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Cranberry pollination and bumblebees

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Pollination assessment

The main cranberry flowering barely lasted for 20 days at two sites on the Pacific coast with 3 or more bumble bees per 10 square yards (0.33 per m^2). With one bumble bee (or it's the combined equivalent in bumble bees and honey bees) per 10 m^2 produced 200 barrels per acre on one bog in 1993. The main flowering persisted for at least 30 days at two sites with less than 3 bumble bees per 100 m^2 and with high flower populations. Prolonged flowering is a first sign of inadequate pollination.

The best crops with over 200 barrels per acre had less than 20 % of the flowers unpollinated. Average crops had 20 - 30 % unpollinated flowers and bogs with a temporary shortfall of pollinators had 35 % or more of the flowers unpollinated. In 1993, it rained almost continuously for about 20 days during the first half of 'Stevens' flowering and 150 barrels per acre were harvested from an isolated two acre bog. This compared with a previous top yield of 380 barrels per acre.

Relative pollinator effectiveness

Sharing commercial bumble bee colonies between blueberries and cranberries should lead to more economic and so wider use of colonies. In 1994, 18 bumblebee colonies were shifted from late flowering blueberries in Oregon to cranberries at Long Beach, Washington. To shift hives growers must close the entrance after dusk to obtain as many of the foraging workers as possible. For safety, keep colonies in the open part of a pick up truck, where any 'leaking' bumble bees will not pose a hazard to the driver. Provided these precautions are followed there seems to be little justification for a business intermediary. From this two crop use of reared bumble bee colonies it seemed that an equal sharing of costs between growers is reasonable provided: **1.** blueberry growers do not introduce colonies appreciably earlier as has been advocated in this report to improve the rate of foraging on the crops **2.** The weakest colonies are retained by the blueberry growers. Weakness can be determined by disturbing the colonies. If less than 20 workers are active on the top then the colony could be opened to verify the lack of workers, but let it settle down for a few minutes. 'Old' colonies of bumble bees (placed a month earlier in another field crop) are valuable to mix with freshly delivered colonies for the early flowering cranberry varieties, because their foraging has reached its highest level. "Old' colonies are of less value for late flowering cranberries, because the colonies become senescent and foraging declines.

Delivery of bees to the bogs

The introduction of honey or bumble bee colonies to the cranberry bog environment releases more bees around the bogs within the colonies flight range. However, colonies only deliver a proportion of the bees to forage (actually visit the cranberry flowers) on the bogs.

Three factors make the delivery rate of honey bee inferior to bumble bee colonies: **1.** Honey bees have a more extensive foraging range than bumble bees. **2.** Honey bees communicate within the hive about the quality of the sources of food. However, each bumble bee learns from experience and sampling what flowers yield resources best for them. Thus honey bees have the ability to shift to masses of better yielding flowers more rapidly than bumble bees **3.** Honey bees forage freely from a wider range of flowers than the short tongued bumble bees. Hence competing pollen sources can be expected to be more important for honey bees than bumble bees. Put another way the main bumble bee species visiting cranberry flowers have a better preference for cranberry flowers.

In Washington, there was no consistent relationship between honeybee populations and the no of hives used per acre. For the early flowering 'Stevens' on average there were 3 (range 1 - 6.8) colonies per acre compared to 2.3 (0.9 - 5.6) at the final stages for 'McFarlin'. Despite the higher initial rate on 'Stevens' the overall rate of honey bee populations measured on 'Stevens' was lower than for 'McFarlin'

By contrast, consistent delivery of the differently colored southern Californian *B. occidentalis* was measured from bumblebees colonies at 10 study bogs between 1992 and 1994. With a medium (4.5 bumble bees per 100 m^2) feral bumble bee population and 0.6 commercial colonies per acre at best 5 -10 % of the bumble bees came from the commercial colonies. With 4.5 colonies per acre eventually the commercial bumble bees dominated the bumble bee complex. These studies show a provisional delivery of about 1 bumble bee per 100 m^2 for each colony of commercial bumble bees. An initial stocking rate of up to 4.5 hives of bumblebees per acre is suggested for them to be the main pollinators. Recommended changes to the timing of introduction of bumble bee hives may change this initial guideline.

If peak activity of the commercial bumble bee colonies is synchronized better with the main flowering in cranberries then results may be twice as good. Colony foraging during flowering can be maximized by bringing colonies to cranberry bogs as or even a week before cranberry flowering starts. This is about 10-20 days earlier than was achieved in 1993 and 1994. With this early introduction of colonies then feeders should be used before the cranberry starts to flower and then turned off unlessit is raining consistently. Turn the feeders on again for the new queens as the cranberry flowering stops. 'Old' colonies of bumble bees (placed a month earlier in another field crop) are valuable to mix in with freshly delivered colonies. 'Old' colonies are suitable, because foraging has reached its highest level for the early flowering cranberry varieties. They are of less value for late flowering cranberry crops.

Protection of pollinators

The diurnal pattern of bee foraging indicates that longer exposure to insecticides at night may be possible without unduly harming the bees. Honey bees are more sensitive to insecticides. Monitoring for bee kill with honeybees is a practical way to know whether bumble bee populations may be being affected too. For pollination and to minimize fungal attacks prudent growers should irrigate early during daylight hours in the morning up until about 8 am.

In the Pacific North-West there are few residential hives of honey bees in the vicinity of bogs so risks of beekeeping losses are not high. Sprays before cranberry flowering on bogs with reasonably attractive flowers (notably white clover, lotus, fireweed, white sweet clover) in or within range of the sprinklers would tend to be more damaging than spraying after flowering. All the bumble bee species are either growing or are at their peak before cranberry flowers and so are vulnerable. Sprays after flowering will have less effect on populations, whose colonies (notably *B. perplexus, B. bimaculatus*) have mostly completed brood rearing and have fed almost all new queens. The valued and common *B. impatiens* and *B. affinis* remain vulnerable at the end of cranberry flowering. A lower rate of Diazinon would perhaps be a better insecticide to use than Guthion or Lorsban, where there is an insecticide threat to bumble bees.

Guthion applied directly to 'McFarlin' bogs toward the end of flowering killed few bumblebee workers and queens directly in colonies. Still the most toxic insecticides could cause some subtle damage to bumble bee brood rearing unless the insecticide is washed off before the bumble bees gather pollen from the flowers.

RESIDENT BUMBLEBEE POPULATION MANAGEMENT

In Wisconsin, variation in resident bumblebee populations will probably be similar to the Pacific coast. Most bogs, especially the large complexes, will have low (less than 2 bumble bees per 100 m^2) populations of resident bumblebees and some will have medium populations (2-8 per 100 m^2). Low and medium populations can apparently fully service respectively less than 10 % and the first and last 10 - 40 % of the cranberry flowers by themselves. A few bogs especially with surrounding woodland and that were less than 5 acres had high resident bumblebee populations and did not need honeybees.

Woodlands and their fringes, and banks along cranberry bogs often provide a range of food sources and some hollow logs and bird nests for bumblebee to nest in. Without cultivation, hibernating queens are not disturbed and the ground retains convenient abandoned rodent nest or tangles of dense grass/goldenrod clumps for the bumble bees to start colonies in. Suburban areas may provide additional surface and aerial nest sites well protected from rain and some valued bee forage sources. Adjoining farmland with flowering crops, but not grass or maize will provide food for the bumblebee.

The main species in central Wisconsin are predominantly mid season emerging and short and medium tongue lengthed species. In sequence of importance these species will be *B. impatiens, B. affinis, B. terricola,* and near woodlands *B. vagans* and townships *B. perplexus* and *B. bimaculatus*. However, in the North of Wisconsin, the early active *B. terricola* and *B. ternarius* will be more important and so early flowering cranberry varieties may perform better on the smaller bog complexes.

The elements of field management of bumble bees are the provision of food, field hives for occupation by queens, and the need for protection against particular colony enemies.

Food supply

The 8-15 bumblebee species in each region emerge at different times in spring to early summer. This suggests that the sequence of local food supply has been one critical factor in bumblebee evolution. Differences the activity of their natural enemies is another factor. I view provision of the best food supply is possibly the most critical element to achieve the highest residential populations. This is partly because even if a colony has started in a hive it can fail. This happens more in the early growth phase, when there are few workers to seek the more distant floral sources. Even in well fed colonies 15 % of the queens (less than 20 % of their body weight is fat) will not enter hibernation. In colonies without food stores during maturity more than 50 % of the queens will not hibernate. After hibernation at least 5 % of the lightest queens die before colony formation. Poor food sources up until about mid spring does not seem to be so critical, because the latest emerging queens of early emerging species and all queens of mid emerging species can still form nests. Hence, I have gained the impression that a favourable sequence of food supply around the period that mid and late season crops flower usually has the greatest impact on bumblebee populations. This is when the food demands for the colonies that have succeeded is greatest.

Bees need nectar from flowers or honey dew for sugar and water in their diet. Pollen provides the protein, vitamins and most of the fat and is absolutely essential for the development of the bees brood (larvae and pupae). Bumblebees prefer to use perennial flowers in most cases, because these plants produce either more nectar or do so more reliably than the more shallow rooted annuals. Open and upwards or outwards facing flowers tend to offer less reliable or poor nectar for bumblebees, because rain can readily dilute the nectar and prevent collection of pollen. Willows, Rosaceae (pip and stone fruits, blackberry), composites (sunflower, goldenrod) flowers are among the less reliable nectar sources. Flowers with narrower and deeper downward facing nectaries are protected from rain. Hence most Ericaceae (blueberries, ornamental ericas, lings, heaths), barberry, legumes (lotus, clovers, beans) and Labiatae, Scrophulariaceae, Boraginaceae are usually more reliable food sources (Table 2). Different plants cease nectar production at a lower critical temperature, which in red and Dutch clover tends to be 2-4°F above the limit of flight for honeybees.

The quality of the food source is important, because the area available for other flowers around buildings, banks, and waste areas is limited. Productive land put aside for bee forage has an opportunity cost apart from rates and other overheads, so plants in these areas must be the best.

Table 2. Quality and sequence of availability of some important food sources

	Quality	Flowering
	Before cranberry flowers	
Willow	Poor	March - early April
Barberry	Good	Mainly April
Rosemary	Good	Mainly April
Blue berry	Excellent	May mainly
	After cranberry flowering	
White clover	Fair	June - August mainly
Lotus	Good	July - August mainly
Golden rod	Good	July - August

Field hives

Field hives for bumblebees are occupied by feral queens, but if better natural underground sites are available then very few hives are used. Only a partial control of the species is possible by choosing to use aerial, surface or hives that at least simulate underground sites. Some further control is possible by choosing the time of the year, when the hives are available for the queens to form nests in. Still too many sites experience less than 20 % of the hives with colonies starting in them. This is too little given the use of hives by unsuitable species for cranberry pollination and colony losses before they reach an adequate size. Hence it is suggested approach that a limited number of hives (about 10 per test site) are tried in what seem more favourable sites to find sites that trap searching queens. If the sites have no success after two years then the site is probably unsatisfactory. Then it is better to extend placement of the hives to sites where some occupation has been achieved. During my stay with you I will try to find such sites if some of you are willing to risk making some field hives to test.

