequate control increased over time?

Nitrate in Cranberry Irrigation Water- Initial Observations during the 2005 Growing Season

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Some Wisconsin cranberry growers with upland marshes have persistent problems with excess vine growth. The greatest vine growth is in areas where there is higher water input than the rest of the bed, particularly next to sprinkler heads and at joints in above-ground irrigation lines (Fig. 1). This problem is most prevalent in beds irrigated with water containing high levels of nitrate. Growers using surface water or groundwater influenced by vegetable production are most likely to have nitrate in their irrigation water.

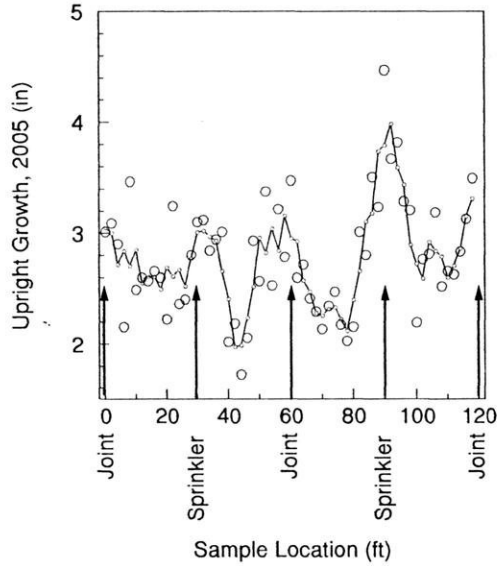

Figure 1. Current season upright growth as a function of position in the bed. Samples collected Dec. 2, 2005 in a transect along the location of the sprinkler line. Circles show average of 5 uprights sampled at each location; line is based on running average of 3 adjacent data points. Cultivar is Stevens.

Equivalent beds on this marsh with a different, low-N water supply do not show this pattern of vine overgrowth, indicating that water deposition alone is not responsible for the stimulation of vine growth.

As we all know, yield is depressed when excess nitrogen stimulates vine growth (Fig. 2). If nitrogen inputs for the bed as a whole are optimal, then the vines are "on the bubble" for response to nitrogen applications. Excess nitrogen will push them into excess vegetative growth. When irrigation water contains a nitrogen source, areas in the bed where water inputs are higher than average will receive higher than average levels of nitrogen.

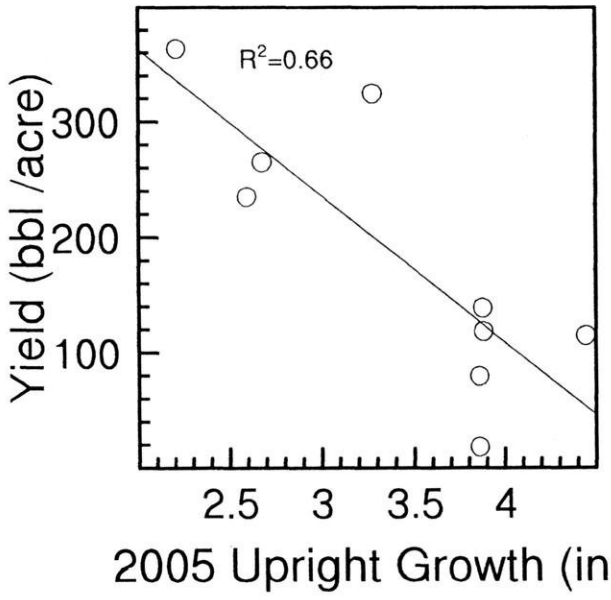

Figure 2 Relationship between current season upright growth (inches) and yield. Values based on berry fresh weight measured in 250 cm^2 quadrates from 4 different beds. Cultivar is Stevens.

To calculate irrigation water nitrogen inputs, we need to know 1) irrigation volumes (inches applied) and 2) nitrate concentration (parts per million (ppm) as nitrogen). The equation is: **pounds N per acre = 0.23 x inches water applied x ppm N.** Growers who had

commercial laboratory measurements of high-nitrate irrigation water reported values up to 9 ppm nitrate N. Between July and September 2005, we measured nitrate concentrations ranging between 0 and 4 ppm in irrigation water from these same marshes.

Using this relationship, we can calculate the predicted distribution of nitrogen inputs within a bed based on measurements of irrigation inputs. Irrigation uniformity in older systems can be poor, with very high levels of water adjacent to sprinklers. Data collected by Teryl Roper and Tod Planer on irrigation uniformity from an older system provides an example of the potential distribution of nitrogen inputs at different concentrations of irrigation-water nitrogen (Fig. 3A). Based on this irrigation-water distribution, at 1 ppm nitrate-N, 1 inch of irrigation, and 5-fold greater irrigation water around the sprinkler, the area around the sprinkler-head receives 2 lbs/acre more N than the rest of the bed (Fig. 3B). At 9 ppm nitrate, a level reported by some growers in spring-time irrigation water measurements, a single irrigation of 0.11 inch would deliver 2 lbs/acre N to the area around the sprinkler head (Fig. C).

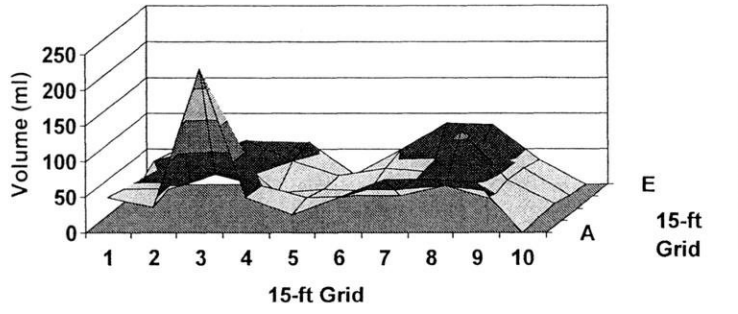

Figure 3A. Irrigation uniformity measurements. Peak inputs are adjacent to sprinkler heads. (Roper and Planer 2005 Cranberry School Proceedings)

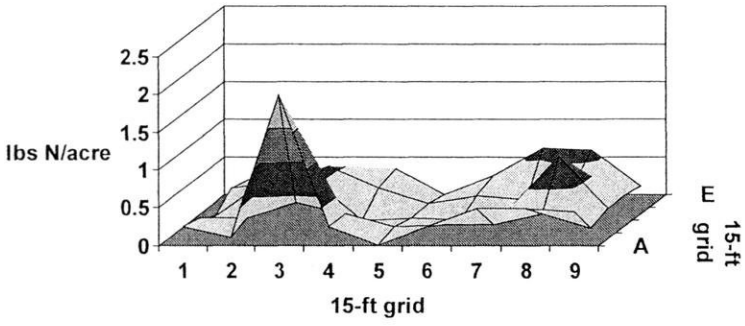

Figure 3B. Predicted nitrogen inputs from 1 inch of irrigation with water containing 1 ppm N.

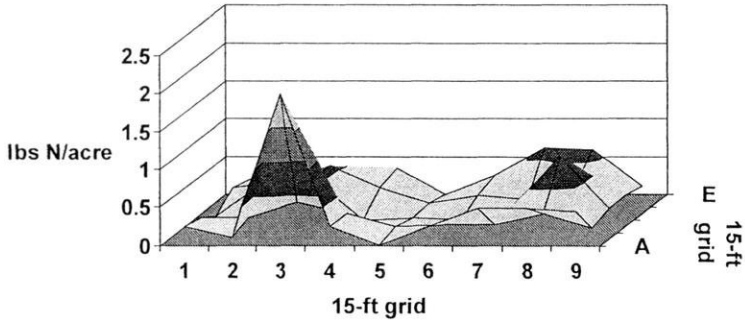

Figure 3C. Predicted nitrogen inputs from 0.11 inch of irrigation with water containing 9 ppm N.

We carried out trials of two kits for measuring nitrate in irrigation water in 2005. The kit from the Hach Company was less expensive ($59 for 50 tests) than the kit from Spectrum Technologies ($179), but required more time per analysis. Both are based on a chemical reaction that produces a colored product, with the color intensity linearly proportional to nitrate concentration. The Hach kit uses visual comparisons of sample color development with a color standard; the Spectrum Technologies kit uses an electronic photometer for analysis of sample color intensity. Each worked well, with grower measurements of irrigation water nitrate concentration very close to our laboratory measurements of the same samples (Fig. 4).

Ion exchange resin columns show promise for analysis of integrated N inputs in irrigation water. These resins are similar to those used in deionizing water, and can capture nitrate and ammonium in irrigation water flowing through them.

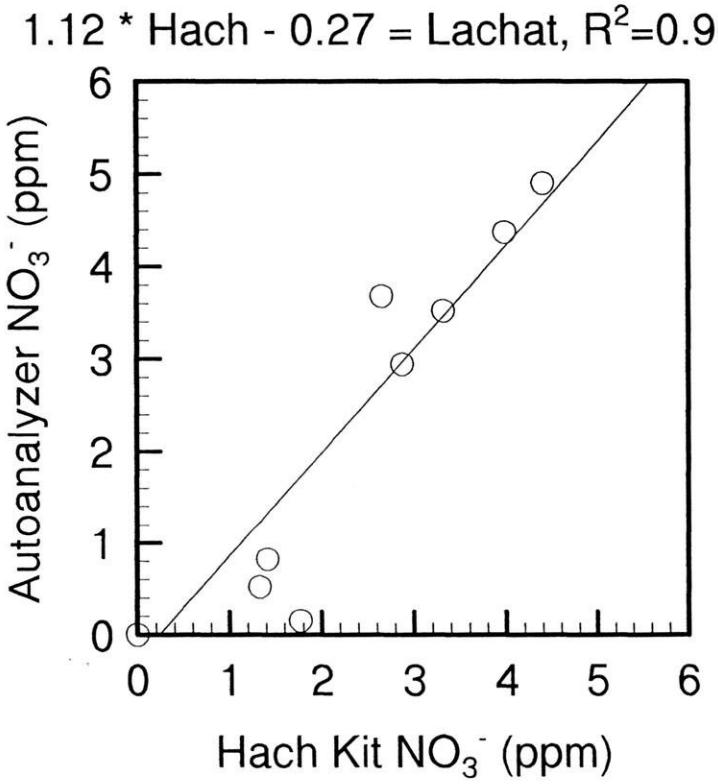

Figure 4. Grower measurements of irrigation water NO_3^- concentration vs. our laboratory measurements of irrigation water NO_3^- concentration. Samples were collected by growers, analyzed, and refrigerated for up to 4 weeks before our analyses.

The impact of excess vine growth stimulation by nitrogen-containing irrigation water depends upon the extent of yield depression and upon the area affected. In the bed sampled for Fig. 1, approximately 5% of the bed area had excess vine growth, with affected areas having predicted yields less than one third of the bed average.

There are several options for managing high-nitrate irrigation water that are worth considering. 1) Improving irrigation uniformity and reducing irrigation line leaks should make growth and yield more uniform, as both fertilizer N and irrigation-water N inputs would then be evenly distributed across the bed. 2) If multiple water sources are available, switching to a lower-nitrogen irrigation source should reduce excess vine growth. 3) Ultimately, this is a watershed-level issue. Improved nutrient management by vegetable growers and other non-point sources of nitrogen inputs to the watershed will provide the most reliable long-term solution to the problem.

Despite the evidence presented here that irrigation water containing nitrate may stimulate excess vine growth, nitrate is not recommended as a fertilizer for cranberry. Cranberry has much higher preference for ammonium. Nitrate would also be prone to rapid leaching, and would be rapidly lost from the rooting zone.

CRANBERRY IRRIGATION WATER MANAGEMENT

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Irrigation water management is the process of determining and controlling the volume, frequency, and application rate of irrigation water in a planned, efficient manner. A properly operated, maintained, and managed sprinkle irrigation system is an asset to a cranberry farm. Low-technology assessment methods and tools are available to assist the irrigation manager to determine maintenance, reconstruction, and replacement priorities and to operate the existing system to manage soil moisture to promote the desired crop response, optimize use of available water supplies, decrease non-point source pollution of surface and groundwater resources, and manage air, soil, and plant micro-climates.

Simple System Assessments and Maintenance

Determine Sprinkler Makes/Models and Spacing

- Generally, sprinklers on a given lateral line should be of the same model and contain the same nozzle size
- Having a variety of heads/nozzles causes variable [typically poor] uniformity, which results in variable frost protection and decreased pumping plant efficiency, while complicating irrigation water management—How much water are you actually applying?

