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MATING DISRUPTION FOR INSECT CONTROL: WHERE ARE WE?

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Introduction.

Many pests are the most damaging when in their juvenile stages. Most of our pest management practices, including the use of insecticides, target the damaging stages. Using these approaches, sometimes damage can occur between the time the pest problem is recognized and control is conducted. One novel insect control approach, "pheromone mediated mating disruption," interrupts the reproductive cycle so that no eggs or young are produced.

Pheromones are volatile chemical odors involved in communication between individuals of the same species. Lots of animals, including most insects, produce pheromones. There are several different types of insect pheromones. One type that is used in pest management is called sex pheromone. Individuals of one gender produce and liberate the chemical to attract individuals of the other sex for mating purposes. Almost every type of insect produces its own unique pheromone.

Once the chemistry of a pheromone is determined, we can use that information in several ways in pest management. Artificially synthesized pheromone is used to bait lures to trap insects. This is used to monitor flight and egg-laying periods so that controls can be more precisely timed. In addition to monitoring, pheromones can also be used to control insect populations. Although several methods have been tried, the one most widely used, and with greatest application to cranberry, is mating disruption. Although biologically quite complex, it is probably most easily explained as follows. Female moths produce a very small amount of pheromone to attract males. By artificially increasing the amount of pheromone in the field much higher than what females produce, males can not find the females. Mating does not take place; eggs are not laid; larvae are not produced.

A little history.

The science of pheromone research is very young. The chemical nature of the first insect pheromone was discovered only in 1959. But mating disruption was already being proposed as a possible control method by the early 1960s. The first successful, but very limited, field trial was conducted in 1967. Work on cranberry pests was started in 1992 in British Columbia, Canada, by Dr. Sheila Fitzpatrick, working with blackheaded fireworm. In 1996, both Dr. Fitzpatrick and Dr. Tom Baker started conducting field work in Wisconsin. Work on mating disruption of sparganothis fruitworm was started in 1997 in New Jersey by Dr. Sridhar Polavarapu of Rutgers University. A large two-year project looking at mating disruption of both species was started in Wisconsin in 1999 by Dr. Mahr of the University of Wisconsin - Madison, in collaboration with several scientists.

Target pests.

Mating disruption is still somewhat limited in scope because of a variety factors. It is probably most widely used in perennial crop situations, such as orchards, vineyards, and forests. But it also has use in annual crops, and is used world-wide for the control of an important pest of cotton. It is used mostly against a variety of types of moths. Moths are mostly nocturnal and have a great need for chemical communication. The chemistry of moth pheromones has been substantially researched, and the chemical nature of the pheromones of over a hundred species is known. Also, moth larvae are often key pests in many crops, and these key pests dictate pest control practices. In some situations, the use of conventional pesticides has been greatly reduced when mating disruption has been adopted. Mating disruption is a method approved and supported by the U.S. Forest Service for controlling the spread of gypsy moth, a serious pest of rural and urban forests. Each year, the United States treats hundreds of thousands of acres to contain gypsy moth. Where conventional insecticides are used, there is significant impact on non-target species. Mating disruption is effective and is preferred because it is so specific. Nearly 80,000 acres in Wisconsin will be treated with gypsy moth pheromone in 2001. Another important example is codling moth, which historically has been the key pest of apples in Washington state. Tens of thousands of acres are treated yearly with codling moth pheromone. Because of its selectivity, beneficial natural enemies of other pests are being conserved using this approach, and there are fewer secondary pest problems.

Benefits and drawbacks.

Interestingly, the same aspects of mating disruption that contribute to its benefits, namely its specificity and low use rates, also contribute to its drawbacks. Pheromones are not intended, in nature, to be toxic, so their toxicity is very low and they are considered to be very safe to use. In addition, they are active at very low concentrations. Even the "large" amounts that we use for mating disruption amount to only grams per acre. Because of their high degree of specificity there are very few impacts on non-target organisms such as wildlife, fish, pollinators, and beneficial insects important in biological pest control. This may result in a decreasing need for insecticidal control of pests of secondary or occasional importance that may be adequately controlled by their natural enemies. Another potential benefit to a few growers is that some types of pheromone deployment technologies are likely to be approved for organic production.

The drawbacks of mating disruption relate entirely to the cost of this technology. Because use rates are low, and crops such as cranberry are of limited acreage, there is no "economy of scale" in producing the pheromone. Costs are expected to decrease as manufacturing technology becomes more efficient and as usage rates decrease, but currently season-long control of a given pest is at least somewhat higher with mating disruption than with conventional insecticides. Because of their selectivity, a different pheromone is needed for each pest species; where pheromone technology hasn't been developed, other pest control methods are necessary. This adds to the total overall cost of pest management, especially if a farm has perennial problems with more than one type of serious pest.

Pheromone deployment methods.

Several methods have been developed to deploy pheromones in agricultural settings for mating disruption. Two different methods have been commercialized for use in cranberry. Microencapsulated sprayable pheromone has been developed and produced by 3M Canada, and, starting in 2001, will be marked through an agreement with Rohm and Haas Chemical Company. These products are formulated as liquids to be applied through conventional pesticide application equipment. They are labeled for application by aircraft, ground equipment, and chemigation. All three methods have been evaluated in our research with apparently equivalent results. Sprayable pheromone needs to be applied once or twice per generation, depending on population size and flight duration.

The second deployment method involves point-source applicators. Essentially, these are small plastic bags filled with pheromone; these are called MSTRS®. They are hung on stakes so that they are a foot or so above the tops of the vines, at a rate of eight per acre. One deployment lasts for an entire flight period.

In side-by-side research trials for the past two years, the two deployment methods resulted in statistically identical results as measured by trap captures in decoy-female traps.

Research results: blackheaded fireworm.

Based on the favorable early research in British Columbia and Wisconsin, funding was acquired to conduct two final years of research on blackheaded fireworm mating disruption. This research was conducted in 1999 and 2000.

Methods. Four farms each were chosen in central and northern Wisconsin. Each farm had one plot (replicate) each of four different treatments: sprayable pheromone, mechanical MSTRS, MSTRS Baggies, and no pheromone. Each plot was 4-11 acres. Cooperators had final say on all pest management decisions, and insecticides were used for various target pests on virtually all research plots in both years. Three types of data were gathered: pheromone trap data, sweep samples for larvae, and fruit injury at harvest.

Results. In both years and on all farms, all pheromone treatments drastically and significantly (by statistical measures) reduced the number of male moths captured in "decoy female" sticky traps. These traps were baited with special lures loaded only with sufficient pheromone to mimic the output of an individual female moth. The following graph is representative of the flight data collected during the two year period. Note that it is only from the beds that were not treated with pheromone that we had large trap catches. The numbers of fireworm on the northern farms in this study were very low, but, other than the numbers being only a tiny fraction of those from central farms, the lines are similar.

Larval populations were low in all of our research plots. There were no significant differences in either numbers of larvae in sweep samples or amount of fruit injury between any of the plots. In other words, pheromone-treated plots had no more larvae nor suffered greater injury than the standard insecticide-treated plots. However, bear in mind that pheromone plots were also treated with insecticides as necessary.

Dr. Fitzpatrick is continuing her research in British Columbia, and has been monitoring farms that are using mating disruption on a commercial scale. Her results continue to be positive, and farms that are committed to mating disruption have generally had very favorable levels of control.

SCOUTING AND CONTROLLING CRANBERRY INSECTS

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The University of Wisconsin started its cranberry Integrated Pest Management (IPM) program in 1986. With continuing university involvement, the cranberry industry, partnering with private and corporate pest management consultants, has overwhelmingly adopted IPM philosophies and methods such that the industry is widely recognized as a leader in IPM use. Routine pest monitoring (also called "scouting") is an integral component of all IPM programs. With the current economic situation facing the industry, some growers have been forced to abandon professional IPM consulting. The purpose of this presentation is to provide information on how growers can conduct their own insect IPM programs, with emphasis on pest scouting.

Insect Scouting: Some generalizations.

In order to be effective, insect scouting must be part of the weekly crop management routine. Failure to scout for as little as a week or two can result in significant crop damage. Although scouting is usually done weekly, certain scouting activities can be done more frequently (every 2-4 days) as a particular event, such as egg hatch or moth flight is anticipated.

Scouting is a "hands-on" activity. Although driving the dikes and observing the planting from the cab of a pickup can be an integral part of scouting, the real important aspects are done down amongst the plants.

Typical pest scouting activities include

- using pheromone traps
- using an insect sweep net
- careful observation for things out of the ordinary
- keeping accurate records.

Insect Scouting: Equipment needed.

- ✓ A good set of eyes.
- ✓ A good quality, large-field, 10-15x magnifying glass (hand lens).
- ✓ An agricultural insect sweep net, with a standard 15" diameter rim.
- ✓ Pheromone traps and lures.
- ✓ Small containers to catch and store unknown samples for later identification.
- ✓ Data forms and bed maps for recording problem areas and scouting data.
- ✓ Survey flags for marking problem sites.
- ✓ A shovel to look for soil insects.

- ✓ Knowledge of pest identification, pest biology, action thresholds, etc.
- ✓ **Commitment!**

Insect Scouting: Be a keen observer.