In Washington, *B. occidentalis* populations were sensitive to rainfall 50 % or more above average during colony formation. Hence all four of the underground nesting all four species of underground nesting *Bombus* in Wisconsin (Table 3) may be similarly sensitive. Painted hives with overlapping lids, and a floor 0.5-1 inch above the ground, but with 4-6 drainage holes around the side of the fllor and an entrance level with the floor overcome much of the problems associated with wet hives. Wetness is undesirable for the queens, because she needs a dry site to help her keep her brood at 86 - 90 °F , while she incubates and forages for the nest. Trials with field hives in Washington showed the importance of having dry hives that are either underground or above ground to simplify management.

Use upholsters cotton to line the hive or pink wall insulating material or wool. Wool and wall insulating are harder to check for colony establishment. Other materials can result in the workers and queen becoming tangled in them and dying of starvation.

The erratic use of hives at different sites, which at least partly linked to the adequacy of food sources as the colonies are being formed. Hence, put hives near attractive flower sources during nest formation or otherwise few if any hives may be used.

Table 3. Bumble bee biology related to cranberry varieties and habitat preference

	Cranberry varieties -flowering Early	Later	Habitat and nest preferences
bimaculatus	decline	mainly inactive	Suburbs, mainly surface
perplexus	peak to decline	mainly inactive	Suburbs, surface-aerial
vagans	peaking	peak to decline	Woodland, underground-aerial
terricola	growing	peaking	North woodland, underground
ternarius	growing	peaking	North woodland, underground
affinis	growing	growing	Farmland, underground
impatiens	growing	growing	Farmland, underground

Limiting losses from enemies

Once a colony has been formed in a hive or commercial colonies are introduced to the crop, they may still experience losses in output due to various natural enemies. Deer mice *Peromyces maniculatus* mainly near woods and house mice *Mus muscularis* more in cropping land consume the brood and bees in founding colonies and those in the first week or so of colony growth. Little is left apart from the bees wings. As well, mice, may consume pupae of colonies in late summer as they approach senescence. Skunks, bears, raccoons and possibly opossums will consume full sized mature colonies for their nutritious pupae. Prevent mice attacks with a metal hole of 7/16 of an inch to stop their entry, while stout hives keep out all but the bears.

Female *Psithyrus* destroy the eggs and young larvae of the hosts and lay their own eggs in the colony. Even the entry of one female tends to disrupt colony development especially during colony formation. *Psithyrus* females suppress the *Bombus* hosts queens egg laying too. Bumblebee queens of their own species or some subgenera related species may invade the colony at a similar stage in its development. If the colony has over 15 workers they usually succeed in killing invading queens, but two or more invading queens on average reduce colony production and 5-30 usually stop it. Limited Ontario and central USA studies suggest neither invading *Bombus* or *Psithyrus* are as serious as they are in New Zealand and southern Alberta respectively. A reduction in losses can be achieved with a few strategic inspections to remove *Psithyrus* and to apply a queen excluder. The commoner cuckoo bumblebees *Psithyrus ashtoni* (hosts *B. terricola, B. affinis*) and *P. citrinus* (hosts *B. vagans, B. impatiens, B. ternarius* are commoner near wooded areas partly because they hibernate there. *Psithyrus* tend to invade colonies that have a few workers or colonies with only a queen in areas with many *Psithyrus.*

The larvae of the bumble bee brood fly *Brachicoma* spp. reduce queen output in bumblebees if there are more than per colony and can prevent queen production if there are 30-60 per colony. Currently the only control method is to remove and squash the larvae and pupae mainly around the margins of the bumblebee canopy. Surface and aerial colonies are more severely affected. This year we want to develop better methods to restrict the impact of bumblebee brood flies and the wax moth from our studies.

Dried fruit moth *Vitula edmandsae* larvae act like the wax moths in honey bee combs. They consume pollen stores and the pupal cells and then pupae of bumblebee colonies from about peak colony development. Hence they disrupt colony food storage and effect the vigor of new queens. Initial trials were made with 2-3 dustings with *Bacillus thuringensis* (BT) at 14 day intervals from the onset of activity (August or earlier). This was coupled with removal of obvious moths, and these controls seemed to delay the onset of infestations until the colonies stop growing. No further control is possible from BT after colony growth has finished, because large wax moth caterpillars were not killed with this dust. Hence, 1995 studies in Wisconsin seek alternative insecticides to treat for it within the bumblebee hive.

CONCLUSION

Until we know the pollinating effectiveness of bumblebees and honeybees better, we can not be sure what management techniques warrant the effort and cost put into them. In the meantime it seems prudent to at least start to develop better techniques for the control of natural enemies. Also to achieve the best use of bumblebees there is a need to gather the basic information on the relative attractiveness and presumably value of food sources for bumblebees. This could become important if the Africanised honeybee increases the cost of colonies to you or even restricts their availability.

Botanical Aspects of Pollination

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What is normally thought of as pollination in cranberry (and other fruit species) actually consists of a number of steps that must occur for fruit set and maturation to proceed. Cranberries have perfect flowers, that is to say, cranberry flowers have both male and female parts within the same flower. Cranberries are also apparently self fruitful, meaning that pollen from an individual flower when deposited on the stigma of the same flower will lead to fruit set and maturation. The purpose of this article is to outline in a simple way the steps that occur between deposition of pollen on a cranberry stigma and development of a mature fruit.

Pollination

Pollination is the movement of pollen from anther to stigma. Anthers are the male portion of the flower and are the site of pollen production (Figure 1.) The stigma is the outer portion of the female portions of flowers. It is connected to the ovary by a long stalk called a style. The stigma is receptive to pollination for up to seven days after emergence. After that point, any pollen deposited on the stigma would be inconsequential. Cranberry pollen is shed as a tetrad (four pollen grains fused together). This is a relatively large pollen that is not easily wind blown. Further, the stigmatic surface tends to point downwards making it unlikely that windblown pollen could land on it. Insects are the common pollinators (agents of pollen transfer) in cranberry.

Once pollen is deposited on a receptive stigma the pollen grain germinates and a pollen tube grows through the style to the ovary. Pollen germination is temperature sensitive, and will germinate in 48 hours at 72° to 86°F. At less than 50°F pollen will not germinate, at greater than 90°F germination begins but the pollen tube frequently desiccates. This pollen tube has three nuclei. One is a tube nucleus that is thought to direct the growth of the pollen tube through the style and into the ovary. The other two are sperm nuclei. These two nuclei are deposited inside a mature ovule.

Fertilization

In order for fruit set to happen two fertilization events must occur. One sperm nucleus unites with the central cell which is binucleate, creating a new cell that has three copies of each chromosome (3n). This cell divides and creates the endosperm which will serve as nutritive tissue for the developing embryo. The other sperm nucleus unites with the egg cell in the ovule to create a zygote which become an embryo after repeated division and differentiation (Fig. 2). This double fertilization is characteristic of higher plants but is not found elsewhere in the plant kingdom.

Subsequent events

It is well documented that an increased seed number within a cranberry leads to larger berries. Indeed, each seed results in an increase in fruit size of 36 milligrams. Early opening flowers at lower fruit positions are more likely to set fruit than later opening fruit at higher positions. Fruit at lower positions also tend to be larger in size.

Following fertilization rapid development of the embryo, endosperm and associated structures appears as rapid growth. The growth is associated with the release of plant growth regulators or plant hormones. Three plant hormones appear to be associated with fruit set and development; Auxin, Gibberellic Acid and Cytokinin.

High auxin concentrations have been found following pollination and fertilization of many plant species. Indeed, in some plants fruit set can be artificially induced by application of synthetic auxins (cranberry is not among them). Auxins are associated with cell growth, particularly elongation. Developing meristems (such as the shoot apex) are also rich sources of auxins. In these situations auxin is also associated with inhibition of growth or branching below the apex. Auxin can be both a growth promoter and a growth inhibitor. The release of auxin as the ovule develops is likely integral to the growth of the fruit.

Gibberellins are a large family of closely related chemicals. They are associated with both cell division and cell expansion. Gibberellins are known to be released from developing seeds. Fruit set in some species can be induced by applications of synthetic gibberellins (cranberry included), but unless more resources are provided this usually results in many small fruit. Gibberellins released from developing seeds are known to inhibit development of flower buds for the next season in many fruit crops and may be the cause of biennial bearing. Uneven fruit development in apples is associated with seeds missing on the undeveloped side, this can be remedied with applications of gibberellins.

Cytokinins were discovered in Wisconsin are associated with cell division. Cytokinins are attributed to have affects on many plant functions including senescence, cell enlargement and responses to red and far red light. Developing fruits and embryos are a common source of extracted cytokinin. However, because of the technical difficulties of working with these compounds very little literature is available for them with fruit crops.

Conclusion

Before fruit set proceeds pollen must be deposited on a receptive stigma. The pollen grain must germinate and the pollen tube must grow the length of the style to the ovule. Once the two sperm nuclei are deposited in the ovule, one nucleus must unite with the egg to form the embryo and the other with the central nucleus to form the endosperm. Following this double fertilization the developing seed releases growth substances that causes the ovary wall to enlarge creating the mature fruit that has economic value.