Check for Nozzle Wear – use the shank-end of a high-speed drill bit

Check Operating Pressure

- Use a handheld pressure gauge with *Pitot* tube
- Check the first sprinkler or two on beds near the pump, far from the pump, and in-between—consider checking every other bed or every third bed if the sprinkler system is similar from bed to bed

Measure Sprinkler Output

- Use a small piece of hose, a bucket of known volume, and a stopwatch or watch with a second hand
- Compare measured output from worn nozzles to published/calculated values and consider replacing nozzles if measured output exceeds published/calculated output by ~0.5 gpm

Calculate Sprinkler Output and Average Application Rates

- Average Application Rate = $(Q \times 96.3) \div A$, expressed in inches/hour,
  where Q = sprinkler discharge (in gallons per minute),
  and A = distance between laterals (in feet) × distance between sprinklers (in feet)
- Rainbird™ calculator: http://www.rainbird.com/calculators/calculators.htm

Check for and Repair Leaky Pipelines

Determine Your Soil's Water Holding Capacity – submit a sample for testing or refer to published values

Detailed System Assessments

Determine Uniformity ("bucket test") and Estimate Application Efficiency

Uniformity vs. Efficiency

Application Efficiency (E_a) is the percentage of water delivered to the field that is used by the crop

- E_a is difficult to measure
- Potential E_a for a well managed system is perhaps 70% to 85%
- Actual E_a can be much lower…due to poor design (low uniformity) or poor management (over-application)
- To improve:
  - Improve uniformity (see below)
  - Maintain irrigation infrastructure (pump, pipelines, sprinklers)
  - Practice Irrigation Water Management

Distribution Uniformity (DU) is the percentage of the average application amount received in the least-watered quarter of the field

- Measured via catch-can test or estimated using a computer program, such as SPACE Pro™
- Spatially variable within a field and, probably more so, across beds on a given pump
- Influenced by design (spacing, heads, nozzles, risers, etc.), operating pressure, and condition of irrigation hardware (nozzle wear, leaky mainline, etc.)
- Wisconsin cranberry systems are variable: from DU<50% to DU>85%
- To improve:
  - Replace worn nozzles
  - Repair leaky pipelines
  - Operate at the proper pressure for your system
  - Replace or retrofit the existing system

Key Points:

- ✓ Uniformity and efficiency are not synonymous
- ✓ High uniformity does not ensure high efficiency…management is the key
- ✓ Poor uniformity limits potential application efficiency and makes management more challenging

NRCS Standards for New Irrigation Systems

DU ≥ 76% and Christiansen Coefficient of Uniformity (CU) ≥ 85%

- 50' x 60' systems can meet this requirement
- 50' x 40' or 40' x 50' routinely meet this requirement

Velocity of flow in pipelines must be designed to not exceed 5 ft/sec

All NRCS Conservation Practice Standards can be downloaded from the Electronic Field Office Technical Guide (eFOTG), which can be found on the Wisconsin NRCS website: http://www.wi.nrcs.usda.gov/

Additional Information

Procedures for conducting a detailed assessment of your irrigation system are available from the Wisconsin Cranberry Crop Management Library (http://www.hort.wisc.edu/cran/). Follow the "Conservation Planning" link to the "Irrigation Water Management" section. Consider contacting an NRCS technical specialist for assistance with conducting an assessment of your irrigation system and developing an irrigation water management plan.

NUTRIENT MANAGEMENT FOR PERENNIAL FRUIT CROP PRODUCTION

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Hopefully before the end of 2006, the Wisconsin Department of Agriculture, Trade and Consumer Protection's (DATCP) Board will approve a rule related to nutrient management on farms. Current rules are mostly based on nitrogen and can be inconsistently implemented from county to county. This rule would incorporate the September 2005 Natural Resources Conservation Service's 590 nutrient management standard based on nitrogen and phosphorus. DATCP adopted the current rules in 2002 as part of a redesign of state nonpoint pollution abatement programs mandated by the Legislature. DATCP proposes to incorporate the updated federal standard in state nutrient management rules to help prevent manure and phosphorus runoff and improve water quality. This will also to help ensure that manure is applied in a cost-effective and environmentally sound manner. It will also reduce fish kill and well contamination risks. Adopting this rule amendment will fulfill DATCP's nonpoint-rules commitment to keep Wisconsin rules consistent with federal standards.

Cost sharing

Updating ATCP 50 Wis. Admin. Code will allow state cost sharing to be provided to county land conservation departments, and then to farmers, for implementing the September 2005, 590 nutrient management standard. Under this existing DATCP rule, all farmers who apply manure or commercial fertilizer to cropland (not just livestock operators) must implement a nutrient management plan. This requirement took effect on January 1, 2005 in certain watersheds, and will take effect on January 1, 2008 elsewhere. However, state law makes enforcement contingent on cost sharing for farms not regulated by other means. Enforcement is therefore limited by the availability of cost-share funds and state and local authorities. Farms that must comply regardless of cost-sharing include those holding a pollution discharge elimination system permits from the Department of Natural Resources, farms that claim farmland preservation tax credits, and farms that are required by local ordinances to have permits for manure storage facilities or livestock facility expansions. Current DATCP cost-share funding levels make it possible to target about 20,000 acres per year starting in late 2006 (less than 1% of Wisconsin's crop acreage). These cost-share funds will be mainly targeted where runoff has caused fish kills or well contamination or at priority farms noted in the county's *Land and Water Resource Management Plan.*

Counties have *Land and Water Resource Management Plan* to promote compliance with farm conservation requirements (see s. ATCP 50.12). Counties will seek voluntary compliance and will offer information, cost-sharing and technical assistance to help landowners comply. As a last resort, a county may seek enforcement action against a landowner that refuses to implement required conservation practices. A county may not seek enforcement action until it complies with applicable cost-sharing requirements under s.

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ATCP 50.08. A county may pursue any of the following enforcement options, as appropriate:

- The county may suspend a violator's eligibility for farmland preservation tax credits (see s. ATCP 50.16(6)).
- DNR may issue a notice of discharge, requiring a violator to obtain a pollution discharge permit from DNR (see ch. NR 243).
- The department of justice or a district attorney may file a civil forfeiture action against the violator (see s. 281.98, Stats. that authorizes penalties not less than $10 nor more than $5,000 for each violation).
- The county, town, city, or village may take action to enforce its own ordinance, if any.
- County compliance procedures should be consistent with ss. ATCP 50 and ss. NR 151.09 and 151.095. A county should spell out compliance procedures in its land and water resource management plan, as provided in s. ATCP 50.12(2). The DATCP and DNR will work with counties to develop suggested guidelines for county compliance programs.

Nutrient management planning requirements

A nutrient management plan must be prepared or approved by a qualified nutrient management planner. A farmer may prepare his or her own plan if the farmer has completed a DATCP-approved training course within the preceding 4 years, or can prepare a plan that complies with the 590 standard. A nutrient management plan must comply with the NRCS 590 nutrient management standard. A nutrient management plan must identify the lands on which the operator will apply nutrients. The plan must also include the source, rate, timing, and method of application for all major nutrients (N, P, and K).

Changes to 590 - DATCP and NRCS held joint public hearings on the NRCS nutrient management standard that is incorporated in this rule. Some of the changes to the standard are:

- Nutrient applications prior to establishment of perennial fruit crops are determined by soil tests recommendations from UW Publication A-2809 "Soil Test Recommendations for Field, Vegetable and Fruit Crops". A soil test laboratory, certified by DATCP, must conduct the soil tests. Established perennial fruit crops should base nutrient recommendations on plant tissue analysis results and perennial fruit crop publications referenced in the 590 standard. These references are:
    - Cranberry Tissue Testing for Producing Beds in North America (1995) Davenport et al., Oregon State Univ. Ext. Serv. Pub. CM8610.
    - Mineral Nutrition for Fruit Crops, Roper, Univ. of Wisconsin Dept. of Horticulture Pub.
    - Nitrogen for Bearing Cranberries in North America (2000) Davenport et al., Oregon State Univ. Ext. Pub.
    - Phosphorus for Bearing Cranberries in North America (2004) Roper et al., Univ. of Wisconsin Ext. Pub.
    - University of Wisconsin Soil and Forage Analysis Lab Sampling for plant analysis: http://uwlab.dyndns.org/marshfield/ (Click on Lab procedures and then plant analysis).

- If applying manure or other organic byproducts anytime during the crop rotation, then the standard allows P assessments using the PI or soil test P levels to determine P application rates over a maximum 8-year crop rotation. The Wisconsin P Index is a tool to rank fields on their potential to deliver phosphorus to surface water bodies. The PI is available on the web from ***http://www.snapplus.net*** as part of the SNAP-Plus software. Perennial fruit crops are not currently part of this software.
- The conservation plan must address cropping practices that control sheet and rill erosion to tolerable levels (T) and provides treatment of ephemeral soil erosion. Sheet and rill soil erosion calculations shall be based on current NRCS erosion prediction technology. Contact your local conservation department for assistance in developing a current conservation plan.
- Prohibits winter applications of N and P commercial fertilizer except on grass pastures and on winter grains where not prohibited.

References

USDA Natural Resources Conservation Service. 2005. Nutrient Management Code 590 Conservation Practice Standard, NRCS, WI September 2005.

WI Department of Agriculture, Trade and Consumer Protection. ATCP 50 Wis. Admin. Code 2002 and Proposed Final Draft ATCP 50 Wis. Admin. Code, October 24, 2005.

PHOPSHORUS RESEARCH IN MASSACHUSETTS

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Large scale field study

In 2001, with funding from the Department of Environmental Protection, a study of six cranberry bogs was initiated in Massachusetts. Two primary questions were posed: 1) How much P (and N) enters and leaves cranberry bog systems on an annual basis?; and 2) How does reduction in P input affect the system, horticulturally and environmentally. In addition, as we developed the nutrient budget, we tried to determine which activities had the most impact on the movement of P.

The six study bogs were assigned as pairs. Each pair had similar soil characteristics and grower management but one from each pair was identified for modification of P input during the project. None of the bogs in this study were 'flow-through', that is, there was no perennial streams passing though the production area. Data collection was conducted from 2002-2004 during which time we measured water volumes and analyzed P and N concentrations in the water. As a result, we could calculate partial budgets for N and P for each 'Cranberry Year' -- May 15 to May 15. These were not complete budgets since we did not collect and analyze groundwater in this study.

The water measurements confirmed that total annual water inputs were in the range of 8-11 acre feet at all sites and years. Between 1/3 and 1/2 of all input was rainfall and 1/4 to 1/2 of inputs were floods. Floods accounted for ~65-75% of all grower-controlled water inputs in the study bogs.

In the second and third year of the study, fertilizer P inputs were reduced at some sites with minimal if any impact on yield (Table 1). To account for possible biennial trends, we compared the yield in the two years of reduced P to that in the prior two years.

Table 1. Yield and fertilizer P at bog study paired sites.

	Average Yield		**Fertilizer P (lb/acre)**		
Site	**2001-2002**	**2003-2004**	**2002**	**2003**	**2004**
EH	111	146	17.8	14.3	5.6
PV	129	158	24.8	22.3	17.3
BEN	131	133	20.0	16.1	17.4
WS	108	101	20.0	18.3	16.7
MK	187	178	28.7	20.0	21.1
ASH	143*	214	35.4	32.3	27.9

*2001 crop as ASH reduced by insects

At the EH and MK sites, P rate was substantially reduced during the project, yet yield remained unaffected. The concentration of P in the discharge outlet water of the bog with the greatest P fertilizer reduction declined after two years of reduction (Table 2).

Table 2. P concentration in samples taken from outlet flumes (average value for all flood discharge samples collected within each year).

	mean ppm P in flood discharges		
Site	**2002**	**2003**	**2004**
EH	0.377	0.424	0.237
PV	0.384	0.439	0.528
BEN	0.291	0.158	0.165
WS	0.296	0.153	0.343
MK	0.100	0.170	0.118
ASH	0.109	0.127	0.147

The sites with the lowest P concentration in flood discharge were the MK and ASH pair. These were mineral soil bogs, while the other 4 sites were older beds on organic (peat) based soils.