Observe beds from the dikes to look for damaged, weak, or discolored areas. Check such spots up close in an attempt to discover the cause of injury. Don't forget to check the soil for insects such as white grubs or the larvae of cranberry girdler or flea beetle. If damaged spots require further examination or treatment, mark with a wire flag. Watch for unusual bird activity foraging in the vines as birds like grackles and starlings may be foraging for insects.

Closeup observations should be conducted while sweep sampling. In each area swept, inspect the vines closely in two arbitrarily chosen spots. Look closely for insects, their webbing, or damage to leaves, flowers, or fruit. Some insects such as cutworms and armyworms are nocturnal (active at night); these tend to hide low in the plant canopy during the day. Collect any unknown insects and get someone to help in identification.

Insect Scouting: Sweep sampling.

Sweep sampling is one of the most effective and commonly used methods to monitor agricultural pests. Be sure to use an agricultural sweep net with a standard 15" diameter rim. Smaller nets are available for general insect collecting, but action thresholds are based on a 15" net.

In cranberry, sweep sampling is most useful for fireworm, sparganothis, spanworms, cutworms, and flea beetle adults.

Sweep sampling is normally done during daylight hours. Vines must be dry in order to keep the net from getting waterlogged. Although night sampling has been shown to catch more nocturnal insects, action thresholds are based on daytime sweeping. Sweeping should continue to be conducted as the berries continue to size, but sweep only the new growth at the tops of the plants in order to prevent premature harvest of fruit by the netfull.

Sweep samples are taken in continuous sets of 20 sweeps. The number of sets varies with size of bed, with a minimum of two sets in small beds (of 1 acre or less). Large beds (6-8 acres or more) should have a total of 6 sets taken; beds of intermediate size require an intermediate number of sets of sweeps. Sweeps should be taken both along the bed margin ("exterior"; within 5 ft of the edge) and in the interior part of the bed (at least 15 ft from the closest edge). Bed edges tend to warm faster in the spring, and both plant growth and insect activity often starts first along the edges. Therefore, sampling here gives you a head start on activity that will soon be more widespread throughout the bed. However, more sets of sweeps (and accompanying visual samples) should be conducted in the bed interior where the majority of the vines occur. If you do only two sets of sweeps, take one exterior set and one interior set. For larger beds, take one exterior set for every two interior sets.

Insect Scouting: Using pheromone traps.

A pheromone is an odor used by individuals of the same species for chemical communication. One type is called sex pheromone. These scents are given off by adults of one sex (usually females) to attract members of the opposite sex (usually males) for mating purposes. Almost each insect species has its own unique pheromone. These chemicals are identifiable and can be artificially synthesized. When a female sex pheromone is loaded into a lure and placed in a trap covered with sticky material, it attracts males that come to the trap and are captured. Because the lures are very powerful, they can result in the capture of males even when population levels are very low, such as at the beginning of the seasonal flight period. Such lures and traps are used to monitor hundreds of types of insects in dozens of types of crops worldwide. In cranberry, pheromone traps are commercially available for blackheaded fireworm, sparganothis fruitworm, cranberry girdler, and cranberry fruitworm.

There are three main reasons to conduct pheromone trapping. First, it is an excellent first indicator with moths are starting to fly and lay eggs. Even though only males are caught in the traps, females are flying at essentially the same time. The capture of first moths in a generation can be used to predict when egg hatch is going to be, either by using rough estimates or more precise degree day models. Because insecticides generally work best against the youngest larvae, pheromone traps are very important tools in timing insecticide applications.

A second function of pheromone trapping is that, if the data are kept from year to year, you get a relative indication of how big the population is in any given year. However, trap catches are not precise enough to use as action thresholds.

A third function of pheromone trapping is in conjunction with pheromone-mediated mating disruption (see article elsewhere in this proceedings). Here, two types of traps are used, one with a conventional high-strength monitoring lure to identify the beginning of flight, and a second lure with a very low dose of pheromone to determine if mating disruption is still occurring or if there is a need for an additional pheromone application.

We recommend using one trap for each species every 10 acres, with a minimum of two traps per section of beds. Place traps within the beds, where they will get minimal water damage from sprinklers, and so that the prevailing winds blow the pheromones over the beds, not immediately out of the bed. Label the traps as to the insect species and the date the fresh lure was put into the trap; be sure to use a waterproof marker such as a "Sharpie." Lures should be replaced every 2-3 weeks; do not leave old lures within the beds. Traps should be changed as needed as they weather or become filled with insects or debris. Traps should be checked at least weekly and records kept of the trapping results.

Note that although the pheromones are relatively specific, occasionally other insects can be attracted to the traps or randomly fly into them. Therefore it is helpful to be able to recognize the appearance of each moth species.

Insect Control: Some brief economic considerations.

Generally, decisions about pest management are based on economics. If the pests are causing more damage than the price of controlling the pests, then it is economically advantageous to control the pests. In the following sections on specific insects, we make reference to specific "economic thresholds" at which control is normally recommended. However, the thresholds provided were researched when the value of berries was at least

$50 per barrel. Although new thresholds have not been researched for the current market, when prices are low, higher insect populations can be tolerated before controls are justified. These pest management decisions are short-term, based upon the current value of the crop and the current numbers of pests. (See the more detailed discussion about Economic Injury Levels in the Proceedings of the 2000 Cranberry School.)

Pest management decisions must also be based on long-term economics, especially in perennial crops such as cranberry. There are two long-term considerations. First, the plants must be maintained in sufficient health to be vital and productive. Insects that impact leaves, stems, or roots can be sufficiently bad to seriously stress plants or even kill them outright. At least some minimal pest management program must be conducted to maintain plant health. A second long-term consideration involves reduction in fruit quality at harvest by insects that damage the surface or bore into the fruit. A high incidence of damaged or infested fruit has, in some types of crops, resulted in the reduction in value or even the rejection of the crop by handlers. Therefore, although the immediate economics of pest management may not justify substantial control costs, it will continue to be important to keep large populations of fireworm, fruitworm, and sparganothis from developing.

Blackheaded Fireworm: Summary of biology and damage.

Blackheaded fireworm (BHFW) has historically been one of the most serious pests of cranberry in Wisconsin. There are two generations per year. Young larvae appear at about the time plants are coming out of dormancy. This generation feeds on foliage, causing it to turn brown. Leaves and the tips of uprights are webbed together. In addition to foliage, the summer generation also feeds on the surface of fruit.

Blackheaded Fireworm: Scouting.

- ✓ Observe for webbed uprights. In first generation this will first be seen along bed edges next to ditches.
- ✓ Sweep sample for larvae. Threshold is an average of 2 larvae per set of 20 sweeps.
- ✓ Use pheromone traps to determine beginning of flight and peak flight, and to time controls.
- ✓ Scouting for egg hatch is possible but not always conducted. Egg hatch will be underway about 3-5 days after peak flight, which often is during bloom for second generation.
- ✓ Remember that other insects can cause fruit and foliage damage similar to that of BHFW.

Blackheaded Fireworm: Summary of control.

Flooding is one effective option to control first generation BHFW. The flood should occur after most of the overwintering eggs have hatched. The flood should be totally over the top of the vines for 48 hours, although floods of shorter duration will be partially effective. Try to pick a period that will be cool and overcast. If it is predicted to be warm and sunny, apply the flood late in the day and hold it as long as possible into the following day. For more information on flooding, see the Proceedings of the 1992

Wisconsin Cranberry School.

Pheromone-mediated mating disruption is an effective control of BHFW. See the article elsewhere in this Proceedings.

Chemical control is still the most commonly used method for BHFW control. Insecticides should be applied shortly after peak egg hatch. Orthene, Lorsban, Diazinon, and Imidan are effective materials used by many growers; other effective materials are also available (see current UW Extension Cranberry Pest Management publication). In first generation, insecticides should be applied in the morning for day-long activity if frost protection is anticipated that night (sprinkling may wash off effective residues). Second generation BHFW often occurs during bloom. Confirm, which can be used during bloom without an impact on pollinators, is recommended; follow label recommendations for timing. Two applications of Confirm may be necessary. Microbial insecticides containing *Bacillus thuringiensis* (Bt) can also be used during bloom; use as soon as possible as eggs hatch; thorough coverage is important and at least two applications are usually necessary.

Spanworms: Summary of biology and damage.

There are several species of spanworms or loopers (also called inchworms) that can damage cranberry. Most occur from early season through the blossom period; some occur while fruit are developing. Examples include green spanworm, rannoch looper, spiny looper, and big cranberry spanworm. Each has just one generation per year. Larvae do not produce noticeable webbing and are generally bigger than fireworm and sparganothis. Spanworms feed on leaves, buds, and flowers and may nibble on the surface of fruit. Spanworms are often patchy in distribution with a bed.

Spanworms can be confused with armyworms and cutworms, but action thresholds are quite different, so the scout must be able to distinguish the two groups. Generally, spanworms walk in an inchworm fashion while armyworms and cutworms walk in an undulating manner (however, some of the latter group "inch" when they are young). An important distinction is the arrangement of the legs (see cartoons below).