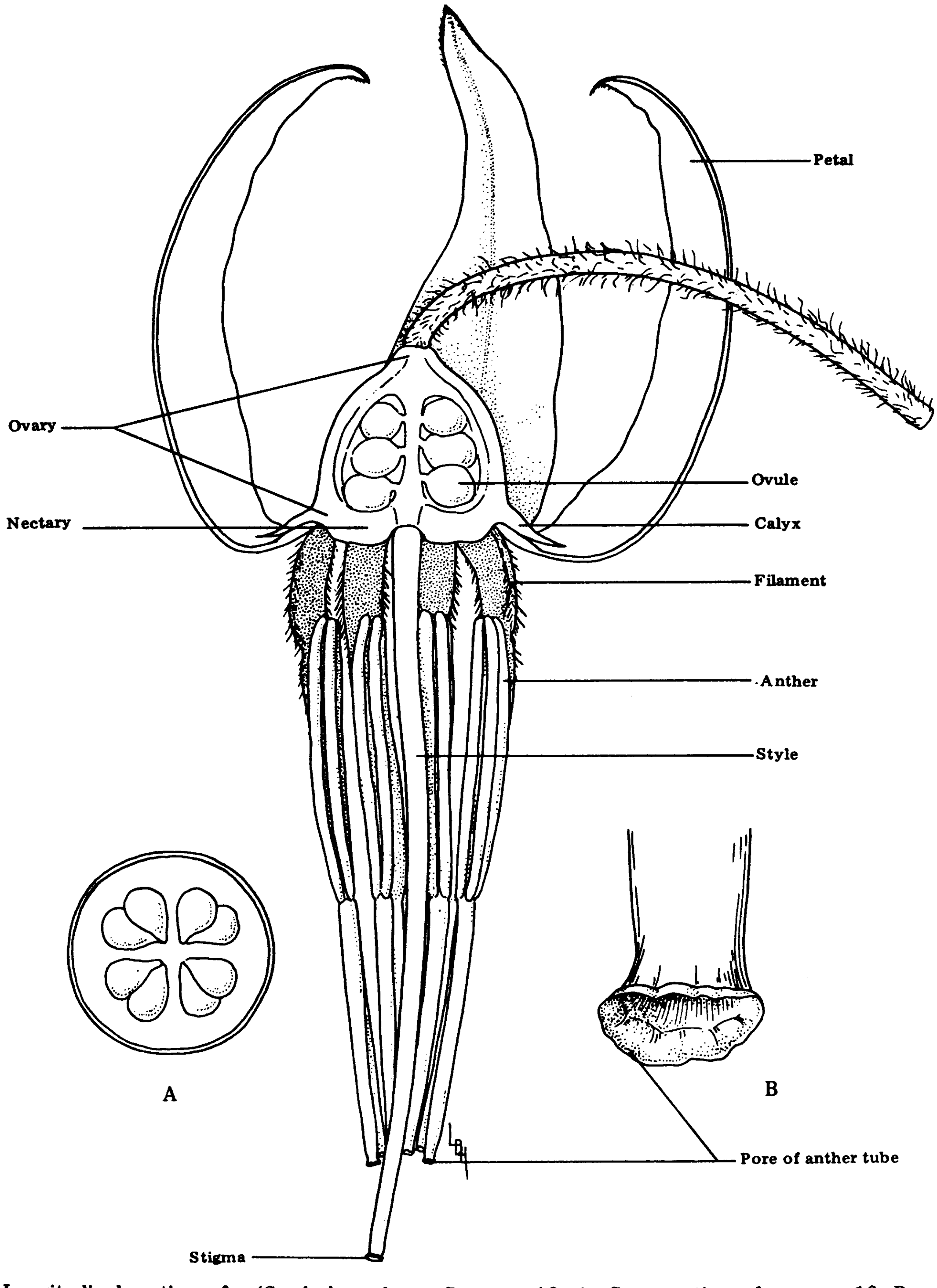

FIGURE 1.—Longitudinal section of a 'Searles' cranberry flower, ×16. *A*, Cross section of ovary, ×16; *B*, pore of anther tube, greatly magnified.

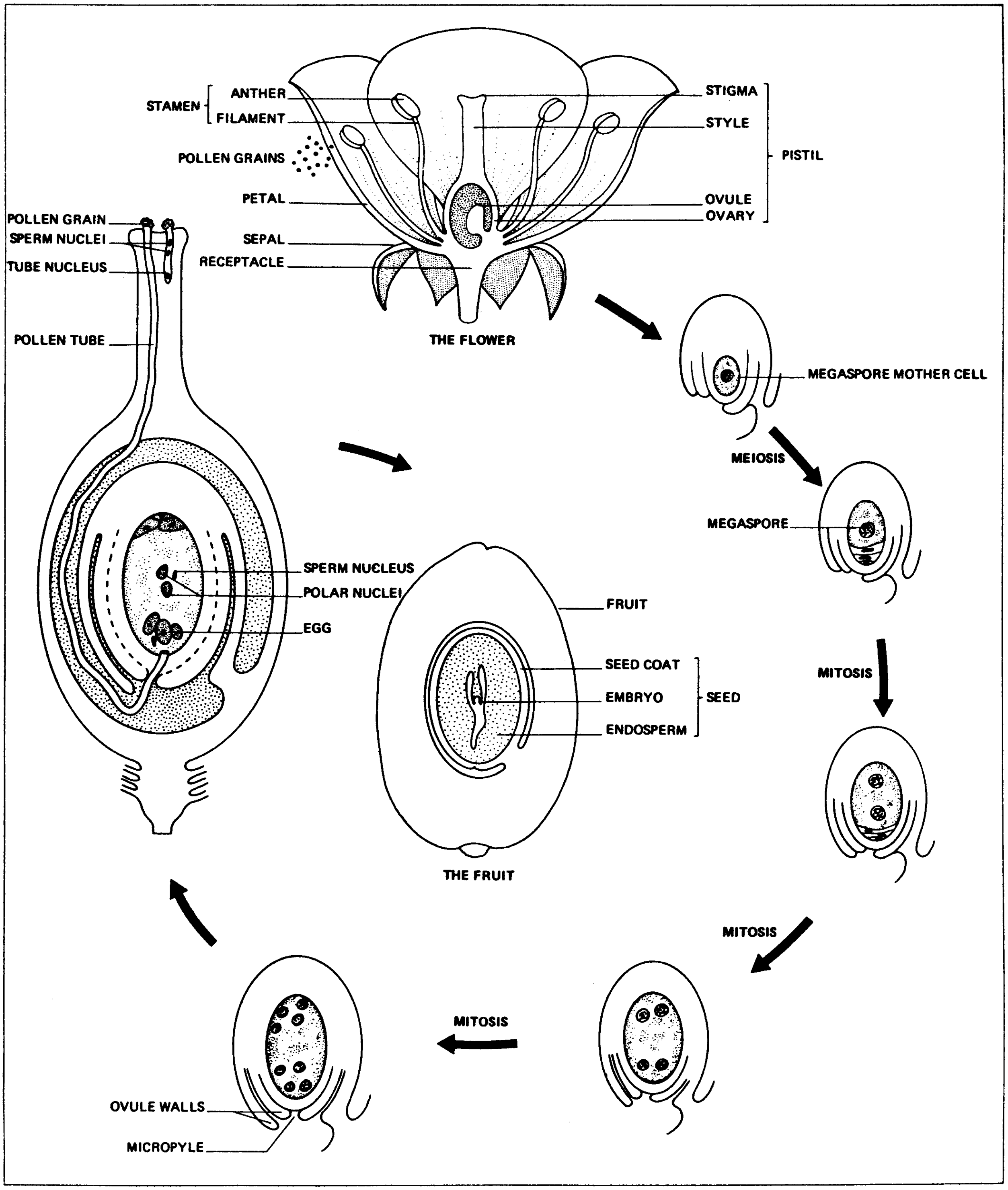

Figure 2. Development of a mature ovary and double fertilization by two sperm nuclei in a generalized flower. *Taken from Biology 4th Edition by J.W. Kimball, 1978.*

Measuring and Managing Soil pH

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This seminar will be presented to you in a format which hopefully covers many of your soil pH questions. Over the past few years, I have been questioned about soil pH, and this seminar is a compilation of questions which were asked. The key to managing soil pH is to understand how it affects plant and soil functions. pH is a very important topic in cranberry production, yet the understanding of pH is minimal. Through the use of a question and answer presentation, I hope to give you direct answers to many of your pH questions.

What is pH?

PH is a measurement which defines the acidity (acid) or alkalinity (base) of a soil solution. The amount of acidity primarily depends on the concentration of hydrogen (H^+) and hydroxyl (OH-) in the soil. As soils get more acidic, the H^+ concentration increases, and this results in a lower pH. At pH 7 the concentration of acid (H+) equal the amount of base (OH-), and this is considered neutral. As pH increases, H^+ concentration decreases, OH^- concentrations increases, and the pH increases. This table outlines a range of pH and their concentrations of H^+ and OH^-.

		Acid H^+ concentration	Alkaline (Base) OH^- concentration
very acid	pH 1	0.1	0.0000000000001
	pH 4	0.0001	0.0000000001
	pH 5	0.00001	0.000000001
	pH 6	0.000001	0.00000001
neutral	pH 7	0.0000001	0.0000001
	pH 9	0.000000001	0.00001
very alkaline	pH 13	0.0000000000001	0.1

How is pH concentration measured?

pH is measured in log units, which is similar to the Richter scale for earthquakes. Each increase of 1 pH unit is actually decreasing the H^+ concentration by 10 fold. As an example, at pH 4, there are 1000 times more H^+ ions in the soil than at pH 7.

Why do some soils have a high pH and others have a low pH?

PH measures hydrogen (H^+) and hydroxide (OH^-) concentrations. Depending on the type of mineral that makes up your soil, a particular soil can naturally have a given low pH. These soils contain a natural abundance of H^+ which keeps soil pH at a particular level. Some of these soils with high organic matter, like a peat bed, has this natural level of H^+ which keeps soil pH low.

What is the optimum pH for growth of cranberry plants and why is this important?

The best pH range for cranberries is 4.2 to 5.5. This is considered very acid when compared to other cropping soils. Plant growth tends to decrease when pH levels are outside this range. The pH of the soil is closely linked with the availability of nutrients to the plant. Within this optimum pH range for cranberries, pH determines the behavior of certain nutrients, making them either available or unavailable.

Why do cranberries grow in low pH soil?

Cranberries evolved in soils where other plants could not grow. They adapted their root systems to tolerate certain elemental concentrations which would kill most other plants. Manganese and aluminum levels are increasingly available as soil pH decreases. Cranberries are tolerant to these high levels of manganese and aluminum, and they live while most other plants would die. This is how they adapted. Likewise at low pH, phosphorus, magnesium, calcium, and molybdenum are less available. Cranberries have adapted themselves to survive on low levels of these nutrients, as compared to other crops, which sometimes need concentrations of nutrients 10 times higher.

When pH is too high, how is the cranberry plant affected?

As pH in a soil increases, there are many nutrients which become increasingly available. Sodium, magnesium and calcium become increasingly available, and are thought to disrupt the balance of nutrients available to roots, and cause a type of toxicity. This nutrient imbalance is not good for cranberries, because they were not adapted for extracting their nutrients from those soils.

Why does the pH of some sandy soil fluctuate, while the pH on a peat soil remain steady?

The answer is in your soil's CEC, the cation exchange capacity. In simple terms, this means that peat soils have a larger amount of reserve H+ and other nutrients (such as phosphorus) which buffer the pH change. This keeps the soil pH stable. Sandy soils have low CEC and thus very little buffering capacity. These soils can fluctuate depending on the amount of H^+ leaching though the soil.

What are the effects of high soil pH on my nitrogen fertility program?

Nitrogen is applied to cranberries in the ammonium form (NH_4^+). Cranberries primarily use ammonium as their sole nitrogen source. In low pH soils, the nitrogen stays in the ammonium form. However, at pH > 5.5, the ammonium form is converted to nitrate, which is not utilized efficienctly by cranberries. Likewise, nitrate is very leachable through the soil.

Can the soil pH in a newly planted bed adjust itself naturally?

I have seen beds with high pH levels (due to liming) decrease when flooded. Essentially, the acidic water supply flushed out much of the alkaline ions which originally caused the high pH. The soil was naturally acidic, and it returned to its natural level of pH 5.0. No other modifications were necessary.