In general, on a per acre basis, there was more P in the water leaving the bog than in that entering the bog, opposite from what we found for nitrogen. However, when all inputs (rain, irrigation, floods, fertilizer) and outputs (discharge water, crop, biomass produced) are included in the budget, P output is negative. That is, P is retained in the

Table 3. P budgets for a pair of organic base bogs, one of which had reduced P fertilizer in 2003 and 2004. Data shown are P load in discharge, net discharge (minus incoming load) and the total budget when all inputs are subtracted from all outputs.

	lb/acre/yr				
	phosphate (dissolved)		Total P		
Site/year	**in discharge**	**minus incoming**	**in discharge**	**minus incoming**	**Total budget**
EH 2002	1.11	1.02	1.64	1.15	-13.32
EH 2003	1.82	1.78	2.84	2.31	-8.64
EH 2004	0.82	0.74	1.09	0.53	-1.19
PV 2002	3.53	2.67	4.58	2.94	-18.53
PV 2003	3.68	2.99	5.14	3.22	-15.62
PV 2004	3.20	2.62	3.92	2.16	-10.92

system. Table 3 shows a comparison of the water budget and total budget at two organic base sites, one of which had reduced P fertilizer in 2003 and 2004. A comparison of the EH site in 2002 vs. 2004 shows that the net discharge in water decreased by half as fertilizer P inputs were reduced.

A comparison of the mineral soil bog pair is shown in Table 4. At the reduced fertilizer site (MK) in 2004, the P load in the discharge was less than that in incoming water. In general the P discharge from the mineral soil bogs was less than that from the organic bogs. Some of this related to lower water volumes discharged at the surface outlet.

Table 4. P budgets for a pair of mineral soil bogs, one of which had reduced P fertilizer in 2003 and 2004. Data shown are P load in discharge, net discharge (minus incoming load) and the total budget when all inputs are subtracted from all outputs.

	lb/acre/yr				
	phosphate (dissolved)		Total P		
Site/year	in discharge	minus incoming	in discharge	minus incoming	Total budget
MK 2002	0.49	0.35	1.02	0.01	-24.25
MK 2003	0.69	0.32	1.42	0.05	-16.12
MK 2004	0.94	0.01	1.66	-1.10	-17.81
ASH 2002	0.51	0.45	1.09	0.24	-32.32
ASH 2003	0.40	0.26	1.32	-0.56	-29.2
ASH 2004	1.09	0.95	1.97	0.17	-22.86

As mentioned earlier, yield was not affected by fertilizer reduction in this study. A comparison of soil and tissue analyses from the sites showed that soil P remained high at all sites for the duration of the study, while tissue P remained in the mid-normal range (0.13-0.15%). With these results, one would not expect P to be a factor limiting yield. In order to determine that long-term impacts of P reduction. The EH-PV bog pair will continue to receive differential P inputs and the effects on yield and harvest flood quality will be determined.

Plot scale research

Since 2000, research into effects of P rates has been conducted in Massachusetts and Wisconsin. While N and K rates are held constant in the plots, P rates varied from 0 to 30 lb/acre actual P. The rate range for the study was based on previous research. In Wisconsin, Greidanus and Dana (1972) compared rates of 0, 10, and 30 lb/acre with deficiency resulting at 0 and 10 but not at 30 lb/acre. In New Jersey, Eck (1985) compared rates from 5 to 80 lb/acre and showed optimum yield results with rates between 20 and 40 lb/acre. In a study in Massachusetts (DeMoranville and Davenport, 1997), plots receiving no P had significantly lower yield than those receiving 20, 40, or 60 lb/acre but there was no difference among the non-zero rates.

Through the end of the 2005 season, there were no treatment effects of the rate of phosphorus fertilizer applied on total yield in any year in the well established Wisconsin plots (Table 5). Yield varied significantly between years, underscoring the biennial bearing nature of individual cranberry uprights. After 5 years of treatment, tissue P varied in the WI plots with lowest P in the controls and highest in the 30 lb P plots receiving slow release fertilizer. However, all were above 0.1%, the critical level which may account for the lack of yield effects.

Table 5. Yield and tissue P in sand based cranberry beds treated with different rates of phosphorus fertilizer for five years in Wisconsin. n=8 for yield, n=4 for tissue P.

Treatment	Yield (g/ft^2)				
Rate (lb P/a)	***2001***	***2002***	***2003***	***2004***	***2005***
Control	116.7	274.5	215.9	128.7	179.4
5	116.7	248.9	230.1	140.0	226.2
10	112.2	273.3	268.6	117.6	199.1
15	118.9	276.5	221.9	126.2	208.6
20	126.9	242.7	269.4	157.4	224.0
30	130.3	261.6	216.6	131.3	198.7
Significance	ns	ns	ns	ns	ns

Treatment	Tissue P (% dry weight)			
Rate (lb P/a)	***2001***	***2003***	***2004***	***2005***
Control	0.127 f	0.126 f	0.105 d	0.102 b
5	0.143 cdef	0.131 ef	0.127 bc	0.102 b
10	0.144 cdef	0.138 def	0.126 bc	0.112 ab
15	0.145 bcdef	0.157 bcd	0.130 bc	0.120 ab
20	0.147 bcdef	0.142 cdef	0.131 bc	0.124 ab
30	0.170 ab	0.143 cdef	0.142 b	0.121 ab
Within columns, values sharing a letter are NOT statistically different				

In the Massachusetts plots that were treated for 3 years (Table 6), we found year to year variability but no yield differences attributable to P rates. Plants from all plots showed sufficient tissue P at the end of three years and soil P in the high range based on the Bray test. More recent plot studies in Massachusetts are showing similar results as regards yield. However, in 2005, some of the lower rate plots are showing tissue P just below sufficient.

Based on previous research, we know that some P input is better than no P in supporting production. However, in the current plot studies we have found few differences in yield at the P rates applied, including no P. One difficulty has been showing a soil and/or tissue response that increases with increasing P addition. In addition, the controls have not shown deficiency as yet, making calibration impossible using these plots. We continue to study the long-term effects at these sites.

Table 6. Yield, tissue P, and soil P in sand based cranberry beds treated with different rates of phosphorus fertilizer for three years in Massachusetts. n=5.

P rate lb/acre	Location 1 yield (bbl/acre)			Location 2 yield (bbl/acre)		
	2000	***2001***	***2002***	***2000***	***2001***	***2002***
0	239	163	79	344	113	222
2.5	212	146	94	304	93	219
5	263	94	56	326	80	183
10	230	187	93	274	91	244
15	247	150	93	307	95	191
20	278	123	118	343	68	224
30	253	125	69	339	81	193

P rate lb/acre	Location 1 % P in tissue		Location 2 % P in tissue	
	Year 1	***Year 3***	***Year 1***	***Year 3***
0	0.12	0.16	0.13	0.16
2.5	0.11	0.15	0.14	0.16
5	0.11	0.17	0.12	0.16
10	0.11	0.15	0.15	0.18
15	0.12	0.13	0.15	0.17
20	0.12	0.17	0.15	0.17
30	0.14	0.16	0.16	0.16

P rate lb/acre	Location 1 Bray P (ppm)		Location 2 Bray P (ppm)	
	Year 1	***Year 3***	***Year 1***	***Year 3***
0	31	62	31	49
2.5	34	62	51	50
5	38	66	39	50
10	32	83	46	64
15	53	73	39	46
20	37	71	46	58
30	42	69	48	65

Phosphorus interactions with flooding in cranberry production

In the large-scale field study in Massachusetts, we have demonstrated that, at least in the short term, reduction of P to 20 lb/acre on 'Stevens' in mineral soils is possible and that further reductions are possible with native cultivars on organic based soils. More importantly, we found in that study that flood discharges are the primary mode for off-site P export. We looked more closely at flooding practices to determine how flooding impacts water quality.

We observed that during the several days that water sat on the bog following a typical harvest, total P levels declined, presumably due to the settling of particles that

were stirred into the water during harvest. This led to an experiment where we had the grower hold the harvest flood for about 2 weeks, then release the water very slowly. While the slowly released water did have less P than that remaining in the bed, we noticed an increase in discharged P over time. After about 12 days, the P load in the water both in the bed and in the discharge, began to rise. An examination of the data showed that inorganic forms of P increased dramatically as the flood was held beyond 12 days (Figure 1). This study indicated that using slow flood discharge to filter particulate P was effective but if the release took too long, inorganic phosphate was released into the flood, presumably from the bog soil.

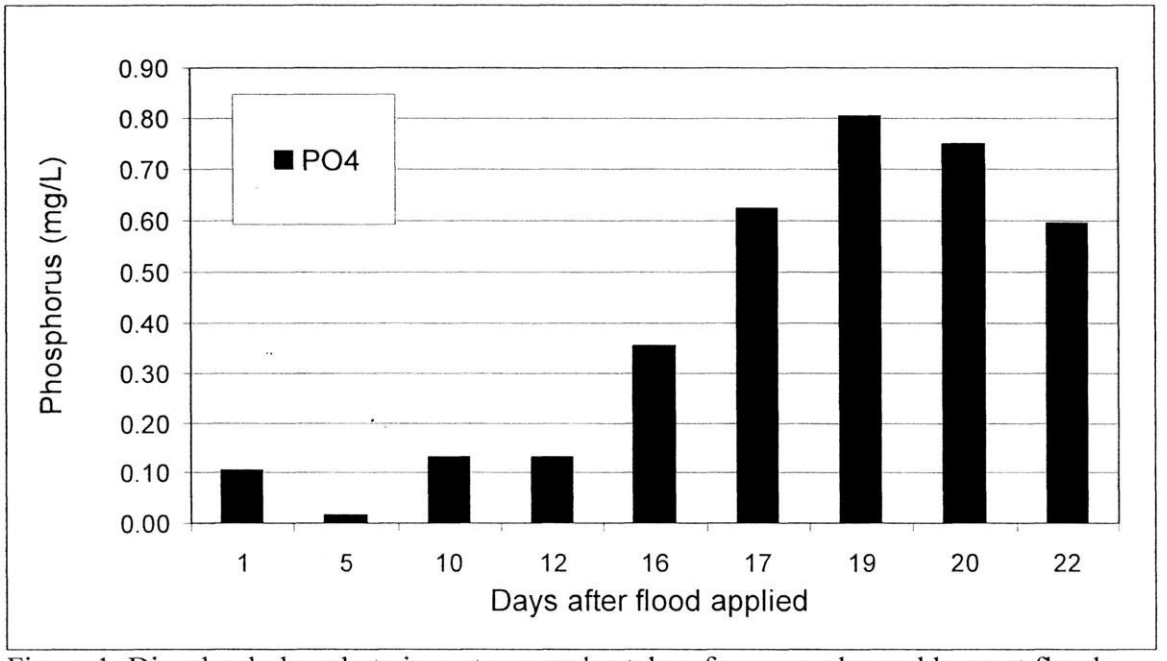

Figure 1. Dissolved phosphate in water samples taken from a prolonged harvest flood.

Other studies confirm that P can be released from the bog soil during floods. In a study of cranberry soils in the laboratory (Davenport et al., 1997), P was released into flooded cranberry soils with the amount released varying by soil type. In a field study of cranberry bogs with a perennial stream running through, the primary discharges of P were during releases of the harvest and winter floods (Howes and Teal, 1995). To further study the interaction of flooding and soil P, we worked with scientists from UMass Dartmouth to conduct a laboratory study. Soil cores were collected from working cranberry bogs and placed in cylinders. Flood water was introduced and the cylinder was sealed. Over time, oxygen and phosphorus content of the water was monitored. Figure 2 shows the change in dissolved P in the flood water as oxygen depleted in the system. All of the soil tested showed similar behavior, whether from abandoned, natural, or high input production areas. Only the magnitude of the phosphate release varied depending on management. This indicates that taking a bog out of production will not prevent P losses to the surrounding environment if the beds are subjected to flooding cycles.