Cranberry Disease Management: Impacts of Letting It All Go

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The recent economic crisis in the cranberry industry has called into question every ounce of pesticide used and every hour of labor invested in spraying to manage disease, insect, and weed pests. In an effort to reduce production, questions are being raised regarding the long-term impacts of not spraying and in some cases, not harvesting or only partially harvesting beds. These questions are hard to answer because up till now, pest management research has focused on maximizing yields. However, if we piece together everything we know about the biology of cranberry pests and their history on Wisconsin marshes, we can attempt to predict the risk of "letting it all go" for the major types of diseases in Wisconsin: fruit rots (including cottonball, field rot, and storage rot); leaf spot diseases; and shoot (upright) diseases.

Cottonball. The disease cycle and biology of cottonball have been covered at length in previous Cranberry School Proceedings. Briefly, the fungus *Monilinia oxycocci* invades flowers and fills fruit with the fungus. The diseased fruit harden into mummies, which serve as the overwintering stage. In the spring, small mushrooms grow from the mummies and release spores. The spores infect newly elongating cranberry shoots. Just before and during bloom, infected shoots turn brown and become covered with *Monilinia* spores. These spores are carried by wind and/or bees to flowers, starting the cycle anew.

In weighing the long-term impact of not controlling cottonball, the following points should be considered:

- The fungus absolutely depends on fruit to complete its life cycle—it cannot overwinter in leaves or wood.
- The fungus not only overwinters as mummies but persists, possibly for decades, in this form.
- If there are no fruit, there will be no new mummies formed. So, one way of reducing disease, if you don't care about yield loss, would be to prevent fruit set altogether (e.g., freezing or flooding).
- Harvesting removes most mummies. Harvesting is possibly the most effective way to control cottonball.
- Not harvesting will increase the pathogen population in the field.

Bearing these points in mind, the long-term impact of not controlling cottonball would be a steady increase in disease. In the future, a more intensive fungicide program would be needed to bring cottonball under control. The long-term impact of not harvesting cottonball-infected fruit would be similar to not spraying, but the effects might be felt sooner. Although it has not been tested experimentally, harvesting is almost certainly more effective than spraying a fungicide to reduce the population of the pathogen. The bottom line: Don't let a cottonball-infested bed go unharvested, or partially harvested. At least not for many years in a row.

Fruit rot. Fruit rot is generally broken into two categories: field rot, which occurs before harvest and impacts all growers; and storage rot, which occurs after harvest and impacts fresh fruit growers. Fungicides are marginally effective in controlling storage rot, and most fresh fruit growers make at least one spray per season. Because field rot disease pressure is generally low in Wisconsin, fungicides have rarely been used by processed market growers, even when profit margins were high. This no/low fungicide input program has been the rule for many years in Wisconsin, and we have not seen an increase in field rot. There are occasional bad years (1998, for example), but there is no evidence that one needs to spray the following year to bring field rot under control. Rather, it seems the weather in any given year is the deciding factor. So the long-term impact of not spraying for fruit rot would be little or none.

What about not harvesting or only partially harvesting? Intuitively, one would expect this to be a disaster—all that rotten fruit sitting in the field waiting to infect next year's crop. Indeed, it would be a mess, but the impact on fruit rot would probably not be great. Here's the rationale:

Research in the Cranmoor area shows that in most beds, fruit rot at harvest is around 5% or less. So, an unharvested bed would contain 5% rotten fruit and 95% healthy fruit. Healthy fruit usually contain fungi, but these fungi are predominantly non-pathogens or the very weak berry speckle pathogen *Phyllosticta elongata*. So, healthy fruit probably don't carry a lot of pathogen inoculum through the winter. Also important is the fact that most fungal pathogens sporulate profusely on old or dead leaves but not so much on fruit. And leaves outnumber fruit by far. So, even if pathogens *did* overwinter in unharvested fruit, the amount would be negligible compared to the amount overwintering in all those leaves. Harvest removes leaves as well as fruit, but more leaves get left behind than get harvested, and previous history in Wisconsin suggests that they don't cause big fruit rot problems in most years. So the long-term impact on fruit rot of not harvesting would probably not be noticed.

Leaf spot diseases. Many different fungi cause spots on cranberry leaves in Wisconsin. In general, these fungi do not affect fruit quality directly, but one of them, the red leaf spot fungus, can make a small wound on fruit through which the black spot fungus infects. In rare cases, leaf spot diseases are so severe that they contribute to premature leaf drop (leaves drop in the second rather than the third year). Very little research has been conducted on leaf spot diseases, so making predictions based on biology is difficult. However, based on experience, we know that healthy, vigorous plantings will stay that way for decades without spraying for leaf spot diseases. Likewise, beds with severe leaf spot problems will stay that way if not sprayed. So, the impact of not spraying on healthy beds would be none, while diseased beds would continue to be diseased. Leaf spot fungi carry out their lives on leaves rather than fruit, so not harvesting should have little impact on long-term health a bed.

Shoot (upright) diseases. Several diseases affect uprights—upright dieback, Phytophthora root and runner rot, and stem gall (canker) are a few. However, the most common causes of dead uprights are probably not living (biotic) factors but rather are non-living (abiotic) in origin. This would include winter injury, drought or heat stress, poor drainage, and chemical injury (e.g., fertilizers and pesticides). Unfortunately, "dead upright" symptoms look similar, at least at first glance, no matter what the cause. To figure out the problem, one has to take a much closer look at the uprights themselves, the pattern of death in the field, and when during the season symptoms appeared. Upright dieback, stem gall, and Phytophthora were discussed in detail in the 1999 Cranberry School Proceedings.

Stem gall (canker). Of all the causes of upright death, this is the easiest to identify. A close look at uprights and/or runners reveals swollen stems with rough and splitting bark. A closer look with a hand lens reveals that small galls and bumps are the cause of swelling and splitting. Stem gall is apparently caused by bacteria that go berserk under certain conditions. Uprights are killed, but runners send out new shoots, so a planting usually recovers from stem gall within a few years. The bacteria are not controlled by fungicides, so not spraying should have no impact on stem gall. The bacteria might infect through wounds created during harvest, so not harvesting might actually help a bed recover from the disease.

Upright dieback. This disease is characterized by orange-bronze uprights scattered among healthy uprights. The shoot dies from the tip back, and dead shoots are often adjacent to healthy shoots on the same runner. The cause is believed to be the fungus *Phomopsis vaccinii*, which infects during shoot elongation. The fungicide Bravo is applied one to three times from budbreak up to early bloom. In beds with chronic upright dieback, not spraying would probably result in the disease persisting and possibly being severe if mid-summer weather were very hot. Under such conditions, viscid rot (a fruit rot caused by *Phomopsis*) might flare up. *Phomopsis* overwinters and carries out its life cycle primarily in shoots, so not harvesting should not have a great impact on upright dieback.

Phytophthora root and runner rot. In Wisconsin, we don't have the worst species of *Phytophthora* (*P. cinnamomi*), and most cases of Phytophthora root and runner rot can be resolved by improving drainage. In fact, without good drainage, the fungicide available for controlling this disease, Ridomil, will not help. Ridomil has generally been recommended only when *Phytophthora* persists despite good drainage, conditions which are rare. The long-term impact of not spraying under such conditions would probably be the continued decline and death of uprights, especially if large amounts of water are needed for frost protection and/or irrigation. *Phytophthora* thrives in water. Not harvesting would limit water movement during fall when *Phytophthora* is active. The lack of harvest flood might ultimately reduce the growth and spread of *Phytophthora*, thereby allowing a bed to recover from root and runner rot.

Weed Management and Identification

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Understanding the ecological relationships that underlie the interactions between weeds and cranberries is critical for successful weed management. In addition, versatility in correctly identifying the predominant weeds on a commercial bog is also essential. This paper discusses the place of weeds as part of an ecological framework that enables us to think about the present state and the future development of weed IPM and action thresholds in cranberries. Weed mapping, as well as the distinguishing features among grasses, sedges, and rushes, will also be discussed.

Weeds can be described in a variety of ways. Often, we assign anthropomorphic terms to weeds. They are "aggressive", "competitive", "undesirable", or "unsightly". Often they are defined as "plants out of place" (Radosevich et al., 1997; Zimdahl, 1999). Most certainly, weeds are plants of minor economic value that compete directly with desired agricultural activities. Weeds can also be described from a biological perspective. They are successful colonizers of disturbed habitats (e.g., new plantings). They are noteworthy for their high germination rates (annuals), vigorous vegetation reproduction (perennials), and rapid growth. Often, they have unspecialized needs for pollination, which promotes genetic variability and reproduction. From a biological point of view, weeds are very successful organisms.

How are weeds different from insect pests and how does this affect IPM? Weeds function in the agroecosystem in different ways from their insect counterparts. Weeds are closely related to cranberry vines biologically in that they are both stationary organisms that compete for water, space, nutrients, and light. The distribution of weeds on a farm can be influenced by pH, the presence of (the) water (table), and location (edge or middle). Organisms occur in particular places in time because they are successful at capturing resources from the environment. In other words, they established or occupy a certain niche in the agroecosystem. Our challenge as scientists and growers is to better understand the dynamics that enable a weed to be more successful at capturing resources than the cranberry plant. The next steps would be to manipulate the farm environment to make it less susceptible to invasion by weeds and to reduce the farm's vulnerability to weeds. Ultimately, we would find ways to reduce the ability of the weeds to affect the yield and quality of the cranberry. Table 1 lists several points of distinction between weeds and insects and how these affect the implementation of IPM activities.