If I have a high pH soil, can it be adjusted?

Yes, but if you have a high pH, that means you have more (OH^-) than (H^+) in your soil system, and you will have to add sulfur which increases the H^+ concentration.

What is the best product for lowering soil pH?

Elemental sulfur (ex. DS-90) is an excellent choice for lowering soil pH. Cranberry plants are adapted to tolerate high levels of sulfur in the soil system. Actually, sulfur is a required plant nutrient for cranberry growth, so the application of sulfur will not harm cranberry plants.

How does sulfur lower soil pH?

Sulfur combines with water and oxygen to form and sulfuric acid H_2SO_4. This acid contains H^+ ions which go into solution and lower the soil pH.

$$2\ \text{Sulfur} + \text{oxygen} + \text{water} \text{ --------- } 4\ H^+ + 2\ SO_4^-$$

Is this conversion a chemical or biological reaction?

The conversion to lower pH is bacterial. Sulfur is oxidized to sulfate by sulfur-oxidizing microorganisms. Its name is *Thiobacillus thiooxidans* . It is a bacteria which is always in the soil at low levels, and when sulfur is applied, they build up their populations to convert the sulfur to sulfuric acid (H_2SO_4). This acid (H^+) then lowers soil pH. It is important to note that this reaction takes time. The bacteria may require several months to convert all the elemental sulfur to sulfate. Thus, pH levels should drop throughout the season if elemental sulfur is still available.

How much sulfur can I put on my cranberries?

When putting sulfur on established cranberry beds, the university recommends a maximum of 500 lbs per acre, split equally between two applications. Maximum applications of 250 lbs per acre should be in early spring after the last flood, and again in mid-late July.

Will high concentrations of sulfur hurt my cranberries?

We know that split applications of 250 lbs. per acre for a total of 500 lbs per acre per season will not hurt your established bed. Applying higher rates without incorporation will concentrate the sulfur on the surface of the bed and could hurt the plant. Studies which focus on the maximum rates of sulfur application have not yet been concluded. Actually, it probably won't be necessary to ever annually apply more than 500 lbs of sulfur. The bacteria must convert this to acid (H^+) and this takes some time. If you have a continuous battle with high pH from flood waters or irrigation, sulfur applications will be a yearly event. Until additional research is completed, don't exceed the university recommendations for sulfur applications.

Are there any potential problems concerning sulfur application?

Sulfur needs to be oxidized to convert to sulfate. If applied in standing water, or saturated soils, sulfur may be reduced to H_2S gas, which smells like rotten eggs. I suggest you apply the sulfur when the vines are dry, then water in the material. If you plan to flood the bed for frost protection, delay the sulfur application.

Are there any other materials which can reduce soil pH?

Yes. An aluminum sulfate product, $Al_2(SO_4)_3$ will lower soil pH, but it would take 3500 lbs. per season to do the same as 500 lbs. of elemental sulfur. The pH drop will occur much more quickly than using sulfur. However, the aluminum levels could possibly be toxic to cranberry plants. I don't suggest you try this product for pH control.

Will potassium sulfate ($K_2\ SO_4$) decrease my soil pH?

Absolutely not. Potassium sulfate contains sulfur, but it is already converted to the sulfate form (SO_4), and no hydrogens can be released to drop the soil pH.

$K_2\ SO_4$ ---------- 2 K + 1 SO_4

Will supplying ammonium (NH_4^+) nitrogen help my soil pH?

Yes, but the plant must take up the ammonium nitrogen to adjust pH. When the plant root takes up an ammonium ion, it removes a hydrogen (H^+) and discharges it into the soil solution. This hydrogen will lower the soil pH.

NH_4^+ ----------to plant root----- NH_3 is taken up, and an H^+ is released

Can the pH get too low?

Yes, studies I have conducted show that plant growth is slowed when pH drops below pH 4.2. I have grown cranberries to levels as low as 2.9, but at that pH, the H^+ is actually toxic, and causes plant death.

What can I do about a low soil pH?

If you feel that your pH is too low, it is best to bring up the pH slightly with a good grade of finely ground agricultural lime. I have seen 50 lbs per acre of lime raise the pH of a bed 0.5 pH units, and increase crop growth.

Will my soil pH be affected by irrigating with a high pH water?

Every time you irrigate with a high pH water, you are slowing increasing your soil pH. The amount of increase depends on your soil CEC. As long as your soil pH does not get above pH 5.5, you are fine. Periodic measuring of soil pH will let you know how much pH change happens after a few weeks of irrigation.

How does flooding affect my soil pH?

When you apply a lot of water on at once, the soil structure is filled to capacity. Nutrients and other ions in the soil solution will dissapate into the flood water, and the pH of the flood water could modify your soil pH. If your soil has a low CEC (holding capacity), and your flood water has a high pH, your soil pH will probably increase. This is the reason that some growers may need to apply sulfur on an annual basis.

Prior to planting, can I adjust the soil pH of a bed with high pH?

Yes. I suggest that you apply sulfur into the soil where you can work it in. If your soil pH is about 6.0, apply 500 lbs per acre and incorporate it into the top 4 inches of soil. If your soil pH is at 7.0 or higher, apply 1000 lbs. per acre and make sure it is well incorporated.

What instruments can be used to measure soil pH?

An electronic pH meter is your most accurate method for testing soil pH. There are many types of pH testers available which range from $60 to $300. The more expensive they get, the more accurate they are, or more functions they perform. For doing occassional testing, you don't need an expensive pH meter. I suggest that you invest in a pH meter with an accuracy of +/- 0.1 pH unit. If the actual soil pH is 4.8, your meter will read between 4.7 and 4.9.

How do we measure soil pH of a bed?

Take 10 samples of soil from the bed, each about 4-6" deep. Mix well in a clean bucket, removing all plant material and large rocks. Combine 1 cup of distilled water with 1 cup of the soil. Mix well for 1 minute, then let it settle for 2 minutes. Submerge the probe into the solution, and read the pH.

How often should we test the pH of our beds?

If you feel that you have a pH problem, checking every month is a good idea. The data will allow you to determine how effective your sulfur applications were on the soil pH. Remember, don't expect the sulfur to work immediately. The bacteria must convert the elemental sulfur to sulfate, which then releases the $H+$ ions and lowers the pH. Over the course of a season, you should be able to determine the difference with your pH analysis.

WHY ARE WISCONSIN CRANBERRY YIELDS DECLINING?

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As with most crops, yields of cranberry increased dramatically during much of this century. Wisconsin cranberry acreage yielded about 20 bbls/acre through the first 30 years of the century, after which a steady increase began. Between 1960 and the early 1980s, yields increased nearly 3 bbls/acre each year (Fig. 1). Following the record statewide yield average in 1982, however, the per acre yield of cranberry in Wisconsin appears to be declining, nearly 20% below early 1980 yields and 50 bbls/acre below that expected if the 1960-1980 rate of increase had continued. While all crop yields fluctuate from year-to-year and 10-year periods of little increase are in the Wisconsin cranberry record, the decrease that began in the early 1980s appears to be more than just bad luck. With the accumulated value of these missing berries in excess of $120 million, an explanation is needed. The cause may be due to circumstances beyond our control, or it may be due to factors that improved management and directed research can overcome. A number of possible reasons for the decrease are being considered by a team of UW-Madison researchers. In this paper, I investigate the evidence that the yield decline is more than just chance, and test a number of candidate causes.

Cranberry Technology

One possible explanation is that the new technologies that propelled the yield increase from the 1930s to the 1980s are no longer being introduced, or are wearing-out. By technology, I mean the application of knowledge, be it through design and use of machines and chemicals, or better understanding of how to best manage both pests and the crop. Technologies such as chemical fertilizers, overhead irrigation, water harvesting, and chemical pest control provided great advantages and yield improvements. Are we out of new tricks? Do technologies wear out? In the case of fertilizers and irrigation, improvements are permanent. Chemical pest control can be lost through regulatory changes and genetic mutation of weeds, insects, and diseases. For example, new wheat varieties must constantly be created, to maintain resistance to ever-changing disease organisms.

If a general loss of technology was to blame, other cranberry-producing areas might be suffering the same yield loss as is Wisconsin. However, this does not appear to be the case (Fig. 2). Other states are certainly not in decline, and may be continuing to increase yield per acre. The most rapid increase in Fig. 2 occurred in Oregon, but their industry is but one-tenth of ours, crops of the early 1980s were poor there, and yields fluctuated wildly in recent years. A technology loss might show up first in Wisconsin if growers here had more quickly and thoroughly adopted it, compared to growers elsewhere. If this is the case, peak yields followed by decrease will occur in other states in the coming years.

Effect of Young Beds

Cranberry, like other perennial crops, requires a number of years of growth to reach full productivity. Because young plantings are harvested before reaching full production, they contribute less-than-average yields to the statewide value. How much influence new beds have on average yield depends on the rate at which they are added to the harvested acreage, and the length and amount of yield reduction due to their youth. Oregon's small industry leads the nation in growth rate (Table 1), with Wisconsin a close second. To estimate the effect of expansion on statewide yields, I made a calculation. Two assumptions were required: how the productivity of a bed increases with age, and why harvested acreage is growing. For the first assumption, I guessed that new plantings are harvested the fourth season after planting, that they yield only 35% of a fully-productive bed, and full yield occurs when a bed is eight years old. For the second, I assumed that each annual increase in harvested acreage (approximated by a smooth curve in Fig. 3) was due to addition of four-year-old beds. If these approximations are reasonable, new acreage reduced 1993 statewide yields by about 8%, compared to early 1980 yields. Recovery of statewide yields from this effect depends on how much new acreage is brought into production in the coming years. For example, if no new beds are harvested, the effect will disappear in 4 years, as all beds reach full productivity. Thus, new plantings account for almost half of the yield deficit below early 1980 productivity, but productivity will recover from this effect as new beds mature and the rate of addition of new acreage slows.

Table 1. Rate of increases in harvested cranberry acreage in the U.S.

State	1993 harvested area (acres)	% Increase 1982-93
Massachusetts	13,140	17
New Jersey	3,490	20
Oregon	1,540	73
Washington	1,510	37
Wisconsin	11,330	62

Individual Beds

Is more of the yield deficit due to other unknown factors related to how the statewide average is calculated? Such effects will not be present in records of individual beds; if yields are decreasing in typical, mature producing beds, we must look to weather, pest management, or crop factors to explain the rest of the statewide decrease. Four marshes kindly supplied yield data for as long as available on a total of 20 beds. The eight beds of Searles in the dataset (Fig. 4a) all appear to be yielding less than they did in 1982. The tendency of Searles for biennial bearing (alternating high and low yields) is apparent in most beds when year-to-year variation is traced (points from three marshes were connected by dashed lines). Such cycles in other fruit crops are largely controlled by new varieties or chemical thinning of blossoms. Perhaps these Searles beds are relatively old, and cranberries, like all living things, slow down with age. The, perhaps, younger Stevens beds (Fig. 4b) were mixed in their yield trend over the past decades. It appears that the statewide yield decrease is reflected in records of individual beds, suggesting that technological or weather factors are contributing.