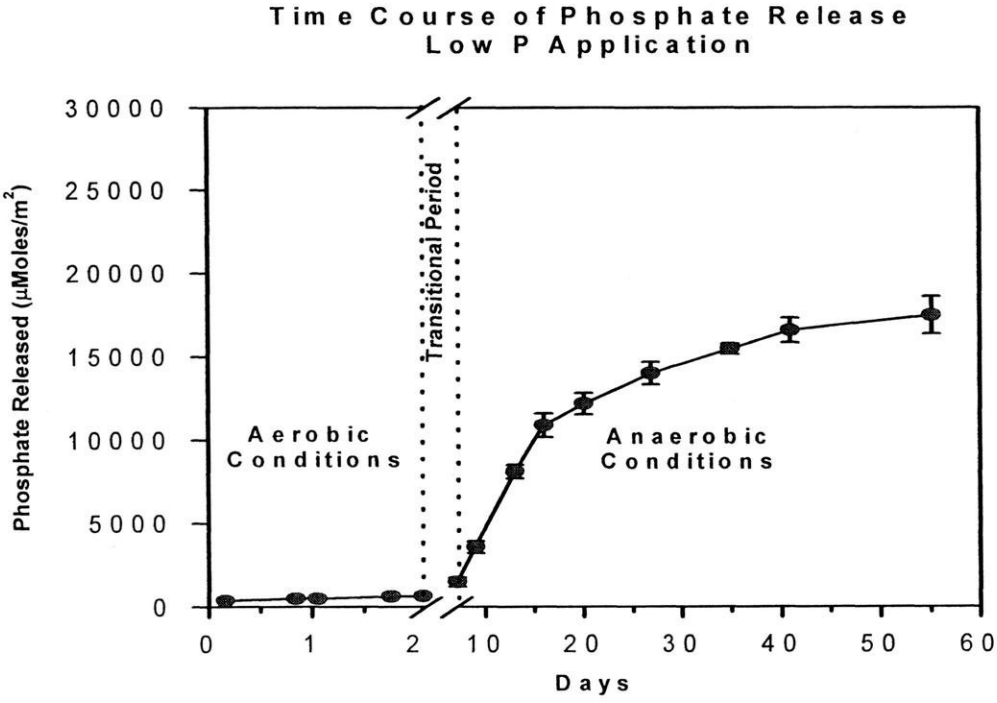

Figure 2. Phosphate in water over cranberry soil. Note the rapid increase after day 10 as the water becomes anoxic. (Schlezinger, Howes and DeMoranville, unpublished data).

Summary

Cranberry bogs, while generally next importers of nitrogen can be exporters of phosphorus. Since most of the P export from bogs was associated with flood discharges, flood management is an area deserving of further study. In order to reduce P output from cranberry systems, an important consideration will be the management of floods to minimize mobilization of soil P. Reduction in P can also be beneficial if managed so as to preserve productivity. In short term studies, fertilizer P reductions were not associated with crop reduction but after two years of reduced P, P load in discharge water was decreased. Long term studies on both plot and bog scale will be needed to determine the actual lowest effective rate for P. At present we recommend using moderate rates with a tissue testing program to monitor results.

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ION EXCHANGE MEMBRANES: AN ALTERNATIVE TO CHEMICAL SOIL TESTING?

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Phosphorus (P) is an essential plan nutrient. Recommended tissue test levels of P for cranberries are 0.1 to 0.2 percent (Davenport et al., 1995). Cranberry growers apply fertilizers containing P during the growing season to keep tissue P levels at or above 0.1 percent.

Soils in typical cranberry production areas of Wisconsin have high concentrations of cations such as iron and aluminum. When phosphorus fertilizer is added to these soils the negatively charged phosphate ions readily form insoluble mineral precipitates with iron and aluminum. Thus, while growers may apply P and the soil may contain substantial amounts of P, the "plant available" P may be quite low. The standard soil test extractant for Wisconsin is Bray-1. This dilute strong-acid extractant (a mixture of dilute hydrochloric acid and ammonium fluoride) solubilizes P minerals including Ca-P, Al-P and Fe-P. *In situ* these minerals do not solubilize in the soil solution, so cranberry soils can test high for Bray-1 P while the vines are P deficient.

Diffusion supplies almost all plant available P. Transport to the soil:root interface depends on the concentration gradient between the soil matrix and the root surface and the rate of diffusion (Abrams and Jarrell, 1992). Phosphorus movement is also affected by soil mineralogy, soil structure, soil pH, and organic P pools (Aharoni et al., 1991).

Over the past several decades the use of ion exchange resins and membranes have been used as an alternative to traditional chemical extraction soil tests (Skogley and Dobermann, 1996). Resin impregnated ion exchange membranes offer many advantages in determining the bioavailability of soil ions. Their almost two-dimensional structure eliminates internal diffusion issues (Cooperband and Logan, 1994). Further, a greater proportion of the exchange sites are in contact with the soil. They can be inserted into the soil with a minimum of disturbance. Newer types of anion exchange membranes will sorb and desorb ions creating a dynamic environment that can truly reflect soil conditions.

Ion exchange membranes can be used *in situ* allowing measurements of ion availability to reflect all soil, environmental, and biological factors that might affect ion availability in soils (Cooperband et al. 1999). Anion exchange membranes potentially are a tool that growers could use to monitor plant available P thus allowing better timing of fertilizer applications and conceivably reducing introduction of P to the environment.

This article will describe experiments we conducted to ascertain the suitability of anion exchange membranes as an alternative to chemical soil testing for phosphorus in cranberry marshes in Wisconsin.

Time to equilibrium. Pieces of membrane (1 x 1 inch) were placed in either sand or peat soil. The sand had 21 ppm P determined by Bray-1 with a soil pH of 5.7 and the peat soil had 101 ppm Bray-1 P and a pH of 4.4. The size and appearance of the membranes are shown in the photograph to the right. 18 membranes were placed in each soil container with four replications each of sand and peat soils. One set of membranes were removed daily and stored in deionized water.

The results of this study are shown in Figure 1. During the first week of evaluation the sand soil released more phosphorus than the peat soil. Apparently during the first week of incubation P primarily moved to the membranes. In the second week some of the P exchanged off of the membranes into the soil and a second steady state was achieved. From these data and discussions with colleagues it was decided to use 6 days as our standard experiment duration.

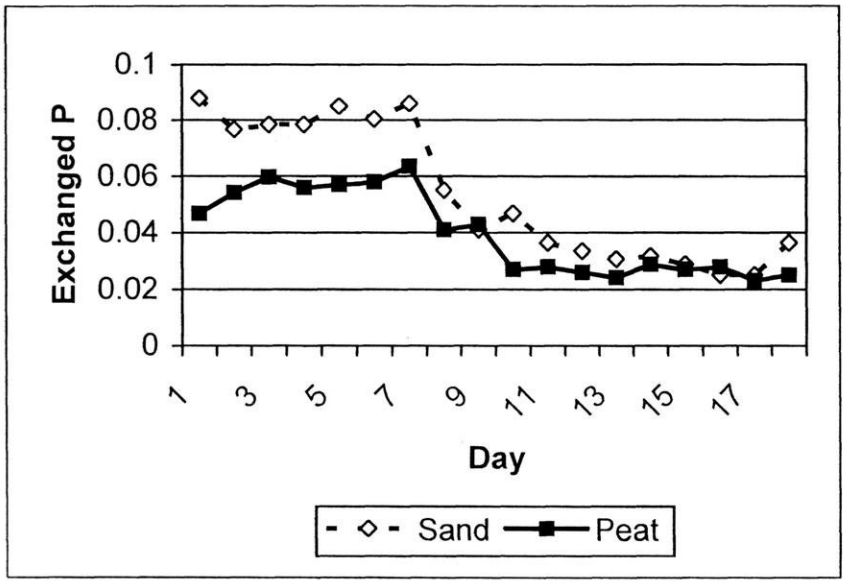

Figure 1. Effect of time on phosphorus sorbed to anion exchange membranes in sand and peat soils.

pH response

The pH of sand soils was adjusted to form a range between 3.6 and 7.5. The soil had phosphorus added at a rate of 20 mg P/kg soil. Membranes were placed into the soil and allowed to equilibrate for 6 days. The results of the experiment are shown in Figure 2. Exchangeable P was altered drastically by the soil pH. As pH declined the amount of phosphorus sorbed to the membranes declined. If this was characteristic of the membranes they would be unacceptable for our purposes. We decided to investigate further.

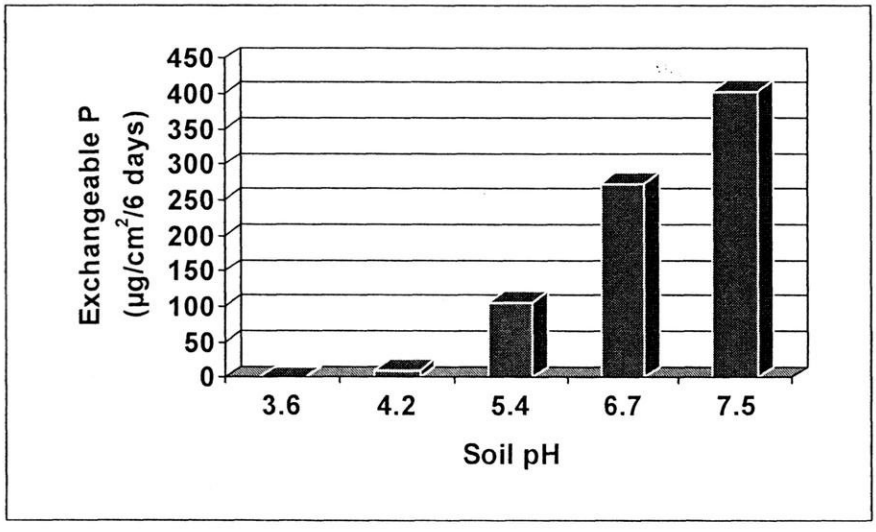

Figure 2. Effect of soil pH on phosphorus sorbed to anion exchange membranes in a sandy soil.

The next step was to use solutions adjusted to various pH without soil to see if the membranes were responding to soil pH or if there were other factors involved. Membranes were placed in these solutions that contained 5 ppm phosphorus and shaken at room temperature for six days at which time they were eluted and the eluent analyzed for P. While there were treatment differences, the

differences were not biologically significant and were much less substantial than the differences in soil (Figure 3).

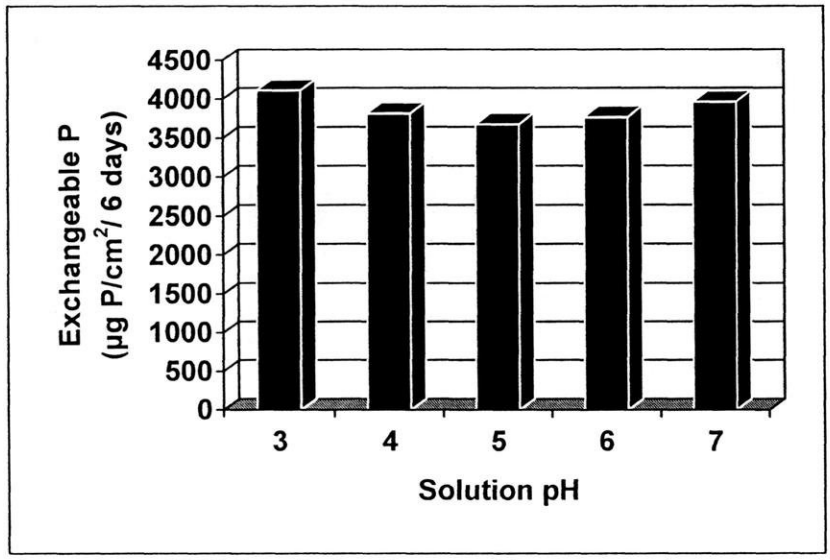

Figure 3. Effect of solution pH on phosphorus sorbed to anion exchange membranes in solution.

It appears that the membranes are not sensitive to substrate pH. The question still remained of what caused the great reduction of available P in the low pH soils. We hypothesized that at low pH high soil aluminum and iron were tying up the phosphorus and making it unavailable to the membranes. We did another experiment in solution where we added iron or aluminum to the solutions at the various pH levels, shook the bottles with membranes for six days and analyzed the eluent for phosphorus. The solutions contained 5 ppm phosphorus and either 5 ppm iron or aluminum. The data shown in Figure 4 clearly illustrate that in cranberry soils and a low pH aluminum binds with phosphate making it plant unavailable. Since the iron was in a chelated form it likely did not react with the phosphorus as readily. Grower experience also supports this conclusion and these data show the dynamics in a simple system.