Table 1. List of distinguishing points between insects and weeds and the impact on IPM activities.

Weeds	Insects
• Weeds are perennials.	• Insect populations may or may not be present in numbers that exceed the action threshold (AT).
IMPACT: "Scouting", in the traditional sense (numbers exceed the AT) is less useful for weed pests.	
• Weeds are typically easier to. control prior to emergence.	• Insecticides usually work best as a contact or systemic after the pest is present.
IMPACT: Use of weed mapping allows you to make management decision ahead of time.	
• Weed damage depends largely on weather, which affect weed-vine interactions.	• Insect damage is usually less dependent on weather.
IMPACT: Precise ATs are more difficult to establish for many weed pests.	
• Many weed species are present at any one time.	• Few key insect pest are present simultaneously.
IMPACT: Strategies must be broad-based in many cases.	
• Weeds and cranberries are both plants. They are more similar to each other than insects.	• Insects are biologically dissimilar to vines.
IMPACT: It is challenging to develop controls that will harm weeds and not harm the vines.	

Correct identification of weeds is key. Flowering plants are divided into two major groups: monocotyledons and dicotyledons. This dichotomy is based upon the number of leaves that emerge from the seed. Monocots have one true seed leaf. Examples of monocots include the grasses, sedges, and rushes. Dicots have two true leaves upon emergence and examples include broadleaf plants. Monocot leaves are characterized by parallel veins. The flower parts (petals, sepals) of monocots are typically in 3's and 6's. Dicot leaves have netted venation and their flower parts occur in 4's and 5's.

It is important to have good identification manuals. If a weed is abundant on your farm and you need to be certain of its identity, be sure to contact your extension personnel for verification. Be especially vigilant about getting misled by common names of plants because they can be confusing. For example, broom sedge is actually a grass; woolgrass is really a sedge; and an entire group of sedges are called bulrushes. For additional information and excellent illustrations on the differences between these monocots, see the University of Massachusetts-Dartmouth publication by J. Sears (Sears et al., 1996).

Table 2. Summary of distinguishing characteristics of grasses, sedges, and rushes.

	Grass	**Sedge**	**Rush**
Stem	hollow, round	triangular	solid, round
Leaves	usually flattened	usually V-shaped	usually reduced
Leaves	in two's	in three's	much reduced
Fruit	single seed	single seed	multi-seeded fruit
Nodes	present	not present	not present
Ligule	may be present	not present	not present

Weed Mapping. Weed mapping is currently the best tool we have to monitor and track weed populations on the cranberry farm. It is recommended to weed map every year, but since many cranberry weeds are perennials, an every other year cycle may also be appropriate. Priority groups have been established based on three criteria (Else et al., 1995): the potential of the weed to cause yield loss, the rate of spread, and the difficulty of control. ***Priority One*** weeds (zero threshold) cause severe losses, spread rapidly, and are difficult to control. Examples would include dodder (*Cuscuta gronovii*), dewberry (*Rubus hispidus*) and silverleaf (*Smilax glauca*). Weeds in ***Priority Two*** are of serious concern. They are less damaging to yields than those in Priority One, but they are still aggressive and difficult to control. Examples would include narrow-leaved goldenrod (*Euthamia tenuifolia*), greenleaf (*Smilax rotundifolia*), and asters (*Aster* spp.).

Weeds of less importance are grouped in ***Priority Three***. Weeds in this group may reduce yields, but yield impact is low. Spread or growth of these plants is relatively slow. Control is not as difficult as with Priority One and Two weeds. Priority Three weeds might include perennial sedges and grasses, rushes, and red maple (*Acer rubrum*). The lowest concern weeds are placed in ***Priority Four***. These species are primarily found in bare spots, weak areas, or along bog edges. Most are relatively easy to control. Weeds in this group include clover (*Trifolium repens*), white violet (*Viola lanceolata*), and annual grasses.

Growers should prioritize their own weed populations into a system that works best in their particular situation. Expenditures to gather this type of information must be balanced by the benefits of the information gained. In general, weed mapping according to the above scheme can be done fairly rapidly and economically. It is helpful to use a pre-drawn map that includes landmarks such as sprinkler heads. More labor-intensive activities (utilizing current technologies) would include GPS and GIS systems. These systems permit very accurate plotting and assessment of weed populations, but they require a great deal of time to input and gather the information.

When mapping, consider how the weed populations may be distributed on the farm. This should aid in the precision application of preemergence herbicides. Populations can be distributed in *regularly* (finding one individual predicts very well where you will find another individual), *randomly* (finding an individual has no correlation with where you might find another individual), or *patchy*. Most populations occur in patches. Thus, if you find one individual, chances are very high that you will find another close by. Bear in mind that finding patches of weeds may cause you to overestimate how many weeds you actually have on your farm. You may be just as likely to monitor in a place that has no weeds; here, you will underestimate your weed population. Try to keep this in context when you are assessing weed populations based on a few monitoring locations.

Why haven't ATs been established for cranberry weeds? In fact, action thresholds for weed species in most agricultural commodities have not been established. First, very low densities of weeds can cause significant loss and thus, growers have an "intuitive" feel for excessive levels. In addition, herbicides have been available at very low cost (for most commodities). In cranberries, many of the preeemergence herbicides are quite expensive, so it would be beneficial to try to pursue the establishment of ATs. However, several other obstacles remain in place that hinder the development of weed action thresholds. First, counting individual weeds is very difficult. We need to develop better ways to quantify weed populations. Secondly, plants can change size and impact over the course of their life cycle. This complicates the modeling aspect of precisely defining a threshold. Thirdly, weed communities on the farm are a mixture of species. Complex interactions over nutrients, water, light, and space have yet to be delineated. Lastly, an action threshold model should consider the incorporation of non-economic criteria such as crop quality and ease of harvesting. These are aspects that are important to the grower, but are not typically factored into the development of traditional ATs.

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TAKING AND INTERPRETING SOIL AND TISSUE SAMPLES

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In addition to water, sunlight, and carbon dioxide from the air, plants require 13 mineral nutrients that are typically derived from the soil. The macronutrients nitrogen (N), phosphorus (P), potassium (K) are needed by plants in relatively large amounts and often have to be added to the soil. Intermediate amounts of secondary nutrients magnesium (Mg), calcium (Ca), and sulfur (S) are needed by plants. Trace or micronutrients [boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo) and zinc (Zn)] are needed in small amounts and are seldom deficient in Wisconsin soils.

In a healthy plant the essential mineral elements are present in adequate levels and in correct proportion to other elements. Plant productivity or fruit quality is reduced if:

- one or more of the required elements is not present in sufficient quantity (deficiency);
- one or more elements is present in too great a quantity (toxicity);

These nutrients perform a variety of functions in plants ranging from being structural components of cell walls and membranes to activating enzyme systems. About 95% of the dry weight of a typical plant is made up of carbon, oxygen and hydrogen. The soil supplied minerals make up only 5% of a plants total dry weight.

The nutrition of plants and animals is very different. While animals need proteins, carbohydrates, vitamins and minerals to be healthy, plants need only water, air, sunlight and the 13 essential mineral nutrients. No scientific evidence supports the use of vitamins or other similar supplements for plant growth. Plants don't need to be "fed". They simply need adequate supplies of water, air, sunlight and minerals.

While fertilizers can be added to soils to supplement less than adequate nutrient supply, the best plan is to establish plantings on an appropriate soil. The soil pH should be between 4.5 and 5.5 for optimum production. Soils can either be peat or sand based.

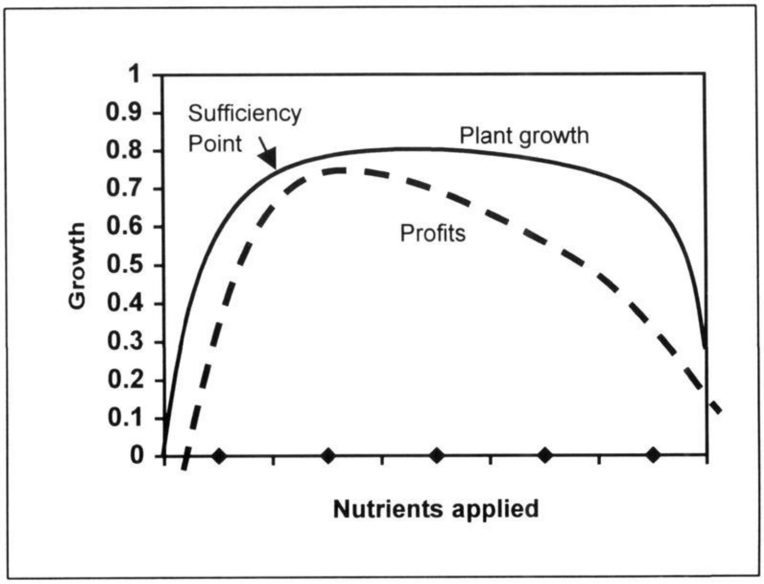
Plant response and soil fertility

Soil fertility can be thought of as the ability of the soil to supply nutrients needed for optimum plant growth. A soil test is the most practical way of measuring the nutrient supplying power of the soil and telling if fertilizer and/or pH adjustment are needed before planting.