Influences of Weather

Is the weather of the recent decade to blame? Agricultural climatologists believe that the period from the mid-1950s through the mid-1970s were unusually favorable for crop production in the Midwest US. Around 1974, the climate may have returned to a more normal state of greater variability (Baker et al. 1993). While this behavior can be seen (or at least imagined) relatively easily in corn production records, no similar pattern in immediately evident in Wisconsin cranberry production records (Fig. 1). However, weather of 1982-present may have differed from that of 1970-1981 in ways that were somehow damaging to Wisconsin cranberries.

Several research teams have attempted to understand how weather affects cranberry production. Morzuch et al. (1983), a team of economists, used early observations of Massachusetts cranberry specialists to attempt to separate the effects of technology and weather on yield increases of the 1970s. Degaetano and Shulman (1987) used a statistical "correlation hunt" to identify important weather influences on cranberry yield. They identified as favorable: warm temperatures mid-May to late June and mid-October to mid-November, sunny skies during May and June, and cold during February and March. Poor yields were associated with early springs and hot summers. However, none of these models are very convincing.

When we study weather effects, they are usually considered to be noise, or fluctuations, on top of a strong upward yield trend powered by technological innovation. Understanding the technology trend is difficult because adoption of improved techniques does not happen immediately on all of the state's acreage. Records of yield must somehow be corrected for the impacts of technology, before the effects of weather can be studied. A little imagination can go a long way toward explaining a set observations.

To test the hypothesis that unfavorable weather contributed to the yield decrease of the past 12 years, I compared their weather to that of the 12 years prior to 1982. Two scenarios (we would call them models) of the role of technology were studied: (1) that the trend of 1960-82 continued, and (2) that no new technology was adopted after 1982. The yields observed during 1970-93 were subtracted from both hypothesized technology trends (Fig. 5), to show the remaining variation. The scenarios are identical in Fig. 5 until 1982, that is they follow the straight line on Fig. 1. After 1982 yield departures are greater for (1), since it is the equivalent of the straight line in Fig. 1 continuing upward until 1993, rather than a horizontal trend line for 1982-93, as is (2).

Six weather factors were tested for influence on cranberry yield: 1) thermal time (degree day, base 45^{O}F) accumulation for April, May, and June (AMJ) of the harvest year; 2) like 1), but for the year prior to the harvest year; 3) thermal time accumulation for July, August, and September (JAS); 4) like 3), but for the year prior to the harvest year; 5) total rainfall from mid-June through mid-July; and 6) number of rain days during the same period. Based on earlier studies, spring warmth may affect current season bud development and growth of the next season's fruiting uprights. Summer and fall warmth may affect fruit growth and development of next season's buds. Finally, rain during flowering may reduce fruit set (Peltier 1954), perhaps due to decreased activity of pollinating insects.

Results are presented in Fig. 6, 7, 8 and 9. The figures show yield departures from the technology trend lines vs. the relevant environmental variable; solid points indicate values from 1970-81 and open circles are from 1982-93. Figure 6 shows how spring warmth (AMJ degree days) influenced yield departures for the two time periods. Assuming a constant increase in technology (Fig. 6a), the vertical positions of the points indicate that yields in 1970-81 were generally below the longer term 1960-82 trend (this can also be seen in Figs. 1 and 5). Additionally, as one would also guess from Figs. 1 and 5, yields for 1982-93 were substantially below the constant increase trend. Because of the essentially random pattern of the points, it does not appear that spring warmth affected yield during either time interval. The lower panel of Fig. 6 shows again that 1970-81 yields were below the 1960-82 technology trend. Additionally, the assumption that 1982 technology applied to 1982-93 resulted in mostly negative departures (points below the horizontal line of zero yield departure). This suggests that the technology model of "no new tricks after 1982" is optimistic--maybe a negative technology trend is needed to explain the data. There might be a tendency for greater AMJ degree days to lead to positive yield departures.

A similar analysis is possible for Fig. 7. The arrangement of data points more closely resembles a shotgun pattern than did Fig. 6, so it appears that between thermal time during JAS of the harvest year is not strongly related to yield, for either of the technology assumptions. Yield departure and thermal time accumulations during AMJ or JAS of the year preceding the harvest year also failed to show a useful relationship, and are not presented here.

Possible effects of rain during pollination are shown in Figs. 8 and 9. As is usually the case with rainfall records, data points in Fig. 8 tend to be clumped toward one end of the graph. Values from the 1982-93 period tend to be at the extremes (high and low), lending support to the idea that the climate is becoming more variable. The pattern of points is not in conflict with the idea that drier is better during pollination, but do not strongly support it, either. The number of days of rain during this period (Fig. 9) are more evenly distributed than were rainfall totals. In the top panel, little relationship is apparent. The technology model in the lower panel, however, reorganizes the pattern so as to suggest that fewer rainy days are better, as one would guess. This demonstrates how important it is to find an appropriate technology model when studying weather impacts.

Summary

Cranberry yields per land area in Wisconsin appear to be decreasing, a trend that began in the early 1980s. Nearly half of the decrease can be explained by the rapid increase in young harvested acreage over the time period. However, individual beds for which long yield records are available reflect the statewide decrease, so other factors, such as the lack of new technology, or the aging of current technologies, must be at work. Comparison of key weather variables in the 12 years preceding and following the apparent change in yield trend did not reveal clear differences between the time periods. Further analysis of yield and weather records is required, perhaps through use of a deterministic cranberry crop model. By this, I mean a model that is derived from expert opinion and research results on specific aspects of the crop's reactions to weather. The decrease in Wisconsin cranberry yields appears to be more than a chance occurrence, and is a challenging and important question. Expanded teamwork, both among researchers and between researchers and growers, is needed.

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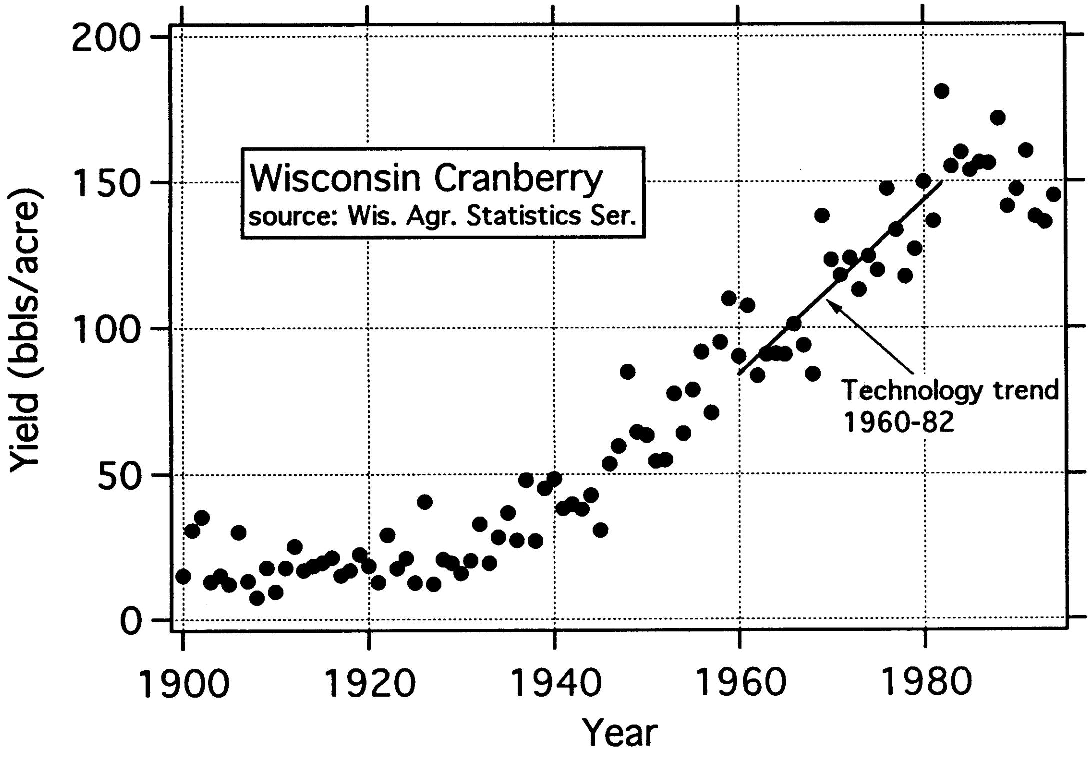

Fig. 1. Yields of cranberry in Wisconsin, 1900-1993

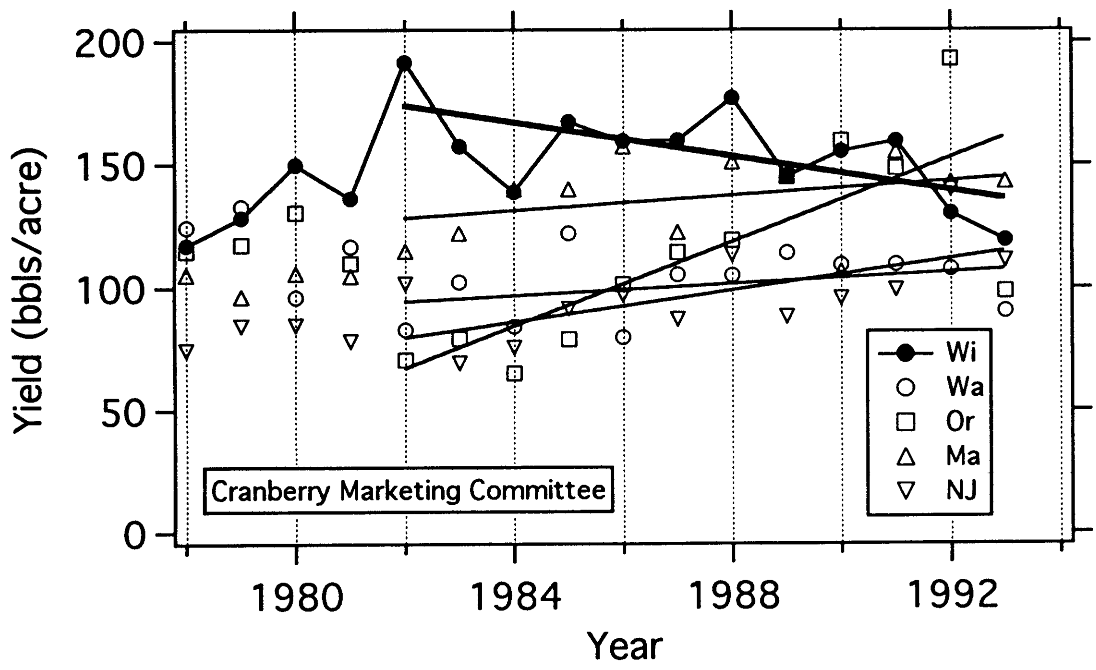

Fig. 2. Yields of cranberry in the five major producing states.