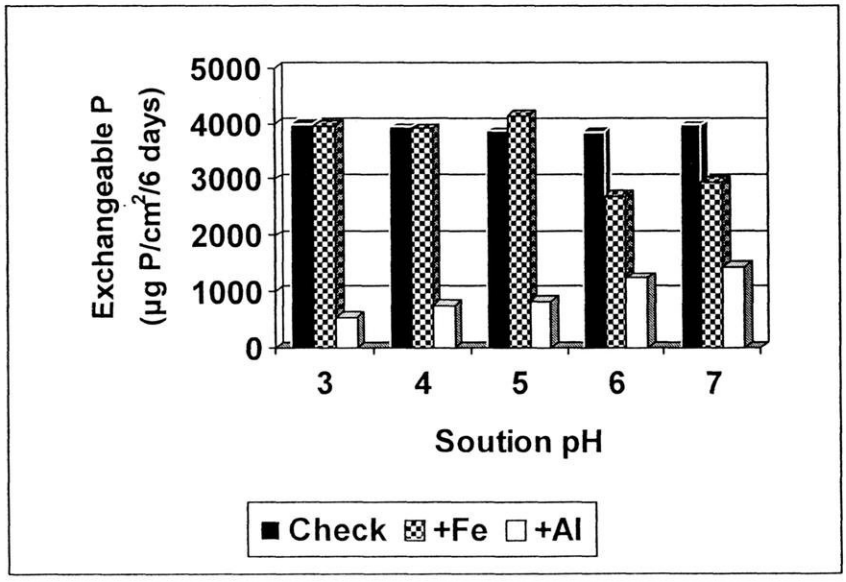

Figure 4. Effect of iron and aluminum ions on sorption of phosphorus to anion exchange membranes in solutions at different pH.

Phosphorus Concentration. We also wanted to see if the membranes would be sensitive to different concentrations of P in the substrate. To do this we made solutions with differing amounts of phosphorus added ranging from 0 to 200 ppm. This would be a range typically found in cranberry soils. Figure 5 shows the linear response of the anion exchange membranes with substrate

phosphorus. These results are very encouraging and give us greater confidence in field data.

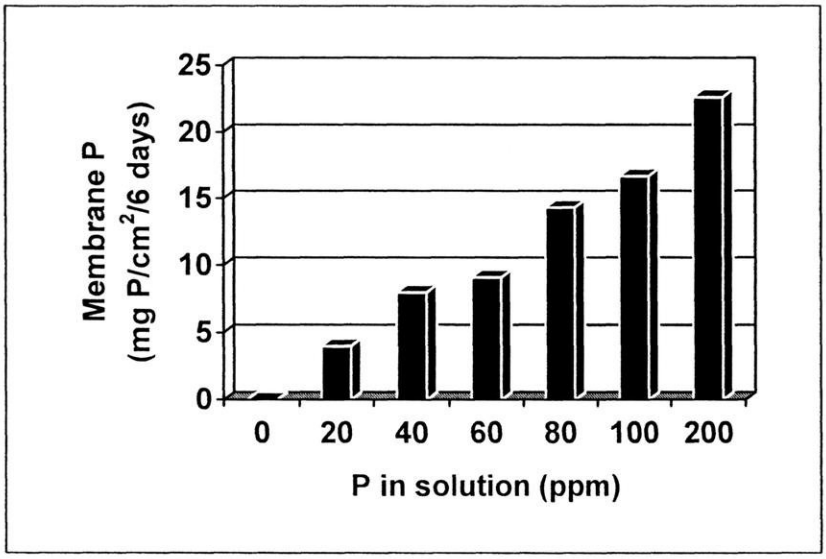

Figure 5. Effect of phosphorus concentration in solution on phosphorus sorption to anion exchange membranes.

Temperature Response

The movement of ions in soil is the result of diffusion from areas of high concentrations to areas of low concentration until an equilibrium is achieved. The rate of diffusion is also affected by temperature. We put membranes into a sandy soil which was amended with phosphorus at the rate of 10 pounds P/a and held them at different temperatures for 3, 6, or 9 days (Figure 6). This result clearly shows that there is a temperature effect. We believe this shows the effect of temperature on diffusion rather than a direct temperature effect on the ability of the membranes to sorb phosphate ions. In a field situation interpretation of results would have to account for the influence of temperature on diffusion, thus samples taken in spring or fall might normally be lower than samples taken midsummer.

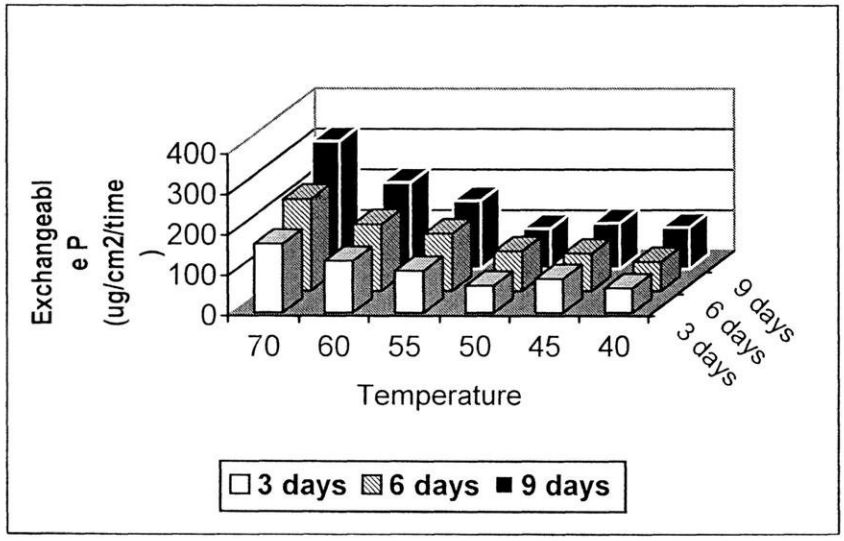

Figure 6. The effect of temperature on exchangeable phosphate from a sandy soil, pH 5.5 that was amended with a rate equivalent to 10 pounds P per acre. n=3.

Field Research

From previous research projects we have plots that have received varying amounts of phosphorus fertilizer annually ranging from zero to 30 pounds P/a/year for the past 4 years. We were able to use these plots to provide field soils with varying amounts of plant available phosphorus. Membranes were placed in the field beginning the first week of June and were replaced weekly throughout the summer for 20 weeks. We would

like to have begun earlier, but the weather was so wet that it was difficult to get into the field to begin the project. To place the membranes, a slit was cut about two inches deep under the vines and a membrane was carefully placed into the slit and the soil pressed back onto the membrane. The soil was then wetted with a spray bottle to ensure good contact between the soil and membrane. The photos below show the sequence of placing the membranes in this project.

A slit is cut into the soil with a knife.

The membrane is cleaned with a spray of water.

The membrane is placed into the soil.

The membrane is watered into the soil to ensure good contact.

Figure 7 shows the results for the 2004 season. The most available phosphorus was present in the early season as the soils warmed and dried. Phosphorus was also available in the week following a fertilizer application in July. What was really striking, however, is that the control always had the lowest sorbed P and the highest rate of phosphate fertilizer always showed the highest amount of sorbed phosphate. The lines don't ever cross throughout the season. This suggests that a high rate of phosphorus fertilizer provides slightly higher amounts of available phosphorus. However, during the bulk of the growing season the relative differences between the treatments were inconsequential suggesting that the 10 pound rate was as effective as the 30 pound rate. We had some trouble with plot identification in 2004 and we will repeat this research in 2005 so that we will have appropriate replication thus allowing statistical analysis.

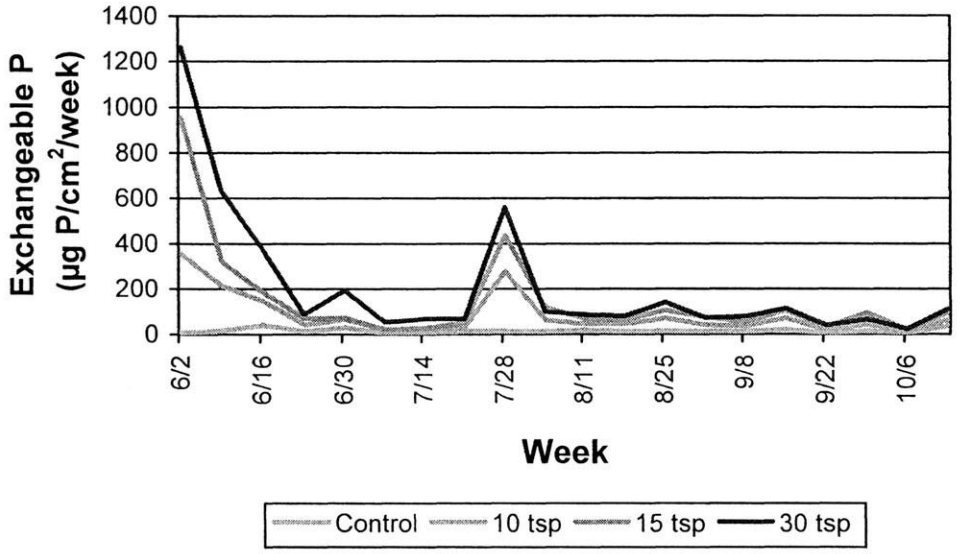

Figure 7. Dynamics of phosphorus sorption to anion exchange membranes in sand based cranberry soils that have received different amounts of phosphate as triple super phosphate for four years. Data are from 2004.

The field study was repeated in 2005 with similar results to 2005 (Figure 8). We were able to get membranes into the field earlier in 2005. Phosphorus fertilizer applications were made on three dates, May 31, July 5, and July 26. The amount of exchangeable phosphate increased rapidly immediately after those dates. Throughout the season the exchangeable P was higher in the 30 pound plots than in the 15 pound plots, and both were routinely higher than the control. However, the control plots never had 0 exchangeable P, suggesting a rather constant supply at background levels. Applications of phosphorus fertilizer elevated soil exchangeable P for about two to three weeks following application.

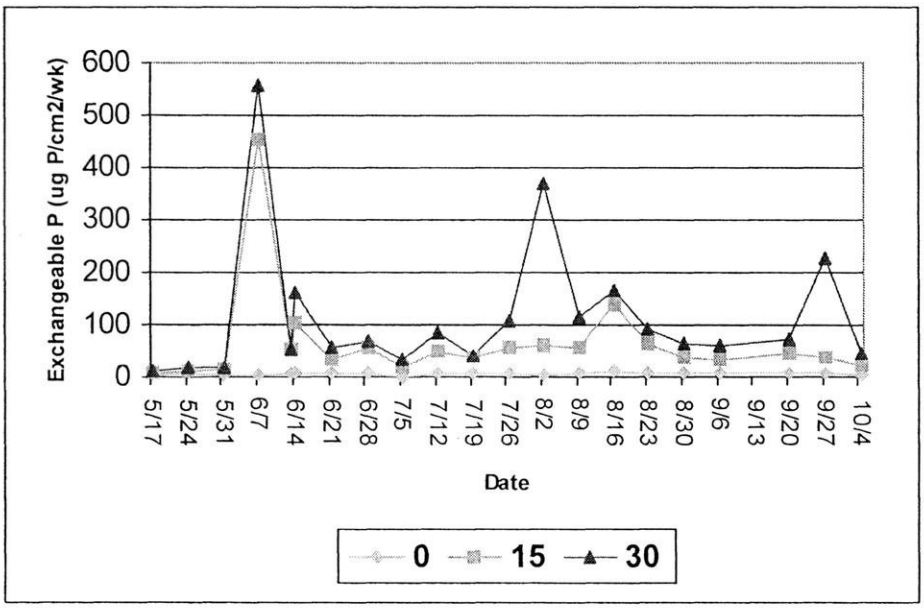

Figure 8. Dynamics of phosphorus sorption to anion exchange membranes in sand based cranberry soils that have received different amounts of phosphate as triple super phosphate for five years. Data are from 2005.

Commercially available Membranes

Through a lease agreement we were able to access a commercially available anion exchange membrane product (PRS™ Probes) from Western Ag Innovations, Saskatoon, Saskatchewan, Canada. These membranes come in a plastic holder. They were shipped to us just before we needed them and we stored them at 4°C until they were put in the field. Openings were made in the soil with a knife and the PRS™ Probes were inserted. They remained in the field for 7 days at which time they were retrieved and returned to the lab for extraction and analysis. Results of three dates in 2005 are shown in Table 1.

Table 1. Exchangeable P as measured using commercially available PRS™ Probes (Western Ag Innovations, Saskatoon, Saskatchewan) in a sand based cranberry bed in Wisconsin at three dates in 2005.

Rate	**May 24-31**	**July 19-26**	**Sept. 20-27**
(lb/a)	(μg/10 cm^2/wk)	(μg/10 cm^2/wk)	(μg/10 cm^2/wk)
0	1.3 a	4.6 a	1.5 a
10	1.5 ab	16.78 ab	2.7 ab
20	1.88 bc	22.98 b	4.8 bc
30	2.28 c	31.23 b	6.8 c

Two experiments were conducted to determine the relationship (if any) between plant available P in soils determined by standard Bray extractant and AEM. In the first experiment soils were amended with varying amounts of phosphorus ranging from 10 to 120 ppm. AEM were placed in the soil for 6 days, then extracted for sorbed P. Subsamples of the soil were then sent to the soils lab for Bray P determination. The results are shown in Figure 9. The overall slopes of the lines appear similar, but the units are very different. The Bray test is quite linear while the AEM line appears curvilinear. Because the slopes are similar a mathematical conversion could be used to interchange one metric for the other.