Fertilizers are applied to supply essential nutrients that may be in short supply or unavailable to plants from the soil. Plants absorb nutrients from the soil and use them to produce new growth or fruit. The application of agricultural fertilizers has greatly increased crop yields over the past 50 years by eliminating nutrients as a major limitation to yield.

When a particular nutrient is in short supply, application of additional nutrient will increase growth and yields (Fig. 1). Initially this may be a linear response where yield increases one unit per unit of fertilizer added. At some point the response levels out and yield increases become less pronounced as additional fertilizer is applied. For cranberry, this is followed by a decline where yield is reduced with additional applications of nutrients (especially nitrogen) as rank vine growth ensues. Sometimes, plants may continue to absorb nutrients without having a corresponding increase in plant growth. This is known as luxury consumption. At the far end of the figure there is a point where excessive nutrient levels, especially micronutrients, may become toxic to plants and will further reduce yields. The goal in applying fertilizer is to supply enough nutrients to provide optimal plant growth without supplying too much fertilizer.

Figure 1. Plant and profit response



Diagnosing the mineral nutrition status of fruit crops

Fruit growers have three main tools to use in evaluating the mineral nutrition status of their plantings. These are:

- examine visual symptoms exhibited by leaves, stems, and fruit;
- analyzing leaf tissue and;
- testing the soil.

Used together properly these are powerful tools that can be used to prevent nutrient deficiencies or toxicities as well as to assess current fertility management practices.

Because cranberry vines are perennial, not all nutrients to support a crop must come from the soil each year. The amount of nutrient removed with the crop each year is also not a good approach for recommending fertilizer. A crop of 200 bbl/A would remove about 7 lbs N, 2 lbs P, and 18 lbs K, yet fertilizer in excess of these amounts are needed for adequate yields.

Visual Symptoms

Visual symptoms have been used for many years to diagnose deficiencies of certain elements. Color photographs of various deficiency symptoms have been published as diagnostic tools. However, there are at least two disadvantages associated with this approach as the primary method for estimating nutrient need. First, once the visual symptoms have appeared the crop quality and yield have likely already been reduced. Second, some visual deficiency symptoms look similar while others may be confused with disease, insect or environmental stress symptoms. Further confusion arises when the symptoms from more than one deficient element is confounded by a deficiency or toxicity of another.

Tissue Analysis

Tissue analysis is a powerful tool in assessing mineral nutrition of crops. Chemically analyzing the concentration of nutrients in the leaves of growing crops can more precisely define the nutrient status than an examination of deficiency symptoms. This fact is particularly true for perennial fruit crops. This method is based on collecting samples of tissue in the field and measuring the amounts of mineral elements in the tissue. Tissue analysis provides a "snapshot" picture of the nutrient status of a crop at a particular point in time resulting from all factors that affect plant growth. In addition to confirming suspected deficiencies, plant analysis can also detect toxicities or hidden deficiencies before visual symptoms appear. Experimentation has shown the amounts of the various minerals that should be present in plants to provide optimal growth. These amounts are different for each crop species.

Collecting a sample

The most important part of tissue analysis is taking a proper sample. The sample must be taken at the right time, the correct plant part must be sampled and the sample must be representative of the planting. If an improper sample is collected it will be impossible to draw correct conclusions from the analysis.

Sample at the right time. Plants must be sampled at the proper stage of maturity in order to correctly interpret the results. Nitrogen, for example, is relatively high in new leaves in the spring, levels off in midseason and then declines in the late summer and fall before the leaves dormancy. Interpretations are based on knowing the relationship between nutrient levels in a particular part of a "standard" tissue in a specific time in the growing season. A leaf sample taken in the spring could show excess nitrogen compared to late summer standards and a sample taken in the late fall could show a deficiency even if it were adequate in late summer. Samples taken at a time during the season different than the "standards" used for nutrient interpretation will likely show erroneous results or will at least be “uninterpretable”.

Sample the correct plant part. Sampling a different plant part than the "standards" will also lead to incorrect interpretations of the analysis. For example, the nitrogen content of one-year-old leaves is lower than for current season leaves. If one-year-old leaves are included in a sample a nitrogen deficiency may be indicated, while if only current season leaves are sampled an adequate amount or an excess may be shown. Table 1 shows the correct plant part to sample.

Take a representative sample. The sample should be representative of the planting because the results of the test can be no better than the sample sent in for analysis. The amount of tissue the lab actually tests is less than a teaspoon, so it is very important that the sample be characteristic of the bed. Take samples throughout each bed to be sampled. Begin at one corner and take samples as you walk to the opposite corner or walk a zig-zag pattern in the bed. Don’t sample just along one edge or only in the corners. This won’t provide a representative sample. Don't sample diseased, damaged, insect infested or abnormal tissue. If you suspect a nutrient related disorder, sample early in the growing season. Submit a sample of abnormal appearing tissue along with a sample not showing the symptoms that is collected on the same day. By doing so a comparison of the two samples can be made and a better evaluation can be made between the nutritional status of healthy and abnormal plants.

Include a soil sample with your plant analysis sample. Take soil samples at about the same locations as tissue samples. Soil test results for pH, organic matter, and available P and K can be useful when interpreting the plant tissue results. At the UWEX lab, a routine soil analysis is included as part of the plant analysis program at no additional cost.

Submitting a sample

Once the tissue sample has been collected, it should be prepared for shipment or delivery to the lab. Any soil or foreign material should be dusted off the sample. DO NOT WASH the leaves as this will remove soluble nutrients. Don't separate leaves from stems, but do remove any fruit. If the sample is to be mailed, allow the sample to air dry for one day to prevent mold from forming during shipment. Place the dry sample in a paper envelope for shipping. Do not use plastic or cellophane bags since these retain moisture and promote molding. Try to ship samples early in the week (Wednesday at the latest) to avoid samples deteriorating in warm post offices over the weekend. Plant samples that are delivered to the lab do not need to be air dried if they are delivered within a day after sampling. Please submit an information sheet describing the crop type, date sampled, and other information necessary to make the best interpretations of lab results. Plant analysis information sheets are available from the laboratory or your County Extension office.

Table 1. Proper cranberry sampling for diagnostic plant analysis.

Crop	Stage of Growth	Plant Part	#Plants to sample
Cranberry	Late August to early September	Current season uprights. Include fruiting uprights, but remove any fruit.	6-10 handfuls per sampled bed. About 200 uprights.

Soil analysis

Soil testing is a means of measuring soil pH and estimating the supply of nutrients available for plant growth. There is a poor relationship between soil and plant nutrient levels in perennial fruit crops including cranberry. When plant tissue levels (from tissue analysis) are compared to corresponding soil nutrient contents (from soil analysis), no correlation is found. Therefore, soil testing alone will not provide enough information to make accurate fertilizer decisions for perennial fruit crops.

Reliable commercial soil tests have not been developed for nitrogen, copper or iron. The need for these elements can best be evaluated by plant analysis. Deficiencies of minor elements can better be identified by plant analysis too. Because cranberries grow under acidic soil conditions, some fertility problems are best diagnosed by both soil and tissue tests.

Soil testing

Soil samples should be taken from the same areas as the tissue samples. Take individual samples with a trowel, soil probe, or small shovel. A good sample consists of about 8-10 subsamples, taken to 6 inches, per area. Mix the subsamples and place about 1 cup of soil in a soil bag or pint plastic bag. Identify the bag with the same sample number as the corresponding tissue sample. Submit the soil sample along with the tissue sample for analysis to the lab of your choice. Be sure the bags are sealed tightly so the tissue samples cannot be contaminated with soil. No fee is assessed for routine soil analysis corresponding with a tissue sample at the UWEX lab.

A soil analysis should always be a part of preparing the site before planting. Because cranberries are long lived it makes sense to amend the soil ***prior to planting***. Take soil samples from the site after the beds are formed and the sand lift, if any, is installed. Phosphorus and potassium can be applied before planting and lightly incorporated. A soil test will indicate if preplant pH adjustment is needed.

Interpreting the report

About two weeks after samples have been submitted you will receive a report showing the concentrations of various nutrients in the tissue and soil. Beside each number is a letter designation indicating that the concentration is deficient, low, sufficient, high or in excess for that nutrient. This interpretation is provided only if the plant was sampled at the proper stage of maturity. Soil pH, organic matter and an estimate of plant available phosphorus and potassium will also be reported if a soil sample was submitted. If soil was not sampled, interpretations of plant tissue results will be based on an assumption of optimum soil test results.

The indication that the tissue nutrient concentration is deficient, low, adequate, high or excessive will tell you whether changes in your fertilizer program is warranted. They cannot tell you exactly how much fertilizer to add as that is based on the soil, vigor of the vines, crop load, weather, etc.