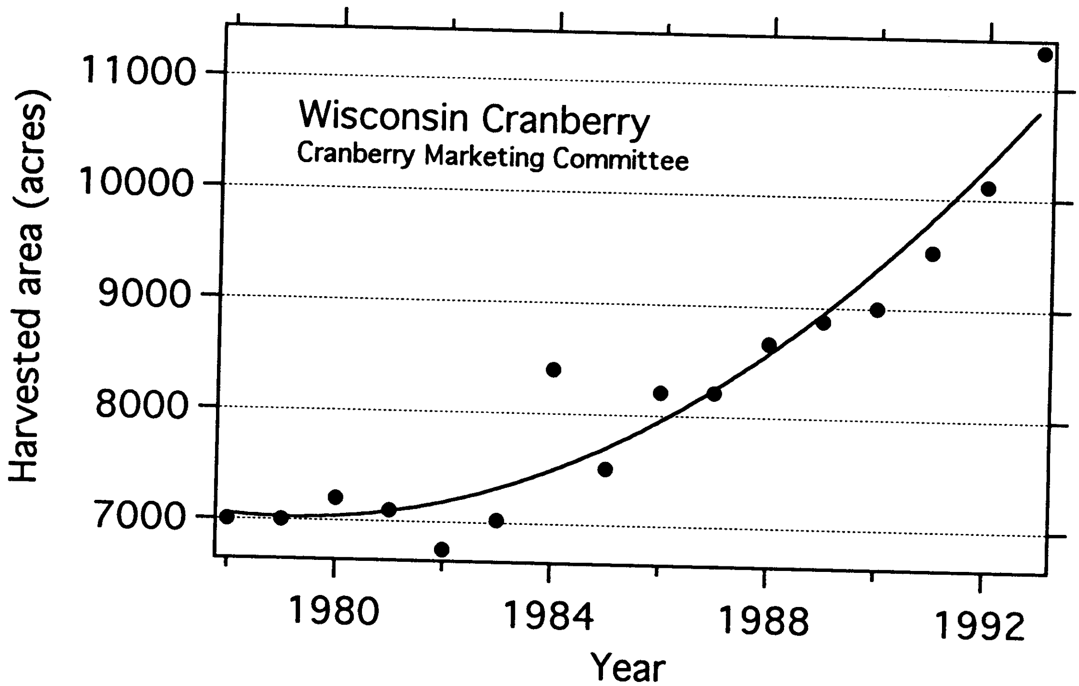

Fig. 3. Harvested cranberry acreage in Wisconsin

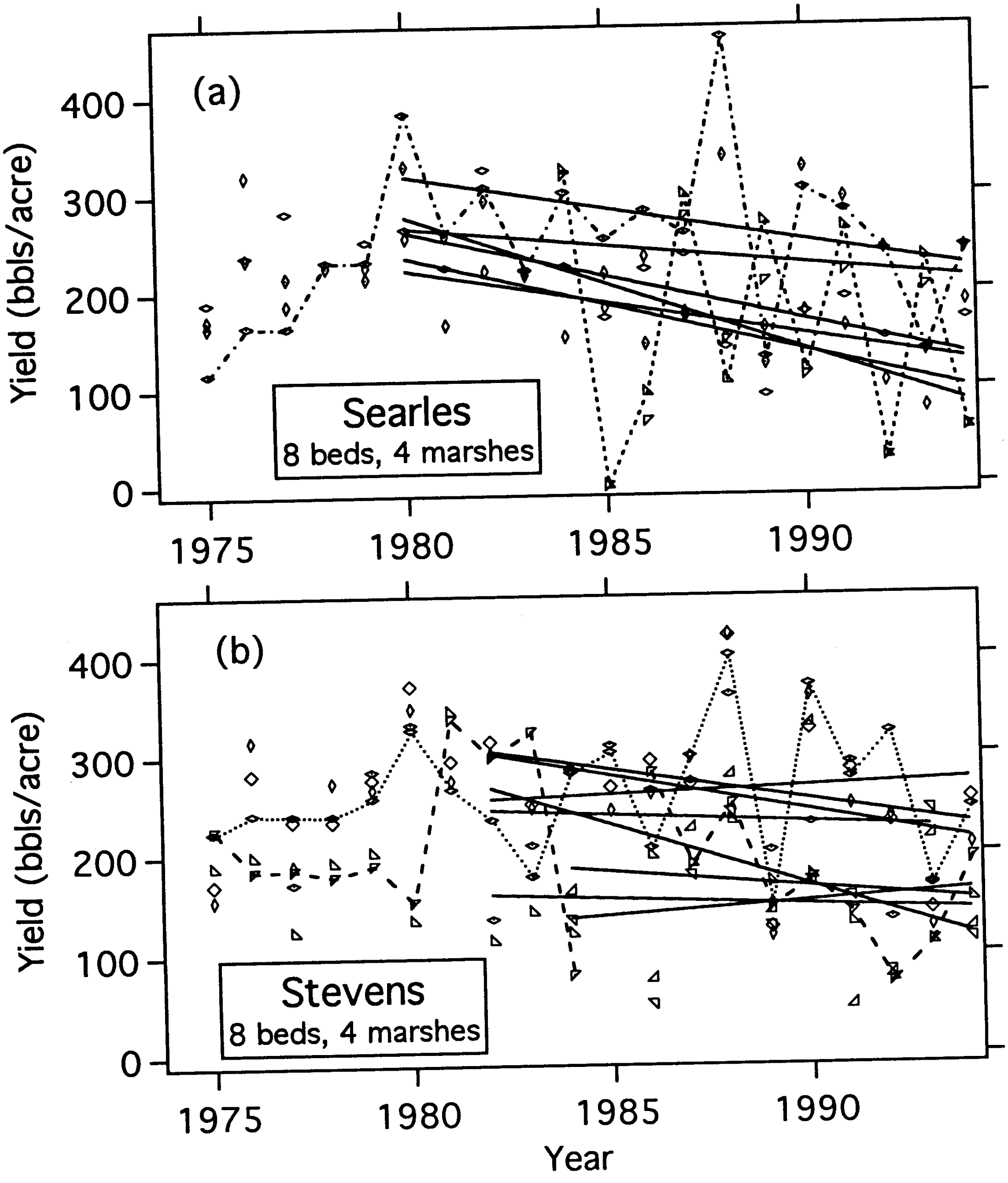

Fig. 4 Yields of individual cranberry beds in Wisconsin for two varieties: (a) Searles, (b) Stevens.

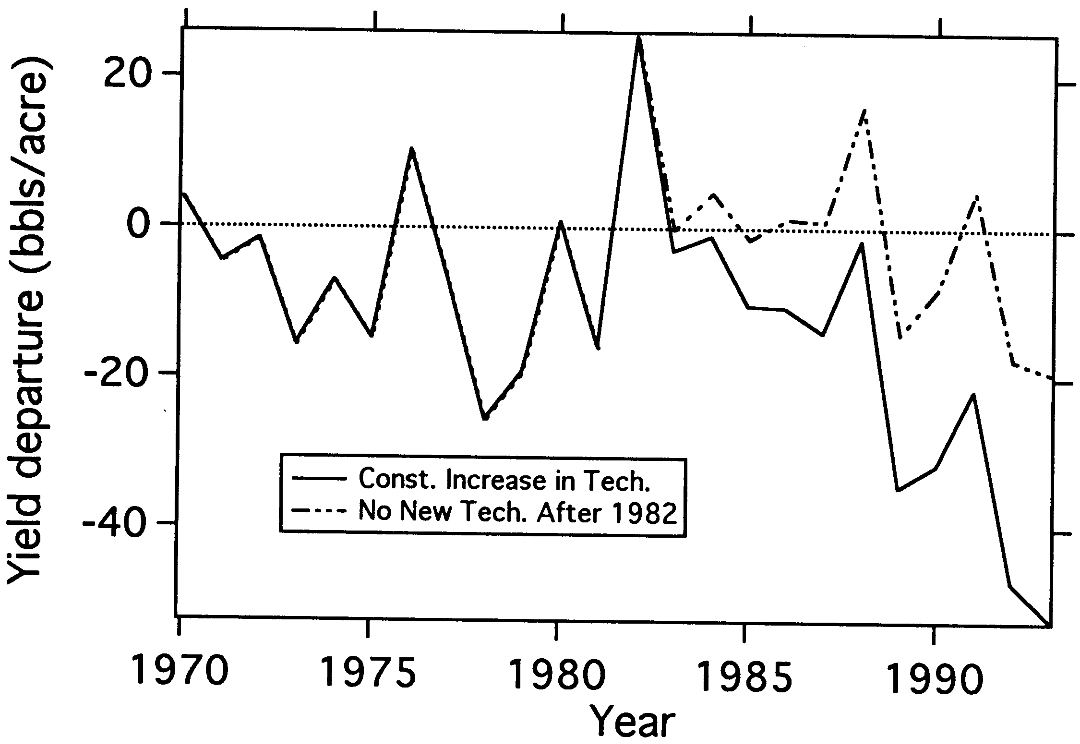

Fig. 5. Departures of Wisconsin cranberry yields from two assumed technology-driven trend lines.