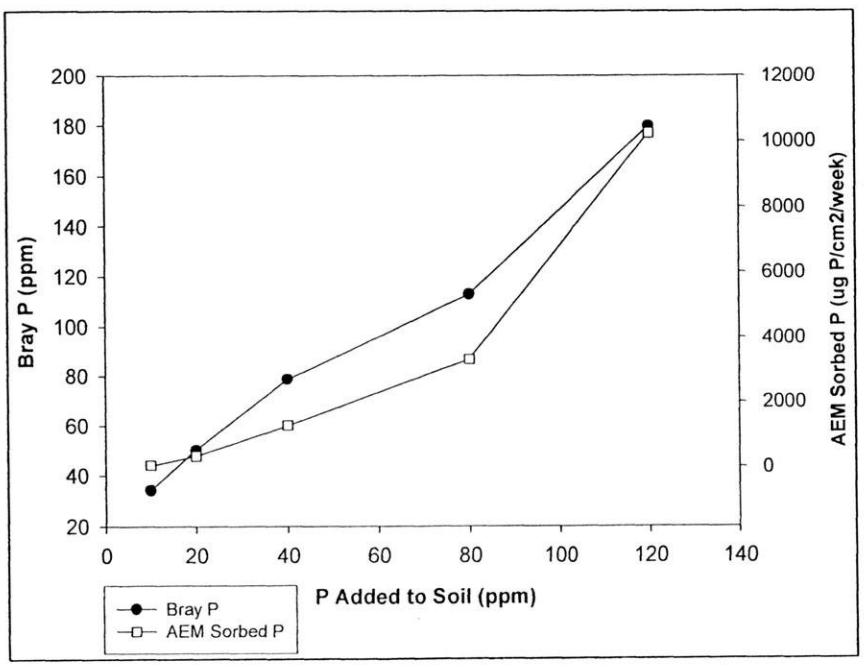

Figure 9. A comparison of the results of plant available P in cranberry soils estimated by Bray P1 and anion exchange membranes.

Field plots receiving various rates of phosphorus fertilizer received AEM (see field research section). In August we collected soil samples at the same time as we collected tissue samples in 2004 and 2005. The results for 2004 are shown in Table 1. The AEM results show much more response to the varying rates of fertilizer application than the Bray results do. This underscores the poor representation of soil available P from the Bray extraction soil test. The 2005 soil samples are currently at the Soils lab for analysis.

Table 1. Comparison of plant available phosphorus in a Wisconsin cranberry soil determined by anion exchange membranes (AEM) and the Bray P1 soil test.

	2004		2005	
	AEM	Bray P	AEM	Bray P
	(µg P/cm2/ 7 days)	(ppm)	(µg P/cm2/ 7 days)	(ppm)
0	7.15	108.3	7.2	37
5		115.7		
10	19.45	128.0		
15	34.17	120.0	40	43
20		125.7		
30	39.83	145.0	39.8	41

Tissue samples were taken in early September of 2004 and 2005 to determine the relationship between tissue test P and AEM extractable P. The samples were dried and ground and sent to the University of Wisconsin-Extension Soil and Plant Analysis Lab for standard analysis. We found some differences in tissue phosphorus concentration according to fertilizer rate (Table 2). We also saw consistent patterns in sorbed P in the membranes (Figure 6). Unfortunately, problems with plot identification did not provide sufficient replication of the membrane data to provide statistically solid answers in 2004. We are still working on statistical analysis for 2005 data. The data in Table 2 suggest there is a good correlation between tissue test P and AEM P, supporting the value of this technology.

Table 2. Tissue phosphorus concentration of cranberry vines in a sand based bed in 2004. N=4.

Treatment	2004		2005	
Rate (lb P/a)	Tissue P	AEM P	Tissue P	AEM P
Control (0)	0.105 d	36.4	0.102 a	6.4
15 TSP	0.130 bc	97	0.120 ab	51.7
30 TSP	0.142 b	121.1	0.121 ab	55.3

Yield was determined in the phosphorus rate trial plots from square foot samples. There were no differences in yield among the treatments even with differences in plant available P and tissue P (Table 3). This is not surprising. Even after four years of

receiving no phosphorus fertilizer the tissue phosphorus in the control plots were still above the critical tissue value of 0.1% P (Table 2). Thus phosphorus was not the limiting factor for yield and no yield response was found.

In 2005 we placed AEM in several grower beds in July at the time of fruit set. We believe this may be the most critical period of time for having P sufficiency. These samples are currently being analyzed and we are still collecting data from the cooperating growers. However, because tissue P would likely have been sufficient it is unlikely that we would find a yield response that would correlate with phosphorus sorbed onto AEM.

Table 3. Yield in a sand based cranberry bed treated with different rates of phosphorus fertilizer for four years in Wisconsin. n=8.

Treatment	Yield (g/ft^2)	
Rate (lb P/a)	**2004**	**2005**
Control	128.7	179.4
10 TSP	117.6	199.1
15 TSP	126.2	208.6
20 TSP	157.4	224.0
30 TSP	131.3	198.7
Significance	ns	ns

Conclusions.

From these various studies we believe that anion exchange membranes hold great promise as an alternative to chemical soil testing for cranberry soils. The laboratory studies show that they behave in predictable quantifiable ways. The field research shows that the amount of P sorbed is related to the amount of phosphate fertilizer applied and to when it is applied. There is also a reasonable relationship between AEM P and tissue test P. Perhaps with more work this technology could be useful for growers.

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CORRELATIONS OF FERTILITY WITH YIELD

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Cranberry growers want to ensure that fertility is not a limiting factor for achieving the highest possible yields. In the fall of 2005 about fifteen Wisconsin cranberry growers shared some of their data from Stevens beds with the University of Wisconsin-Madison. These data were assembled into a single file and statistical correlations were made between yield and various measures of fertility. Data collected included the county where the marsh was located, data year, year planted, percent organic matter in the soil, estimated cation exchange capacity, years since last sanding, soil pH, soil test P, soil test K, tissue N, tissue P, tissue K, pounds of N applied, pounds of P_2O_5 applied, pounds of K_2O applied, and the number of applications of N, P, and K. A summary of the data is shown in Table 1.

Table 1. Summary statistics for grower data from 'Stevens' beds in Wisconsin. Mean is the average value. Median is the middle number with an equal number of observation above and below. R2 values describe the variation in yield described by variation in the parameter measured. P values describe the strength of the correlation. Small p values suggest strong correlations. $198 < n < 311$.

Variable	Min	Max	Mean	Median	r^2	p value
Year planted	1965	2001	1992			
Percent organic matter	0.1	10	1.73	1.1	0.043	0.0047
Cation exchange capacity	0.5	17	4	2.5	0.057	0.0012
Years since sanded	0	8	1.2	1	0.013	0.0612
Soil pH	4.1	6.8	5.1	5.0	0.024	0.034
Soil test P	6	476	165	122	0.011	0.159
Soil test K	0.2	361	87.6	74.4	0.043	0.0043
Tissue N	0.93	1.88	1.26	1.25	0.025	0.03
Tissue P	0.09	0.24	0.15	0.15	0.002	0.04
Tissue K	0.07	0.71	0.55	0.55	0.008	0.234
Pounds N applied	11	69	35.1	35.1	0.159	0.0001
Number of N applications	2	9	5	5	0.136	0.0001
Pounds P_2O_5 applied	26	154	73.5	75	0.051	0.0001
Number of P_2O_5 applications	1	9	4.7	5	0.03	0.0056
Pounds of K_2O applied	28.5	347	162	168	0.149	0.0001
Number of K_2O applications	1	11	6.9	7	0.104	0.0001
Yield	17	439	233	233		

The data shown in Table 1 document that there is great variation in grower practice in the application of fertilizer and there is great variation in the results. Correlations between yield and factors that should, to some extent, determine yield

produced interesting results. Strong correlations do not necessarily mean cause and effect relationships. Further, the fertilizer correlations are not independent because most growers apply complete N-P-K fertilizers so increases in one element are not independent of increases in others.

This article will go through the macronutrients: Nitrogen, Phosphorus, and Potassium and describe the correlations that exist between them and yield and will provide some interpretive comments.

Nitrogen

Nitrogen is perhaps the most important element provided to cranberry vines as fertilizer. While there is a positive relationship between tissue N and yield and between pounds of N applied and yield, the r^2 values are still quite low (0.025 and 0.159, respectively). The p value for tissue N was barely significant. The data suggest that while increases in N do lead to increases in yield, the potential increases are modest. Increasing N applied led to increases in tissue N. However, only about 12% of the variation in tissue N was related to the pounds of N applied suggesting that other factors are also important.

These data for 'Stevens' vines do show that virtually all growers have tissue N in excess of 1.1%. This suggests that 'Stevens' vines can at least tolerate if not benefit from increased tissue N concentration. Therefore, we are increasing our tissue N guidelines for 'Stevens' vines so the sufficient range would be 0.9 to 1.3%. This does not change our guidelines for non-hybrids such as 'Searles' and 'Ben Lear'. Also, this increase in the guidelines reduces the margin for error in managing nitrogen. If one overshoots the target by just a little bit the opportunity for vine overgrowth leading to reduced yields is substantial.

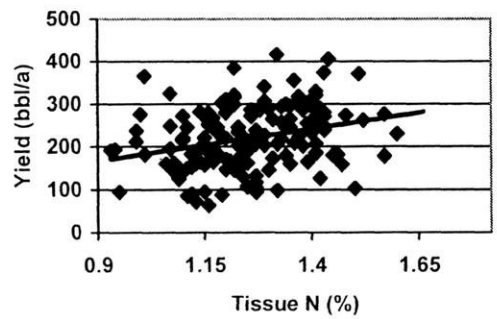


Figure 1. The relationship between tissue N and yield for Stevens cranberries in Wisconsin.

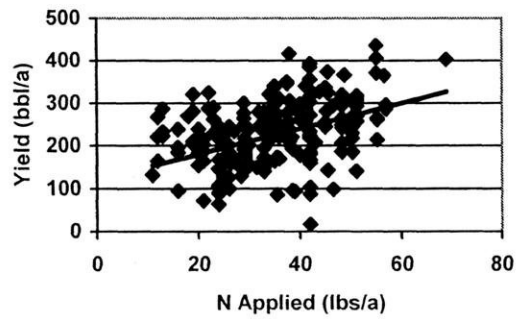


Figure 2. The relationship between pounds of N fertilizer applied and yield in Stevens cranberries in Wisconsin.

Phosphorus

Phosphorus is an important mineral element, but it is also an important pollutant of fresh water ecosystems. Anything that growers can do to reduce the potential of phosphorus leaving their marsh in water will reduce the threat of pollution to associated fresh water bodies.

Tissue P is not a strong predictor of yield in cranberries. While there was a positive relationship the slope is very shallow and the p value is large. There was no relationship between soil test P and yield in this data set. However, because we did not know which lab did the analytical work reported we don't know what soil test method was used. This is at least one reason for the bimodal distribution in Figure 4. The lower soil test P values are likely Bray and the higher values are likely Mehlich. Figure 5 shows the relationship between Bray soil test P and tissue P. In these data soil test P is still not a strong predictor of tissue P. Pounds of P_2O_5 applied was a stronger predictor of yield than tissue or soil test P. However pounds of P fertilizer is not independent of applied N and K. There is not strong evidence that increasing applications of P will lead to higher yields. Virtually all of the samples represented by the data in Figures 3 and 5 show tissue sufficiency in P. Similar results were found in an analysis of samples submitted to the UW Soil and Plant Analysis Lab (Fig. 5). High rates of application of P_2O_5 have not led to high tissue P suggesting other factors are involved.

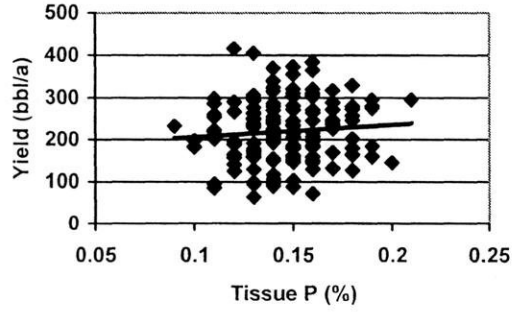


Figure 3. The relationship between tissue P and yield in 'Stevens' cranberries in Wisconsin.