Tissue testing can also help determine if a fertilizer program is working. For example, a previous tissue test showed a deficiency of a micronutrient and you had applied this micronutrient in your fertilizer program. However, a later test still showed a deficiency in this micronutrient. Comparing these results suggests that a change in your fertilizer formulation, applications method, timing, or rates is warranted.

Because soil concentration and nutrient uptake are independent, there is no relationship between soil P or K and tissue P or K. Elevated soil concentrations will not necessarily lead to elevated tissue levels.

Long experience and experimentation has shown what concentrations of each required element should be found in plant tissues. These concentrations are listed for cranberry in Table 2. Interpretation of the results with these standards is possible only if the correct plant part was sampled at the proper stage of maturity. ***No valid interpretation is possible if the wrong part was sampled or the plants are sampled at other times in the season.***

Table 2. Fertility status of cranberries in relation to nutrient content in leaves.

Nutrient	Normal concentration +
Nitrogen (N)	0.9-1.1 %
Phosphorus (P)	0.10-0.20 %
Potassium (K)	0.40-0.75 %
Calcium (Ca)	0.30-0.80 %
Magnesium (Mg)	0.15-0.25 %
Sulfur (S)	0.08-0.25 %
Concentration of (ppm)	
Zinc (Zn)	15-30
Boron (B)	15-60
Manganese (Mn) *	>10
Copper (Cu)	4-10
Iron (Fe) *	>20

+ Normal levels are based on samples taken between August 15 and September 15.

* Cranberry researchers have not established a normal range for Fe and Mn.

Fertilizer application

Fertilizers are materials that contain nutrients required by plants. In some cases, organic materials such as manures and plant residues can supply some or all the nutrients required by plants. However, plants cannot differentiate between nutrients from organic, inorganic, liquid or granular sources. All nutrients are absorbed by plant roots as ions and all ions of a given element are identical regardless of the source.

Fertilizers can be applied to the soil and taken up by the roots or applied to the plant as a liquid for uptake by the leaves, stems or fruit (foliar application). Each method has advantages. Soil application is usually less expensive and is better suited for large application rates of the major nutrients and for pre-plant application. For the most part, soil applications by broadcasting are the most economical and efficient.

Foliar application is best for correcting micronutrient deficiencies or for increasing the concentration of immobile elements to specific tissues. Liquid fertilizers that are foliar applied are more expensive per unit of nutrient. In many cases the liquid fertilizer runs off, or is washed off leaves onto the soil where it is later taken up by the roots. In this case it would have been much less expensive to apply a granular fertilizer to the soil. The expense of foliar applications of nutrients may be decreased if they can be mixed with pesticides in a spray. However, the nutrients may interact with pesticides, spray adjuvants or surfactants and reduce the pesticide efficacy. Mixing foliar nutrients and pesticides, in general, is not a good practice. Fertilizers commonly used on cranberry are described below.

Fertilizers

A soil and/or plant tissue analysis are the most reliable methods to determine nutrient need. Nutrients of most common concern to Wisconsin cranberry growers include nitrogen, phosphorus, potassium, calcium, boron and zinc.

Fertilizers can be blended, complete, or single nutrient. While cranberry growers use all three types, blended is probably the most common.

Nitrogen

Nitrogen is the nutrient most commonly applied to cranberry. Cranberry prefers nitrogen in the ammonium form, although cranberry vines will take up nitrate when ammonium is also present. However, the nitrate is not utilized in plant metabolism. Because nitrate will leach and is a potential contaminant, the commercial practice is to use only ammonium nitrogen sources. At pH 5.5 and above nitrification will occur in cranberry soils, but at a much lower rate than in other agricultural soils. Research studies have shown that at pH 5.5 nitrification began about 20 days after application to the soil.

The amount of nitrogen to apply in a given year depends on a number of factors and cannot be completely discussed here. Actual nitrogen application rates vary by soil type (peat vs. sand), age of vines, vigor of the vines, and crop load. An average rate of N application for bearing cranberries in Wisconsin is about 20 pounds of actual N per acre. Too little N application results in weak vine growth, pale foliage and reduced yields. Too much N results in vine overgrowth, substantial runnering, "bud blasting", poor fruit color and reduced yields.

Nitrogen is applied in split applications throughout the growing season. Recent research suggests that an application of 20 lbs actual N/a split equally between budbreak, peak bloom, fruit set, bud set and preharvest produced the highest yield and best fruit quality. Further, research has shown that N applications have little, if any, influence on yield during the year of application, even for sites that are N deficient regardless of the date of application. Thus, growers cannot increase yield through current season N applications and N application should be a long term practice.

Most growers are using blended fertilizers to obtain their nitrogen. Common formulations are 6-24-24 and 10-20-20. Some will also use ammonium sulfate (21-0-0) or urea (46-0-0). The characteristics of common nitrogen containing fertilizers are shown in Table 3.

Table 3. Characteristics of common nitrogen containing fertilizers.

Fertilizer	%N	lbs material per 1 lb actual N	Soil Reaction
Urea	46	2.22	acidic
Ammonia, Aqua	20	5	acidic
Ammonium nitrate*	33	3	acidic
Ammonium sulfate	20.5	4.88	acidic
Diammonium phosphate	17	5.5	acidic
Monoammonium phosphate	11	9.1	acidic

* *For reference only. Not recommended for use in cranberry.*

Phosphate

Wisconsin soils typically contain enough phosphate to supply plant needs. An average crop of cranberries (fruit + vine growth) would take up only about 20 pounds of phosphate per acre per year. Cranberry growers typically apply more P fertilizer than this per year. This is largely a result of the acidic environment in which cranberries grow. Acid soils "fix" more phosphorus than neutral soils. As phosphate is added to soils it is converted from a soluble form into insoluble forms. The phosphate ion ($H_2PO_4^-$) reacts strongly with iron, aluminum and manganese ions in acid soils to create insoluble phosphate precipitates.

All commonly used phosphate fertilizers presently sold in Wisconsin (except rock phosphate) contain at least 85% water soluble phosphorus. Rock phosphate is insoluble, but research has shown that it can be an effective phosphorus source for cranberries since cranberry soils are acidic.

The common practice is to make multiple light applications of phosphorus per year so that soluble, or at least plant available, phosphate is present throughout the season. However, spring applications are usually not necessary as warming soils release some phosphorus. Fall applications are not a good idea as the soils will soon be flooded. Critical application times are from hook to fruit set when demand is high and availability is low.

High levels of soil test phosphate do not correlate with high levels of tissue phosphate. It is unusual for phosphorus to leave cranberry beds since it binds tightly to the soil. Usually P moves only as soil erodes and moves.

Table 4. Characteristics of common phosphate containing fertilizers.

Fertilizer	Analysis*
Triple superphosphate	0-45-0
Diammonium phosphate	18-46-0
Monoammonium phosphate	11-48-0
Ordinary superphosphate	0-20-0
Rock Phosphate	variable

* refers to the % of P_2O_5 contained in the material.

There is no evidence that different soluble phosphorus sources are superior to each other. When applied at identical rates each of the P sources produced similar crop yields. Research shows no yield response to phosphorus fertilizer beyond 45 lbs P_2O_5 per acre per year. As phosphorus can be an environmental contaminant, growers are urged to apply no more that 45 lbs P_2O_5 per acre per year. Doing so should help keep phosphorus out of both ground and surface waters.

BREEDING AND GENETICALLY ENGINEERED ORGANISMS

-Issues relating to Cranberries-

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There are two topics that I will address in this paper:

1. Describe a selection from our breeding program that has advanced to the release stage.
2. Review the latest results with our genetic engineering of cranberry and the obstacles to its commercial use.

New cultivar release

As you recall from our previous presentations, the cranberry breeding program at UW-Madison is designed to be highly focussed on a few goals of potential importance to the Wisconsin industry:

1. Develop cultivars *for Wisconsin* that have high and reliable yield.
   - Consistent yields from season-to-season (not biennial bearing).
   - Yields equal to or higher than 'Stevens'.
2. Develop cultivars with early and intense fruit coloration.
3. Determine the genetically-controlled components of yield. This information will be useful in designing future breeding programs.
4. Develop breeding lines *for Wisconsin* that reliably transmit useful traits. Again, these lines will be invaluable in future breeding efforts.
   - One aspect of this work is to see if our genetically-engineered cranberries can faithfully transmit their engineered traits to progeny.

Work on all these goals has progressed well considering we are dealing with a perennial plant with a much longer life cycle than the easy-to-breed agronomic annual crops. After talking with many growers about their needs and ideas, one of our first efforts was to conduct a series of crosses between a 'Ben Lear'-type cranberry and 'Stevens'. More than 600 progeny seedlings were planted in a bed in the Cranmoor area and from this, a number of early selections were made based on early and intense fruit coloration. These selections were then planted in other test beds. We are pleased to announce that one selection has performed so consistently well that we are now ready to release it to the industry for their planting and evaluation. Briefly this cultivar has been tested in two regions in Wisconsin northern (Phillips) and central (Cranmoor and Biron) and has been observed in the field for more than 5 years. In comparison to other seedling selections and cultivars planted in the same bed or nearby beds, this selection always has had superior fruit color compared to standard cultivars such as 'Stevens' (Figure 1), 'Pilgrim', and even 'Ben Lear'. In addition, the selection has had estimated yields equal to or greater than the standard 'Stevens' (although these estimates are preliminary as they are based on relatively small plantings).