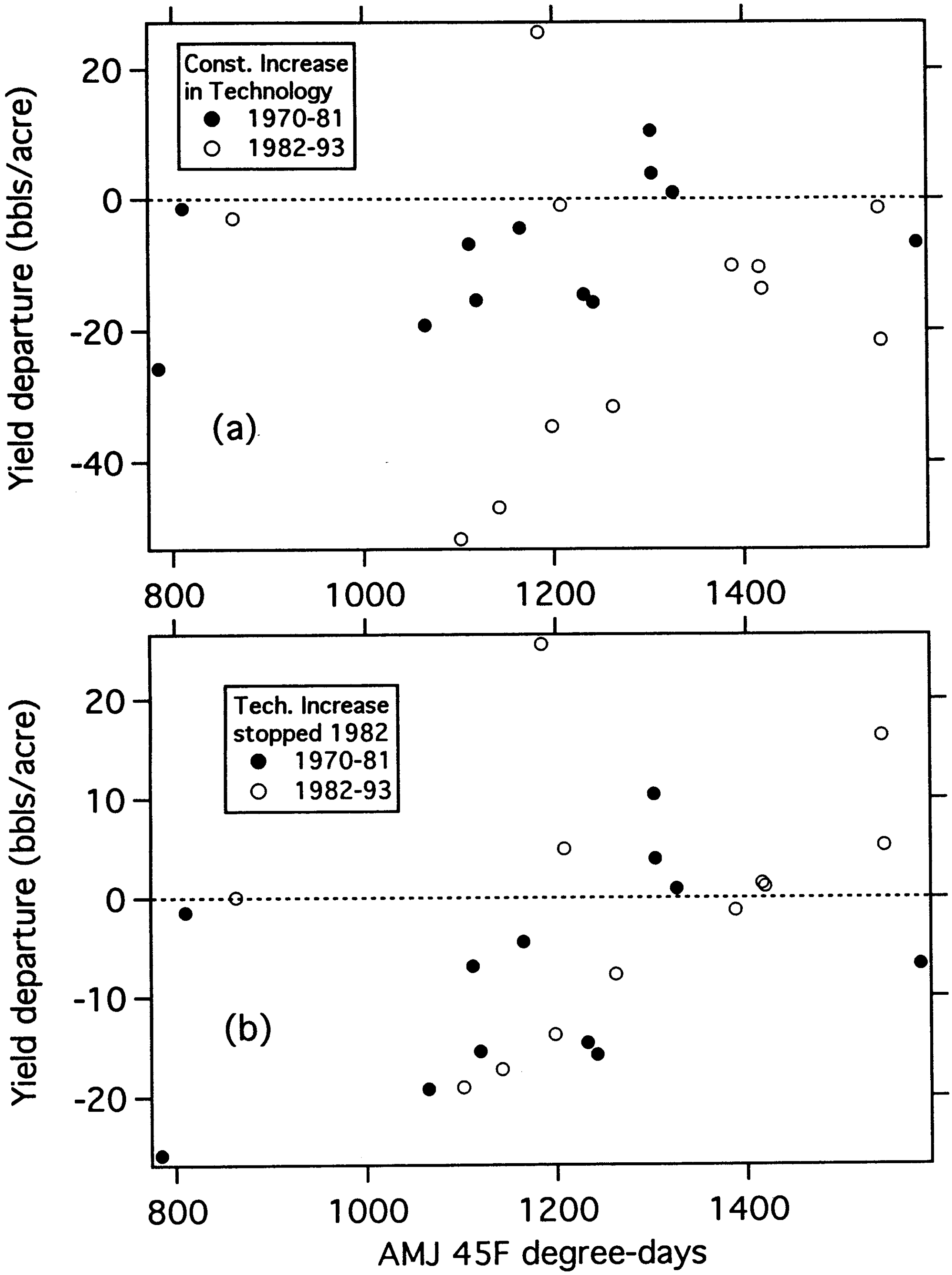

Fig. 6. Relationship of Spring (April-May-June) thermal time accumulations to departures of cranberry yield from two hypothesized technology trends: (a) assuming technology continued to increase yields at the rate observed 1960-82, (b) assuming no new technology was introduced after 1982.

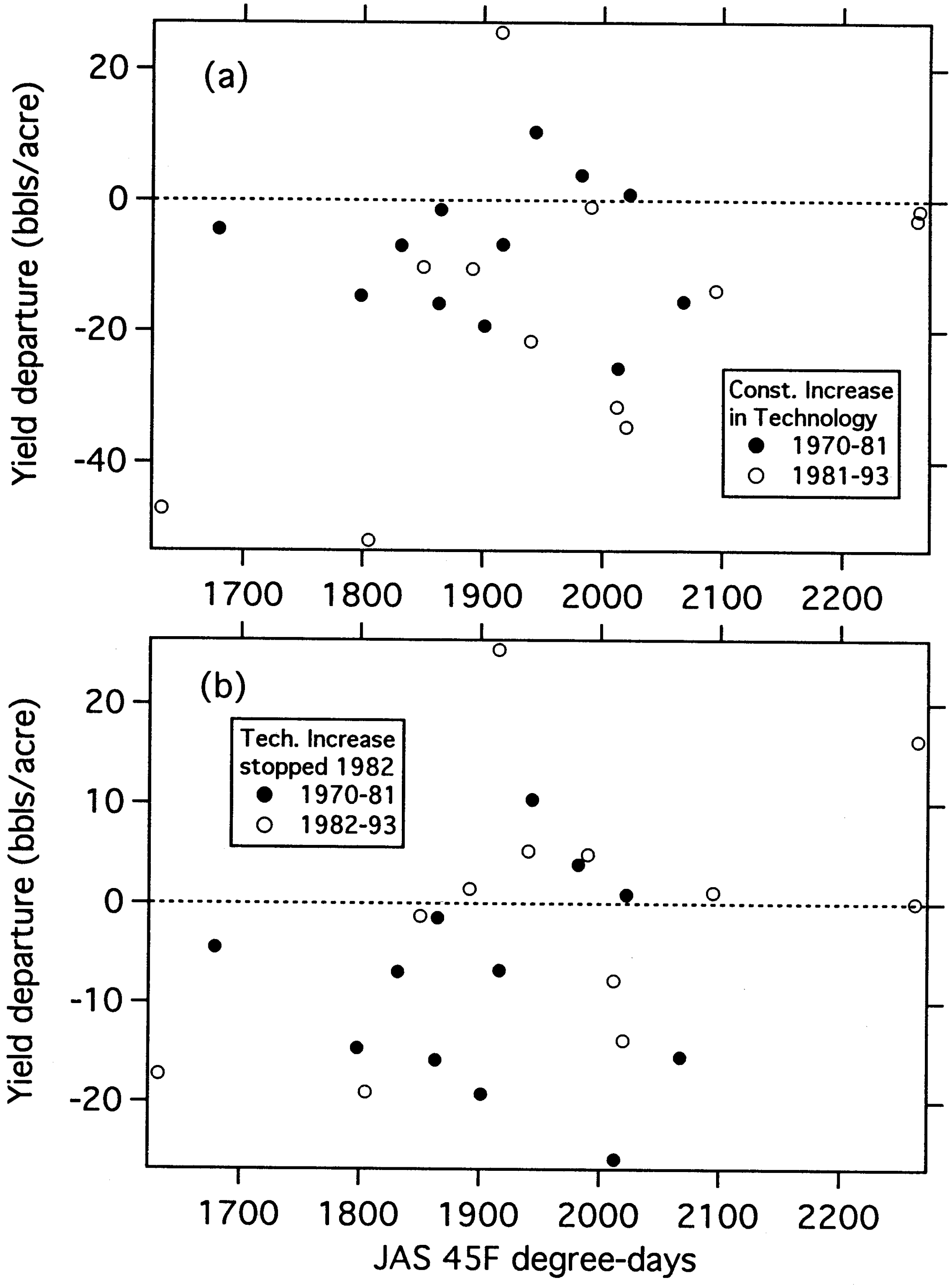

Fig. 7. Relationship of Summer (July-August-September) thermal time accumulations to departures of cranberry yield from two hypothesized technology trends:
(a) assuming technology continued to increase yields at the rate observed 1960-82,
(b) assuming no new technology was introduced after 1982.

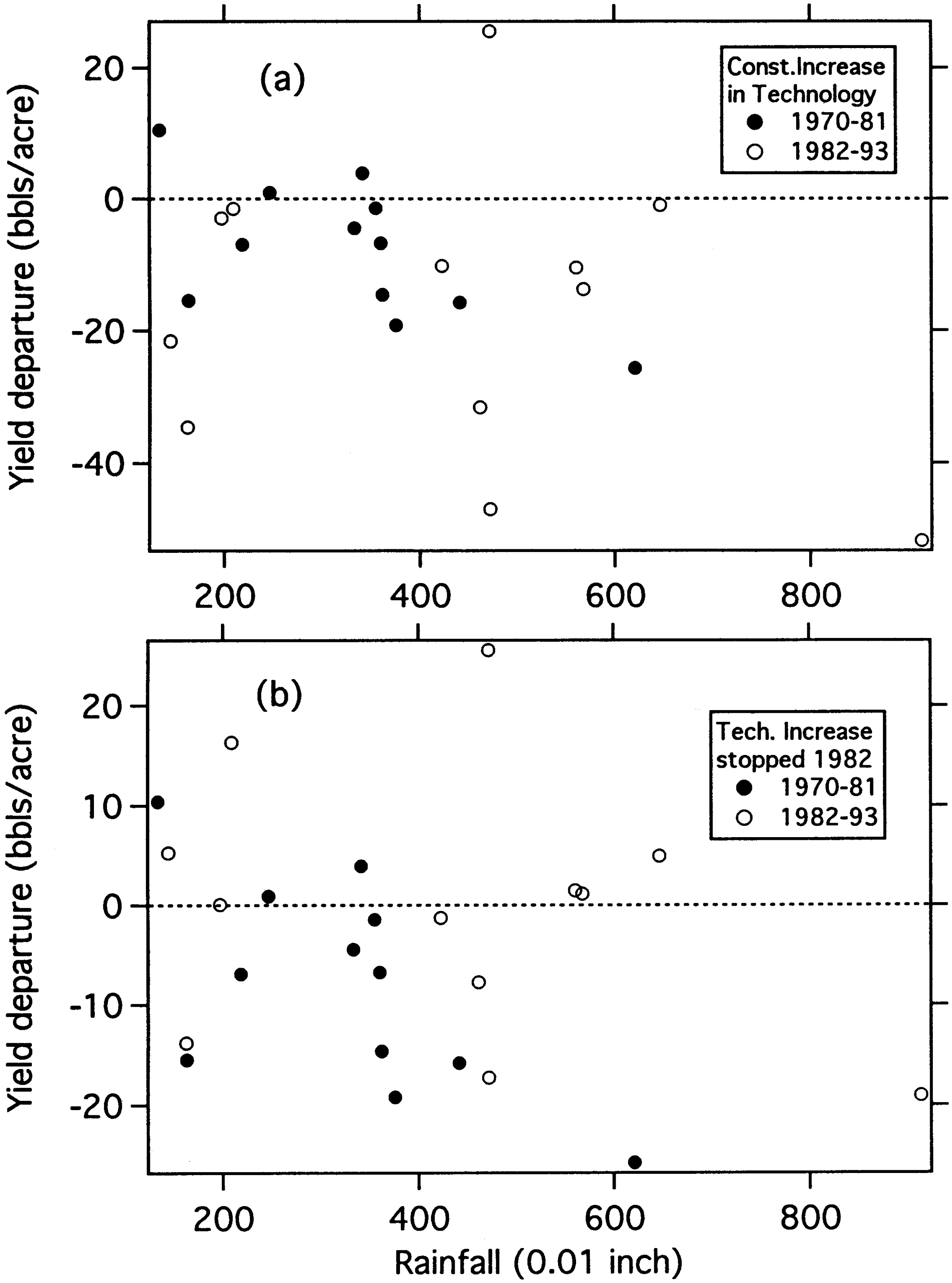

Fig. 8. Relationship of rainfall during pollination (mid-June to mid-July)to departures of cranberry yield from two hypothesized technology trends:
(a) assuming technology continued to increase yields at the rate observed 1960-82,
(b) assuming no new technology was introduced after 1982.