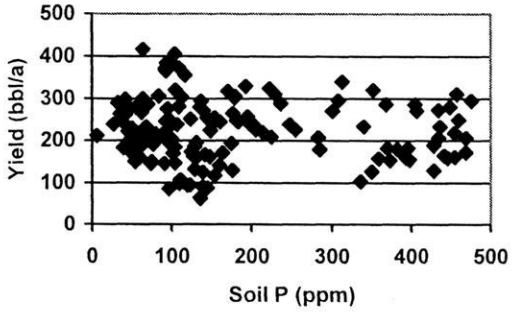


Figure 4. The relationship between soil test P and yield in 'Stevens' cranberries in Wisconsin. This is not a statistically significant relationship.

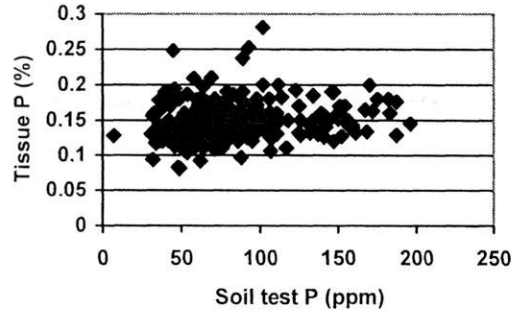


Figure 5. The relationship between soil test P (Bray 1) and tissue P in 200 cranberry samples submitted to the UW Soil and Plant Analysis Lab, 2002-2004.

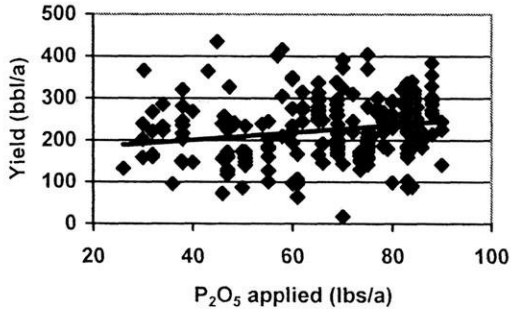


Figure 6. The relationship between applied P_2O_5 and yield in 'Stevens' cranberries in Wisconsin.

Potassium

Potassium is an important mineral element for all fruit crops. However, growers may be overemphasizing the importance of potassium. In a 400 bbl/a crop only 35 pounds of potassium are removed in the crop. [40,000 lbs x 12.5% dry matter= 5,000 lbs dry matter x 0.7% potassium in fruit = 35 lbs K/a].

Both tissue K and soil test K had a negative relationship with yield, particularly soil test K. This may be the results of too much K in the soil, but it may also be related to chloride injury if the chloride form of potassium is used or it may simply be a salt effect. This may also reflect the effect of other soil parameters that also influence the ability of a soil to retain K such as K content and organic matter content. There was a positive correlation between K fertilizer applied and yield, however since most fertilizer is applied as a complete N-P-K this may simply be residual effects from N and P. It is impossible to segregate these effects in this dataset.

There was not a significant relationship between soil test K and tissue test K. Thus, increasing soil K did not lead to higher tissue levels. Virtually all samples in this dataset were within the guidelines of 0.4 to 0.7%.

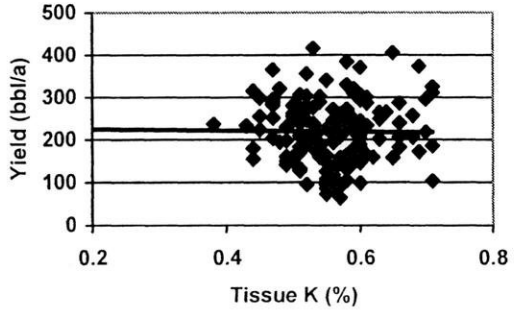


Figure 7. Relationship between tissue K and yield in 'Stevens' cranberries grown in Wisconsin.

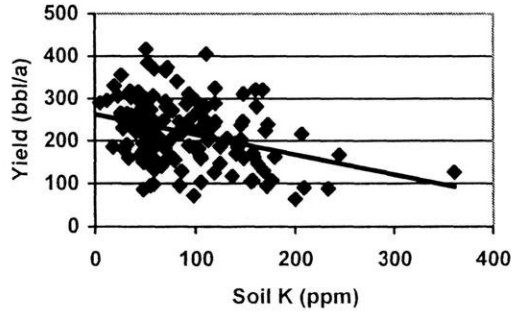


Figure 8. The relationship between soil test K and yield in 'Stevens' cranberries grown in Wisconsin.

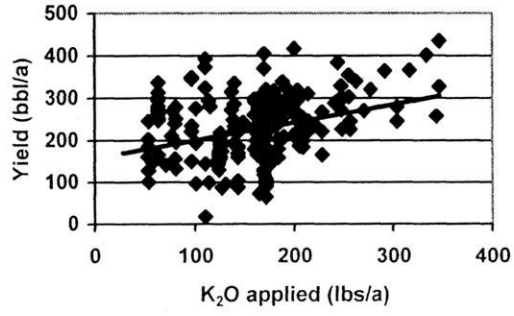


Figure 9. The relationship between the amount of K_2O fertilizer applied and yield in 'Stevens' cranberries in Wisconsin.

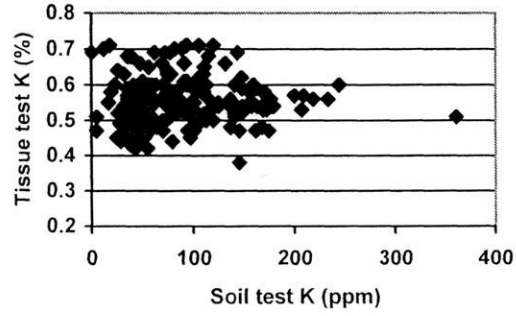


Figure 10. The relationship between soil test K and tissue test K for 'Stevens' cranberries grown in Wisconsin.

If yield is negatively related to increasing soil potassium, perhaps it is useful to consider what affects soil potassium. The amount of potassium fertilizer applied had a positive relationship with soil test potassium, but this was not a strong correlation (Figure 11). The best correlation with soil test potassium was cation exchange capacity (Figure 12). This is not surprising since potassium is a positively charged ion (cation). The other soil factor that correlated well with potassium was percent organic matter in the soil (Figure 13). This suggests very strongly that a large fraction of the ability of soil to retain and exchange cations resides in the organic fraction of cranberry soils (Figure 14).

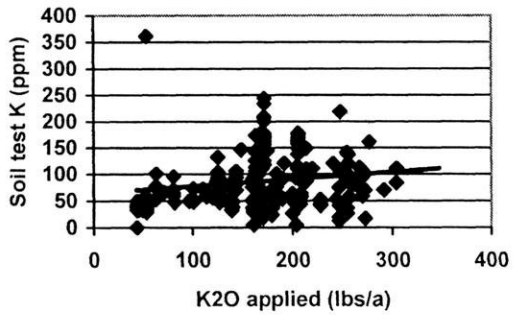


Figure 11. The relationship between applied potassium fertilizer and soil test K for 'Stevens' cranberries grown in Wisconsin.

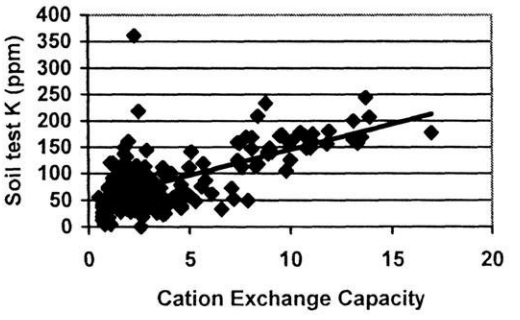


Figure 12. The relationship between estimated cation exchange capacity and soil test potassium in Wisconsin cranberry soils.

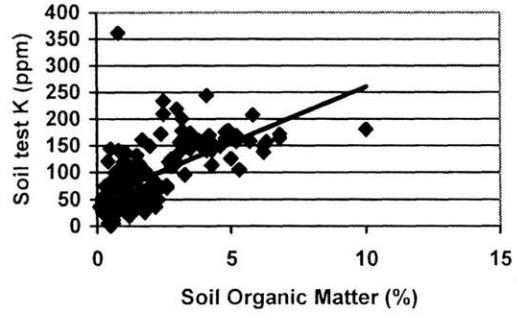


Figure 13. The relationship between soil organic matter and soil test potassium in Wisconsin cranberry soils.

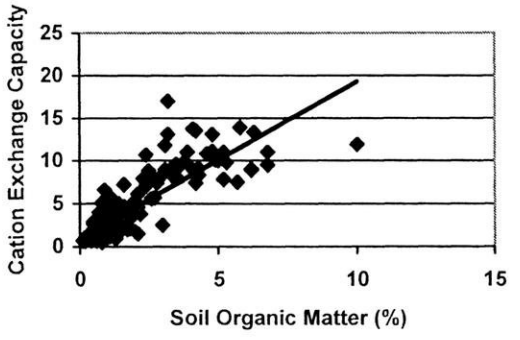


Figure 14. The relationship between soil organic matter content and estimated cation exchange capacity in Wisconsin cranberry soils

Summary.

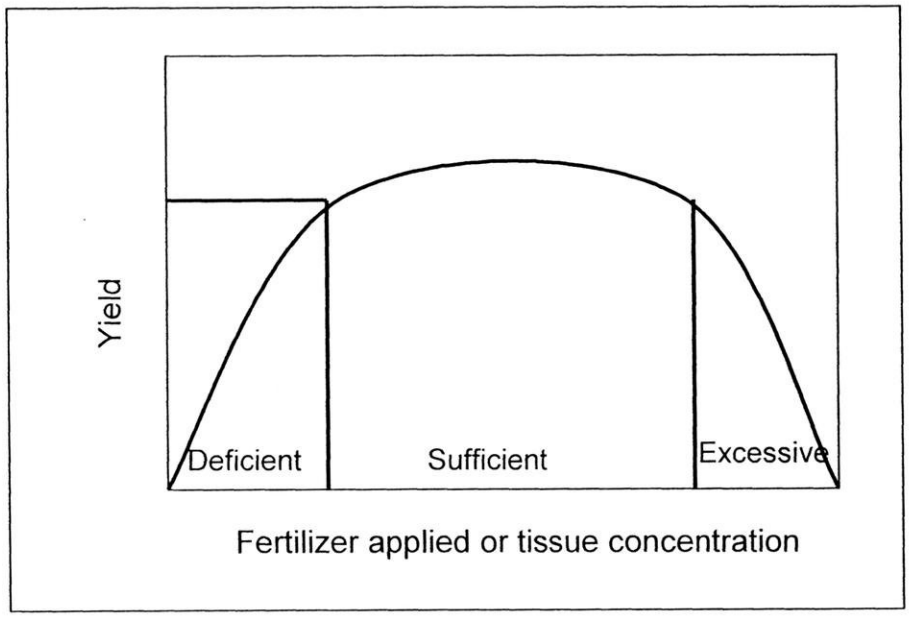
In summary there were generally positive correlations between the amount of fertilizer applied and yield, but not between tissue test levels and yields for N-P-K examined in this study. Drawing conclusions from the fertilizer application data is

troublesome because the data for individual elements are not independent from the other two elements since most growers apply complete products containing N-P-K.

One important weakness of the data included in this analysis is that there was no control. None of the data represented beds that had received no fertilizer. Further, virtually all of the samples included in this study were in the sufficient range for N, P, and K. Because all samples were in the sufficient range increases in yield resulting from additional applications of fertilizer are negligible. Figure 15 shows a normalized response curve for crops to either increasing fertilizer application or increasing tissue concentration of a critical element.

These data do not justify growers being able to apply N-P-K fertilizers at amounts substantially higher than those rates in guidelines published by the University of Wisconsin-Extension.

Figure 15. A generalized yield response curve for application of fertilizer or mineral nutrition status of crop plants. The aim in designing fertility programs is to achieve and maintain tissue sufficiency. Once in the sufficient zone adding more fertilizer does not lead to significant increases in yield.