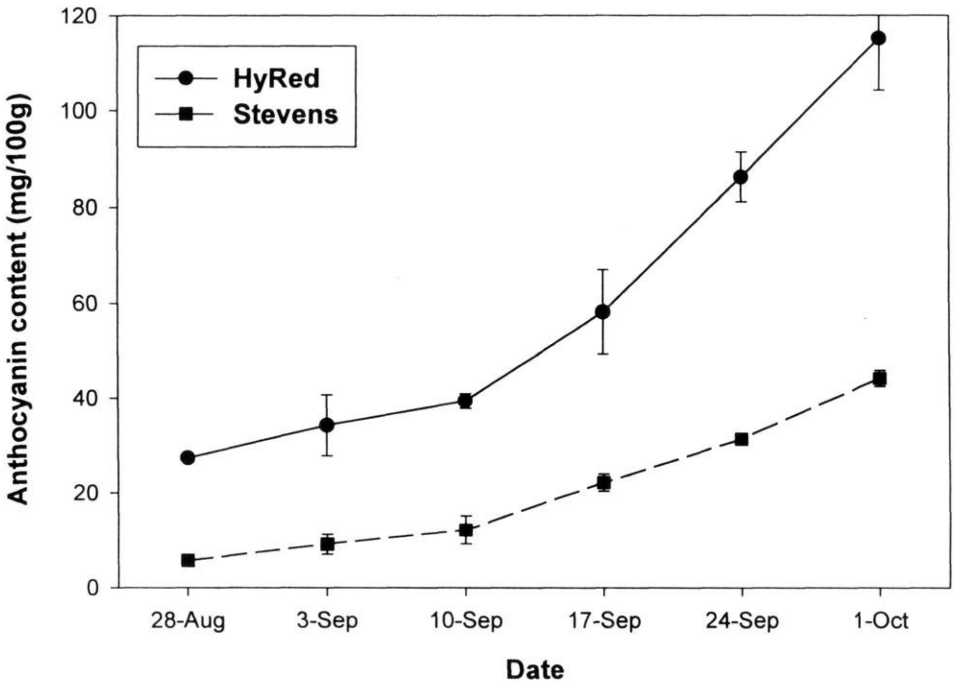

Figure 1. Seasonal fruit color analyses of a new hybrid selection, 'HyRed', compared to the standard cultivar 'Stevens'. Data from plots in the Cranmoor area during the 1997 growing season. Note both the early fruit coloration and very high color levels of 'HyRed'. Similar results were obtained in 1996.

The necessary path involved to finalize such a release consists of a number of steps:

1. Testing
   - Characteristics of this selection in tests:
     - Early maturing.
     - Mid-Sept harvest potential.
     - High color, TAcy greater than 60.
     - Consistently good yields (estimated).
   - The ultimate test will be in larger plantings in grower's fields.
2. We then write-up the data and-
   - Apply for a Plant Patent through WARF (Wisconsin Alumni Research Foundation).
   - Seek Department of Horticulture approval for the release.

3. We need to determine how best to distribute materials to cooperating growers:
   - Do we contract with a professional propagator(s)?
   - Should WCGA or the WCB be involved in managing the release?
   - In any case, we wish to give Wisconsin growers first priority to obtain the plant and then Ocean Spray growers (in any region) will have second priority. Once these demands are met, then any grower can obtain materials.

Probably the hardest step is finding an appropriate name for this selection. We prefer to have the name say something about the plant itself. The leading contender is the name 'HyRed'.

Genetically engineered cranberry

In past years, we reported on our success with applying modern genetic-engineering techniques to cranberry. One of these efforts involved inserting a gene that gives tolerance to the herbicide glufosinate, better known as Liberty herbicide. In mid-90s, we recovered transformed plants of 'Pilgrim' that expressed this tolerance, but at a level that was marginally useful for commercial purposes. We then went on to use this engineered 'Pilgrim' plant as a parent in breeding and recovered many seedlings that also showed tolerance. This work accomplished three purposes:

1. We now know that the inserted gene (originally from a soil bacterium) and its expression is stable in our Pilgrim' plant and thus can be relied upon in commercial settings.
2. This work also demonstrated that we can use regular crossing techniques, perfected earlier to create 'HyRed', to pass this herbicide tolerance trait to other hybrids and selections. Thus herbicide tolerance to glufosinate can now be a part of the parental lines that we are developing for future breeding. For example, we can now preserve the high fruit color and herbicide tolerance traits while selecting for improvement in other important traits.
3. Most startling, some of the progeny showed markedly increased levels of tolerance to glufosinate. One selection has tolerance levels 5-10 times that of originally engineered parent, a level that certainly is commercially useable.

So, why don't we release this engineered cranberry as a new selection? Unfortunately, there are some major obstacles that stand in the way of such an effort. One concern is environmental in character and asks, "Will the genes in this cranberry escape into the wild?" Of course, the answer is yes as we can see no way to absolutely prevent pollen or fruit from moving into areas surrounding plantings of this engineered cranberry. Thus the next question, and the most important environmental one, is, "What will be the ecological effects of the movement of glufosinate tolerance genes?" Cranberry in its native Wisconsin setting is not a dominant plant and occurs as a scattered and patchy component of the groundcover. Thus any changes in cranberry cannot lead to major disruption of the ecosystem in which it grows as a native. In addition, the trait of tolerance to glufosinate will have no relevance in the native areas; we know of no natural sources of this herbicide thus the gene will have no function in native areas. Thus the gene coding for glufosinate tolerance will not give any selective advantage to those cranberries possessing it. Most likely the gene will be rapidly lost in future generations of wild cranberries. Our conclusion, then, is that the environmental question is not a major detriment to the commercial use of glufosinate-tolerant cranberries.

A second set of obstacles involves getting complete access to the technologies used to create the herbicide-tolerant cranberry. There are at least three different patents that apply to this glufosinate-tolerant cranberry. Although we can get the rights to some of them, efforts by us and others to obtain the right to commercially use the gene that directly codes for the herbicide tolerance have been unsuccessful. In addition, Liberty herbicide is not approved for use on cranberries (although it is approved for many other food crops) and this registration process would have to be pursued.

A more difficult impediment to the commercial use of glufosinate tolerance in cranberry production is consumer acceptance of food products containing this trait. For example, a recent (1999) survey of consumer attitudes in all the EEC countries showed that there was strong negative sentiment in regards to the use of biotechnology for foods. Many consumers strongly agreed with the statement that "biotechnology is not natural". Although the attitude of consumers in the U.S. is not nearly so negative towards biotechnology, that appears to be changing. Since cranberries are considered a "healthful" food that is "natural", do we want to risk a consumer backlash by commercially using cranberries that have employed genetic engineering in their breeding? To us, at least at present, the risk seems too high.

The EEC survey also noted that consumer attitudes toward the use of biotechnology for human health and medicine are relatively positive. One future scenario might be that as the public gets more comfortable with biotechnology as used for medicine, this comfort level will carry over into the use of biotechnology for food purposes. Thus in five years or so, select and beneficial uses such as reducing the use of chemicals in cranberry production areas may become more widely acceptable.

As always, time will tell.

Economics of pollination
Is renting honey bee colonies worth the money?

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Ensuring adequate and reliable pollination of cranberries is critical for fruit yield and quality. Relying on wild populations of bees (bumblebees, feral honey bees, other solitary bees) may not always provide adequate and reliable pollination. Naturally nesting bumblebee colonies are not a reliable source of pollinators for cranberries, although when present, they are the most efficient of the bee pollinators (Macfarlane 1995). Most cranberry growers rent honey bee colonies to ensure proper pollination. However, there are questions about how many honey bee colonies to bring into a property and the timing of honey bee colony introduction. Although honey bees are effective pollinators of cranberry, some growers doubt the efficacy and necessity of renting honey bee colonies, especially during economically hard times.

The usual practice is to place 1-2 honey bee colonies per acre of cranberry property, and to leave the colonies for the duration of the bloom. This year, 2000, provided a unique opportunity to examine the effect of honey bees on cranberry pollination as many growers that usually rent honey bees colonies did not rent them due to yield restrictions. We compared yield, bee visitation, and pollen loading on stigmas at a property that brought in 2 honey bee colonies per acre with a property that did not rent honey bees. We also compared yield on the property that rented no honey bees this year with the yield of the same property in 1999 when the grower rented 3 colonies per acre.

Bees visiting flowers

In 2000, at the property with 2 colonies per acre, the highest levels of honey bee visitation and pollen collection by honey bees were seen during mid to late bloom (20% to 50% out of bloom). Bumblebee numbers were low but relatively constant throughout the bloom.

There were few bees visiting flowers at the property that brought in no honey bees. A few bumblebees but no honey bees were seen on the cranberry bed, although a few honey bees were seen foraging on clover alongside the bed. There was no apparent increase in wild bee pollinators with the absence of honey bees.