FERTILIZERS: TYPES, REACTIONS, AND RESPONSES

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Fertilizer types

Fertilizer can be categorized in several ways based on physical and chemical properties. Fertilizers may also be broken up into two broad groups -- soil applied or foliar applied. As the terms imply, these categories define the target of the application: either the material is meant to be placed on and incorporated into the soil or it is applied to the plant surface. The nutrients in soil applied fertilizers are intended for uptake by the plant roots while those in foliar applications enter the plant primarily through the leaves, although some material may wash onto the soil and be taken up by the roots. Generally we think of soil applied fertilizers as solids or granular materials. However, liquids may also be used in soil applications. A good example of this is fish hydrolysate fertilizer which is applied at relatively high rates (gallons per acre) and is intended to be washed onto and into the soil and eventually taken up by plant roots.

Soil applied fertilizers are most commonly granular materials. The predominant granulars used in cranberry production are soluble inorganic materials. These manufactured materials may be ammoniated (chemically produced materials in which each particle contains all of the fertilizer minerals and the nitrogen is in the ammonium form) or blended (combinations of particles any one of which may contain only some of the mineral content). Both types may have a variety of sizes of particles. This is not an issue for the ammoniated fertilizer, since each particle is minerally complete. However, in a blended fertilizer, as the particles sort by weight during application and are distributed unequally, the various minerals in those particles are also unequally distributed. Additionally, some blended fertilizers contain filler materials, often lime. Many growers prefer ammoniated fertilizers since this assures the ammonium form of nitrogen (preferred by cranberry plants), no carrier materials, and equal distribution of the fertilizer mineral components. But, cost and availability are increasingly an issue for ammoniated fertilizer.

In addition to untreated granular materials, the soil fertilizer category includes organic fertilizers, liquids, and slow release materials. A primary difference among these materials is the timeline from application until the mineral elements are available for uptake by the roots. The minerals in soluble inorganic fertilizers are immediately available if applied in a liquid formulation and quickly available if applied as granulars (as soon as they dissolve into the soil water). The mineral elements in organic forms only become available as the fertilizer breaks down in the soil, a process that is often mediated by soil microorganisms. Slow release fertilizers are intentionally designed to be slowly available. Depending on the product, the minerals are relcased to the soil water over a period of one to several months. The release may depend on soil temperature, moisture content, pH, coating thickness, and/or microbial activity. The mineral elements in all of these products are used similarly by the plant once the minerals dissolve or are digested and move into the soil solution. Mycorrhizal associations may also mediate direct uptake on small organic molecules containing nitrogen (for example, amino acids).

Foliar fertilizers are liquid materials designed to be sprayed onto the plant. Once in place, the minerals move directly into the plant through the leaves. By nature, the fertilizers are designed to deliver modest amounts of nutrient. Uptake may be limited by the thickness of the plant cuticle, wet period after application (generally there needs to be moisture present for uptake), concentration of the spray solution, and wash off. Specific elements may be limited in their mobility out of the leaves to the rest of the plant. Foliar fertilizer have advantages in situations where root uptake might be limited. They are also useful for quickly delivering supplemental nutrition. Urea is frequently used in foliar applications to deliver quick supplemental nitrogen.

Fertilizer movement and reactions

As previously stated, granular fertilizers may be distributed unequally depending on product type and delivery system. Once the fertilizer is applied, it must weather, dissolve, or be digested so that the mineral components are dissolved in the soil moisture. Once an element is in solution, it moves through the soil by diffusion (elements move from a concentrated area to an area with lower concentration until all concentration are equal) or through mass flow (dragged along in moving water within the soil).

Elements in the soil water follow three paths -- into the plant roots, away from the target area in water (leaching or runoff) or into a bound form in the soil. Soil binding of minerals varies in strength or permanency. That is, many minerals are loosely bound on exchange complexes in the soil. An example is cation exchange capacity (CEC). CEC is the ability of a soil to loosely hold positively charged particles (cation such as potassium, calcium, and magnesium ions) in such a way that they are retained in the soil but remain available for plant uptake. In cranberry soil, most of the CEC is provided by organic material in the soil since our soils are poor in clay (the common source of CEC in agronomic soils). In acid cranberry soil, strong binding also occurs, particularly binding of phosphorus to iron and aluminum. Strongly bound P is less available to the plant and over time the bond may become virtually permanent.

Plant roots can only take up 'free' minerals so even those bound to the CEC must be released to the soil solution prior to plant uptake.

Plant uptake of fertilizer

In field studies in several growing regions, dissolved, labeled nitrogen was applied to cranberry plants. Uptake was confirmed within 24 hours and continued for about 7 days in Wisconsin. Rate of uptake was temperature dependent, with more rapid uptake at the warmer sites. More N was taken up in WI and NJ in the first 7 days than was taken up in MA after 14 days or OR after 21 days. Examination of weather records suggested that the differences were likely due to temperature.

pH responses and interactions

Ammonium sulfate, one of the most common cranberry N sources, is taken up by plant roots in an active process. As the plant takes in the ammonium ion from the fertilizer, a hydrogen ion (acid) is pumped out of the plant. In this process, the soil is acidified. So it is the uptake process that provides the soil acidification associated with ammonium sulfate. The sulfate is not an acidifier -- only elemental sulfur has that property.

Soil pH plays an important role in the nitrogen cycle in cranberry soils by its impact on two processes: mineralization (the digestion of organic nitrogen by microorganisms to produce ammonium N) and nitrification (the microbial conversion of ammonium to nitrate N). The table below shows nitrogen release from cranberry soil organic matter at three pH levels. As the soil becomes less acid (pH 6.5), more total N is released compared to soil at pH 3.5. However, most of that N is in the nitrate form. An examination of the microbial population in the soils at pH 6.5 vs. 3.5 showed that at the lower pH microbes were suppressed. So at cranberry bog pH, one can expect low microbial activity, slow mineralization (conversion of organic to ammonium N) and little conversion of that ammonium to nitrate. This is good, since nitrate is poorly used by cranberries and readily leaches away from the root zone.

N leached from a sand cranberry soil.

Soil pH	Total N	NH_4-N	NO_3-N
6.5	56.60 a	6.38 a	50.22 a
4.5	10.34 b	3.89 a	6.45 b
3.0	14.07 b	5.46 a	8.61 b

As mentions previously, soil pH also plays a role in the reactions of phosphorus in the soil. As pH moves away from neutral (7.0) in either direction, P becomes more strongly bound to other soil minerals, At low pH P binds to iron and aluminum while at high pH P binds to calcium. Since cranberry soils are strongly acid with large reservoirs of aluminum and iron, large reservoirs of P can build up in cranberry soil. Unfortunately, much of the P is, at best, poorly available to the plant. The only elements that are more available in acid soils are the minor element metals iron, manganese, zinc, and copper.

Salt index and salt injury

All common mineral fertilizers are salts. The 'salt index' was developed as a standard of comparison among fertilizers. The salt index measures the potential soil solution salt concentration that will occur as the fertilizer dissolves in the soil water. If the soil solution becomes to salt laden (concentrated), it becomes difficult for the plant roots to take up water. Such salt effects are not specific to a certain element but rather to the overall concentration in solution.

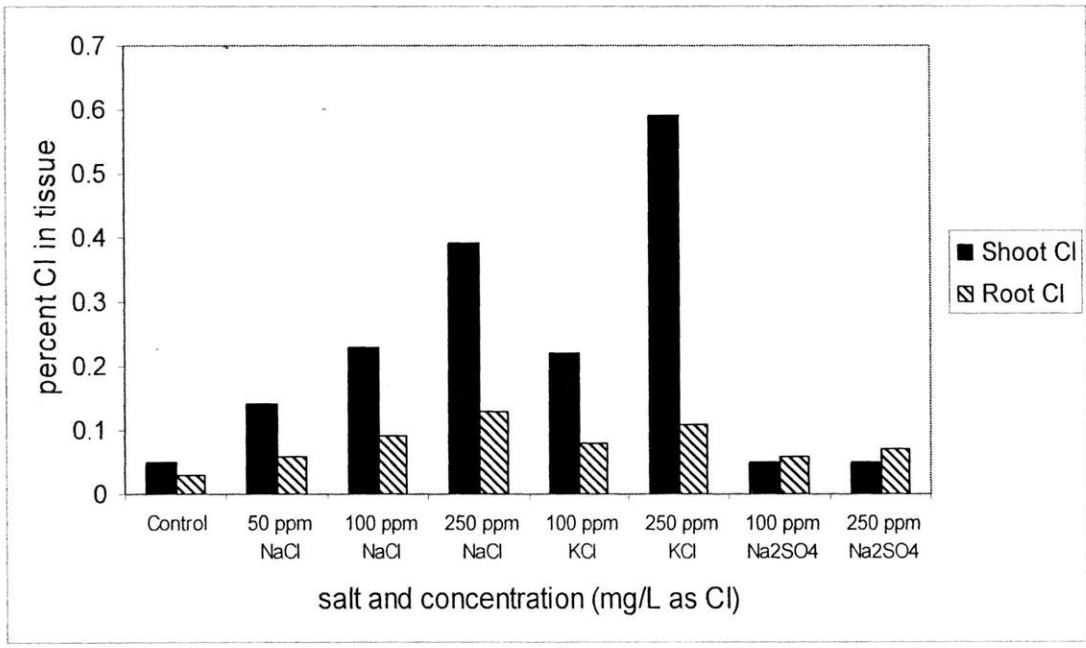
The standard of comparison for the salt index is sodium nitrate whose value is set at 100. Generally other N sources are at or less than 100. Most P sources are between 20 and 30. K sources can be much more variable with most between 40 and 60 with the exception of KCl (muriate of potash, potassium chloride) at 116. Potassium sulfate and SulPoMag are 43.

In addition to generalized salt effects related to salt index, specific salts may present challenges for some plants. In a greenhouse study of lingonberry (a Vaccinium related to cranberry), yield declined and growth was stimulated with increasing concentrations of chloride (Cl). Salt injury to cranberry vines has been observed following east coast hurricanes and in areas that receive highway treatment overspray in the winter. In both instances, the salt in question is sodium chloride (NaCl). Finally, growers have reported that they can 'shut down' cranberry growth with have rates of KCl

(0-0-60). So the question is -- are we looking at a general salt effect or a specific toxicity of Cl (or Na)?

In Massachusetts, we did a study looking at the interaction of K form (KCl, 0-0-60 or K_2SO_4, 0-0-50) and rate with N rate. Plots were set up in a grid pattern so that rows received various K rates and forms while columns received high or moderate N rates. The results showed that K at 100 or 200 lb/A gave higher yield than that in zero K rows. After the first year, yield declined in the high N columns and fruit rot increased. Further, increasing K rates with either source did NOT overcome the deleterious effects of high N. So, we could not shut down growth and restore yield but neither did we observe any damage to the plants with KCl application at these rates.

In order to further investigate the possibility of Cl toxicity in cranberry plants, a cooperative project was initiated by researchers at UMass, University of Wisconsin and Washington State University with funding from the Mass Highway Department. In a greenhouse study in sand culture, cranberries exposed to 250 ppm Cl in irrigation water showed leaf reddening with Cl provided as NaCl *or* KCl. At lower concentrations, runner production was stimulated and at 250 ppm as KCl, many plants died. The figure below shows the Cl concentration in plant tissue after several months of exposure to contaminated irrigation. Not surprisingly, the Cl in the shoots rose as the concentration of Cl in the irrigation water was increased from 50 to 250 ppm.



However, it was notable that when 250 ppm Cl was provided as KCl, more Cl accumulated in the shoots than when that same amount of Cl was provided as NaCl. This is a good indication that KCl (0-0-60) at high rates may not be suitable for cranberry production.

Fertilizer choices for cranberry

Ammonium is the recommended form of N for cranberry production due to its ready uptake by the plants (10 times greater than nitrate), its slow conversion to nitrate in acid soils, and its lower leachability compared to nitrate. Urea, organic fertilizers, and many slow release materials deliver N as ammonium during their breakdown. P is supplied primarily as phosphate (ammonium phosphate or triple super phosphate). The preferred form for K is the sulfate as previously discussed even though this form generally costs 50% more than the chloride.

Most growers use complete fertilizers, those that contain N, P, and K. Since most growers fertilize based on the rate of N to be delivered, choice of NPK ratio is important to determine the P and K that a bog will receive. In the past, many growers used N:P rations as high as 1:4. Current recommendations call for no more than a 1:2 and often a 1:1 is preferred. Custom blends are becoming more available and affordable. This allows a grower to choose a fertilizer based on plant needs and environmental considerations, so that only what you need is what you get. When choosing a cranberry fertilizer, the following should be considerations:

- method of application
- uniformity of material
- cost
- N:P ratio no more than 1:2
- N as ammonium
- K as sulfate