Pollen deposition

The property with 2 honey bee colonies per acre in 2000 had more pollen tetrads (the clumps of four pollen grains produced by cranberry flowers) present on the stigmas of the cranberry flowers during mid to late bloom (20% to 50% out of bloom) than the property that brought in no honey bees (Figure 1). There was no difference between the properties during early bloom (25% in bloom) when honey bee visitation and pollen collection rates were low.

It has been shown that 8 pollen tetrads is the minimum number required for fruit set in cranberries(Cane and Schiffhauer 2001). Presently there is no available information on the number of pollen grains required for the best quality berries. Many of

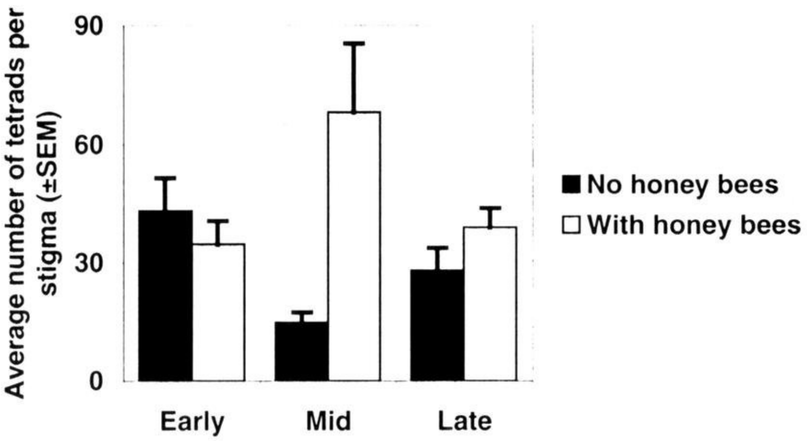

Figure 1. Pollen deposition. The average number of pollen tetrads on each examined stigma ± the standard error of the mean is displayed for different bloom stages (early bloom, mid bloom, and late bloom) for a property with no added honey bees and a property with honey bee colonies. For ANOVAs, all data were transformed using log10+1 tranformation. For early bloom, ANOVA revealed no significant difference (F=0.04, df=1, 59, P=0.84). For mid bloom, ANOVA revealed a highly significant difference (F=20.68, df=1, 57, P<0.0001). For late bloom, ANOVA revealed a significant difference (F=4.26, df=1, 60, P<0.05).

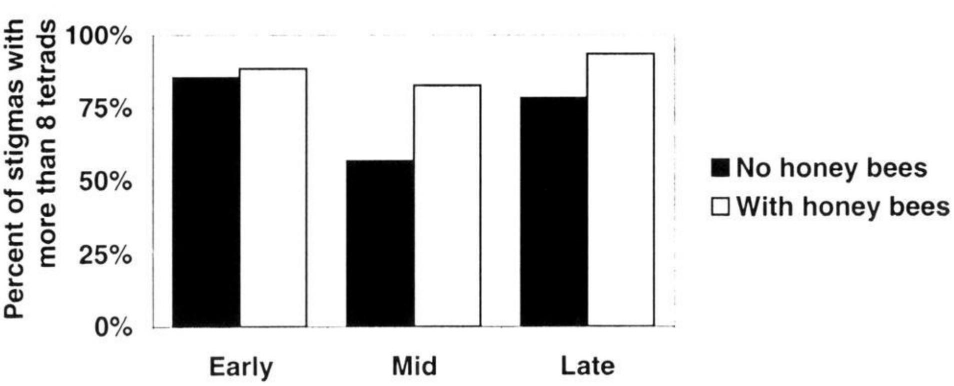

Figure 2. Percent of stigmas with more than 8 tetrads for different bloom stages (early, mid, and late bloom) for a property with no added honey bees and a property with honey bee colonies.

the stigmas at the property with no honey bees had 8 or more tetrads during early and late bloom, but there was a drop in the number of stigmas with more than 8 tetrads during mid bloom (Figure 2). The difference in the percentage of stigmas with more than 8 pollen grains between the property with honey bees and the property without honey bees was greatest during mid bloom. Even though rates of flower visitation where low throughout the entire bloom on the property with no honey bees, there may have been enough wild pollinators to effectively pollinate cranberries during early bloom, when there were not as many flowers. However, during mid bloom, there were too many flowers for the low numbers of wild pollinators to be effective pollinators. A large number of bees is needed at this time to ensure visitation of the majority of flowers. During late bloom, wild pollinators may again possibly provide sufficient pollination. Other possible causes of pollen deposition are wind and self-pollination. Self-pollination often results in abortion of fruit so these pollen counts may not reflect actual fruit set (Sarracino and Vorsa 1991).

Yield

Cranberry yield was examined using three measures: 1) berry counts per 20 cm^2, 2) individual berry weights, and 3) weight of all berries in a 20 cm^2 plot. The weight of all berries in a 20 cm^2 plot is most closely related to the barrels per acre used by most growers to assess yield. However, individual berry weight is the best measure of the effect of honey bees on cranberry production because it does not confound yield with planting density.

In 2000, the cranberries were significantly larger on the property that brought in 2 colonies per acre than on the property with no honey bees (Figure 3). Also, within the same property, the cranberries were larger in 1999 when 3 colonies per acre were present than in 2000 when no colonies were rented (Figure 4). The owner of this property reported a 30% decrease in barrels per acre between 1999 and 2000 for the beds included in this study.

Conclusions

Good pollination results in increased fruit size and quality. Pollination of cranberries by honey bees increases the size of individual cranberries which may have a positive effect on fruit quality. It is clear from our study that honey bee pollination increases cranberry yield. Honey bees appear to make the biggest difference when cranberries are between 20% and 50% out of bloom.

The effect of not renting honey bee colonies will vary between properties depending on the numbers of wild pollinators in the surrounding area and differing management practices. Wild pollinators are most likely to be effective during early and late bloom, but their numbers may not be sufficient during mid bloom, particularly at larger properties.

Good honey bee pollination results in larger berries and higher quality fruit. Lack of honey bee pollination reduces yield, and produces smaller berries. Is renting honey bee colonies worth the money? If producing and purchasing large quality fruit are the goals of growers and consumers, then renting honey bees is worth the money. Growers can reduce yield by not renting honey bee colonies, but fruit quality will be compromised.

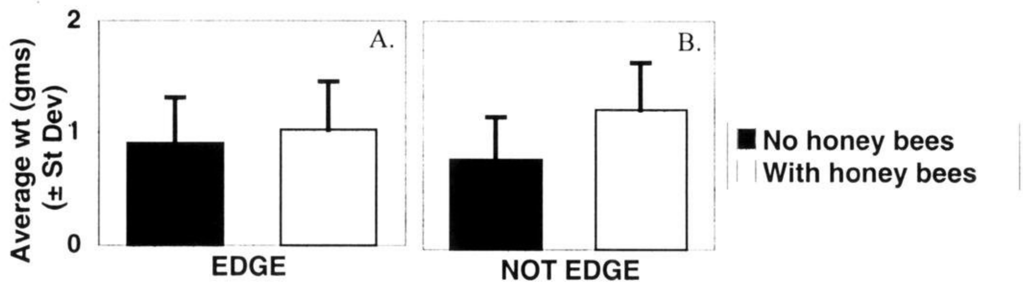

Figure 3. Weight of individual berries (average ± standard deviation) taken from the property with no added honey bees and the property with added honey bees. A. Average weight of individual berries from plots on edge of bed. ANOVA revealed a significant difference (F=4.79, df=1, 256, P<0.03). B. Average weight of individual berries from plots not on the edge of bed. ANOVA revealed a highly significant difference (F=120.77, df=1, 387, P<0.0001).

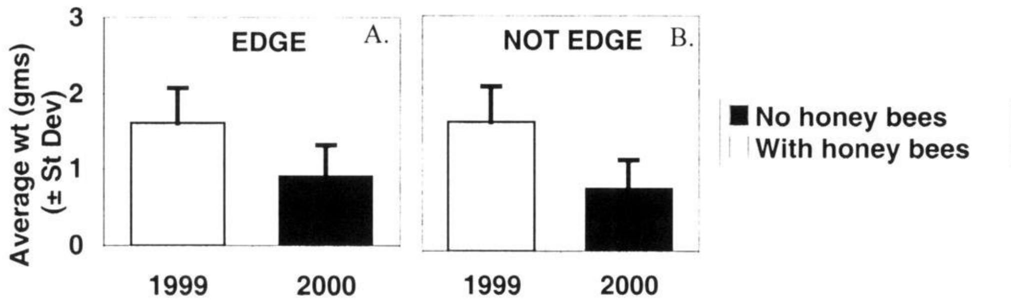

Figure 4. Weight of individual berries (average ± standard deviation) from the same property with added honey bees in 1999 and no added honey bees in 2000. A. Average weight of individual berries from plots on edge of bed. ANOVA revealed a significant difference (F=232.73, df=1, 357, P<0.0001). B. Average weight of individual berries from plots not on the edge of bed. ANOVA revealed a significant difference (F ratio=468.19, df=1, 440, P<0.0001).

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