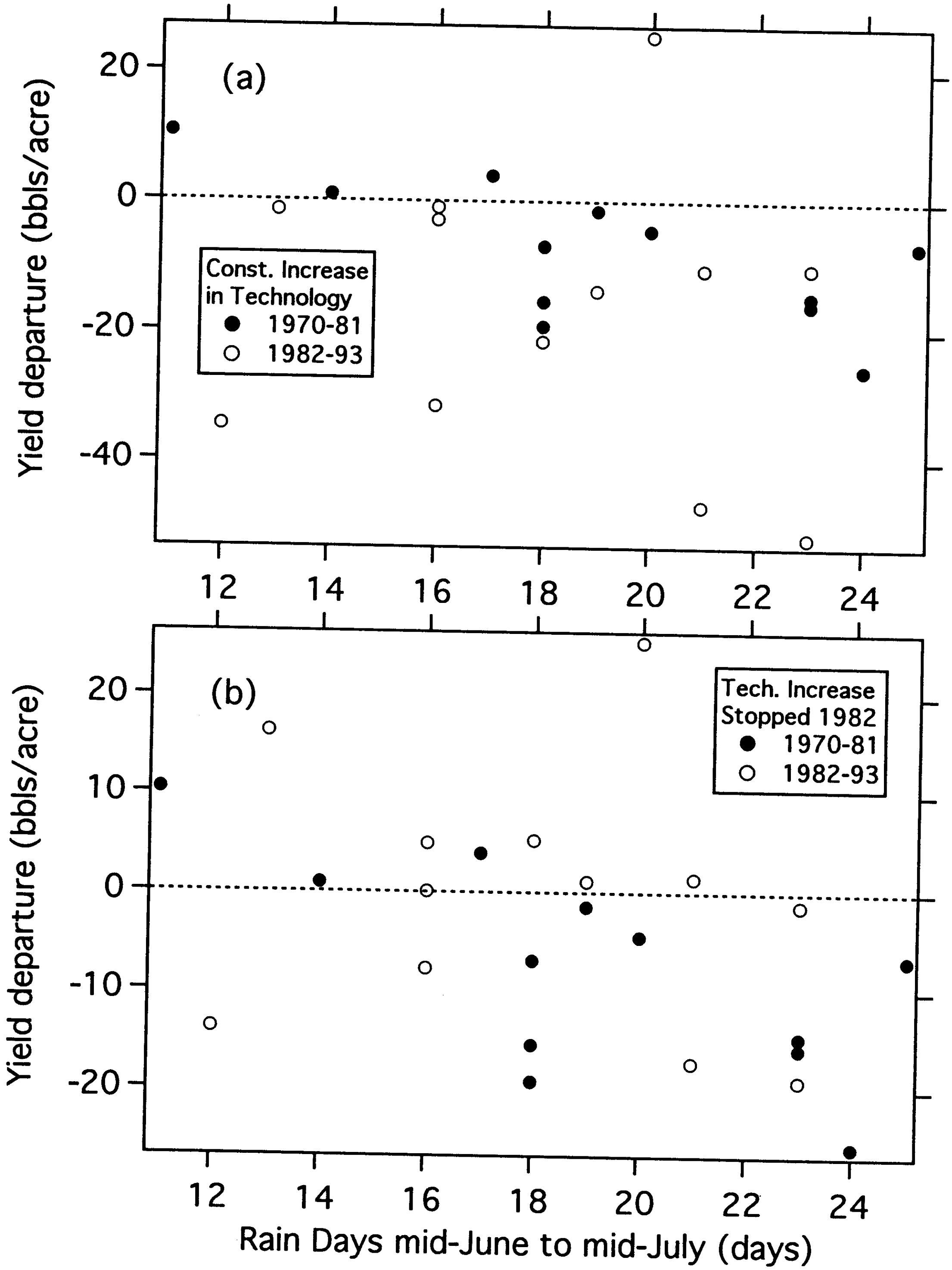

Fig. 9. Relationship of days of rain (mid-June to mid-July)to departures of cranberry yield from two hypothesized technology trends:
(a) assuming technology continued to increase yields at the rate observed 1960-82,
(b) assuming no new technology was introduced after 1982.

Bumblebees as Pollinators and Management Options

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BUMBLE BEES AS POLLINATORS

The value and effectiveness of bumblebees should be compared to honeybees to keep their practical use in perpective. Almost all of the pollinator force on cranberry crops is from honeybees and bumblebees. These pollinators and a few wasps and solitary bees provide cranberries with the pollination they need. Flower populations (yield potential) and actual yields in response to increases in the pollinator force must be known to determine how many bees are required on the bogs. Then we can derive the bees value to the grower.

Efficiency

On many crops, bumblebees (*Bombus* species) are 2-4 times more effective pollinators per bee than honeybees (*Apis mellifera*) and solitary bees such as the alfalfa leafcutter (*Megachile rotundata*). This is due to a 50-200% faster flower working rate and an average of 50 or more % longer hours worked each day. The importance of the working day remains underappreciated, and it is virtually unquantified worldwide. The greatest differential in average working days between bumblebees and honeybees occurs in wetter and cooler regions (e.g. coastal pacific Northwest North America) or seasons during crop flowering. The least difference occurs in consistently warm dry climates e.g. parts of California.

For a few crops, bumblebees can be 10-20 times more effective pollinators per bee than nectar collecting honey bees. This is either because bumblebees either contact the stigma more consistently on cranberries, blueberries, red clover, some vetches or their larger bodies contact much more of the stigma e.g. curcurbits (pumpkins, squashes, melons, cucumbers), cotton, kiwfruit, cranberries, feijoa. As well they may carry about twice as much pollen on their body hairs for transfer to stigmas.

Pollinator role of bumblebees

In Wisconsin and eastern North America, feral (unmanaged) populations of short and medium tongued species of bumblebees (notably *B. impatiens, B. affinis, B. terricola, B. vagans,* and *B. perplexus*) provide backup pollination that adds an element of reliability to pollination of other crops. These crops include lotus, Dutch, alsike clovers, sunflower, buckwheat, *Phacelia*, chicory, pip and stone fruits and berries. The honeybee is an effective and economic pollinator of most of these crops except for some major sunflower cultivars. Long tongued bumblebee species (*B. fervidus, B. pennsylvanicus* and the rarer *B. borealis,* and *B. auricomus*) prefer other flowers to cranberries. They are affective pollinators of red clover, many vetches, faba or tick and runner beans, blueberries, cherries, and curcurbits.

Bumble bees tolerate a wider range of insecticides than honeybees and solitary bees (alkali bees *Nomia melanderi*; alfalfa leafcutter bees; and perhaps mason bees (*Osmia* spp). *Osmia lignaria* (American) and *O. cornuta* (Japanese) in USA are of potential value for fruit pollination.

Colony characters and development

Commercially reared colonies of bumblebees will always tend to be expensive compared to honeybees. This is partly, because bumblebees are used only for pollination and adverts and can never be kept for honey production. Honeybees have potentially perennial colonies, because they can be requeened and so only colonies lost to disease and enemies need replacing. As well, all temperate species of bumblebee colonies last for 3-5 months. Colony formation takes about 4 weeks, colony growth (3-10 weeks - workers and males reared), maturity (2-4 weeks - new queens emerge) and senescence (2-4 weeks - brood rearing has ceased). Species with large colonies last about twice as long as species with small colonies (20-50 active bees per colony). Even the American species with the largest colonies (*B. impatiens, B. affinis, B. occidentalis, B. vosnesenskii*) only last at peak pollinating activity for 6-8 weeks. During this time the colony approaches and then passes through maturity. Hence year round production of glasshouse tomatoes requires several colonies per year.

At their peak each colonies of commercially reared species can have 200-400 bees including the non stinging males. Maximum foraging averages 2-3 bees entering or leaving per minute. During summer a honeybee colony has 20-50,000 bees and the better colonies have 100-150 bees foraging from them per minute.

In spring, the queen (the large bumblebees) forms a colony, before the 6-8 workers (small, main stingers) from the first brood take over foraging for nectar and pollen for the colony. Usually, 10-30 % of the colonies that produce workers mature provided field conditions are reasonable (an adequate sequence of food supply, lack of major parasitism, bee poisoning, predation). Species with large or medium-large (*B. terricola, B. perplexus,* and perhaps *B. ternarius*) colonies produce an average of 60-200 queens per colony. Variation in total seasonal output between mature colonies within commercial species is quite large (800-3,000 bees and 1-900 new queens). Eventually there should be less variation when a few key pathogens have been eliminated and the more productive lines have been bred.

This output of new queens allows considerable potential for dispersal of overwintered queens to sites with more favorable food. For each queen this can occur over 2-3 weeks in spring before she starts her colony. Spring dispersal is usually within 2-3 miles, but can be as much as 10 or more miles. The high queen output allows for population recovery after unfavorable seasons. New Zealand and 1993-1994 Washington studies with two *Bombus* species confirmed that most (over 70%) of the new queens do not survive to emerge next spring from soil hibernation sites. However, if colonies are well fed during the production of new queens then at least 2 times as many enter hibernation. Hence, at Washington, queens from commercial colonies were overwintered artificially. Overwintered queens emerged for 30 days. In 1994, a sheltered cage (within a shed) was tried in an attempt to improve overwintering.

CRANBERRIES AND POLLINATOR EFFECTIVENESS

The following results were obtained on 60 cranberry bogs on the Pacific coast during 1993 and 1994. Half the virgin cranberry flowers visited once by honey bees formed berries. Two pollen collecting honey bees = one bumble bee based on working rate and a 30 % longer working day for bumble bees. On a favorable, 10 hour day one bumble bee would visit 6, 000 flowers and on an average 4-5 hour day 2,500 - 3,000 flowers will be visited. Pollen collecting honey bees are 10 times more effective in pollen transfer than nectar collecting honey bees. This is based on working method (contact with the stigma) and pollen on parts of the body that contact the stigma.

Foraging and delivery to bogs

The rate of entrance activity of honey bees varied considerably between locations as well as with temperature and during the day but it did not change much throughout cranberry flowering. The general average of 80 entrances per minute for honey bees, was only marginally below the rates recommended for pollinating colonies. Foraging activity of *Bombus occidentalis* colonies direct from the producer 'Bees West' upon release produce about 0.5 entries and exits per minute. Within 30 - 50 days foraging builds up to the maximum of 1.5 - 2.0 per minute. Hence honeybee hives had 40 -160 times greater activity than bumble bee colonies.

The introduction of honey or bumble bee colonies to the vicinity of the cranberry bogs releases more bees into the environment around the bogs. However, only a proportion of the bees that forage from the colonies are delivered (actually visit the cranberry flowers) to the bogs that are within the flight range of the colonies.

Three factors make the delivery rate of honey bee inferior to bumble bee colonies: **1.** Honey bees have 2-3 times the average foraging range of bumble bees except in adverse weather. **2.** Honey bees communicate within the hive about the quality of the sources of food, while each bumble bee determines from what flowers are yielding resources best from experience and sampling. Thus honey bees have the ability to shift to masses of better yielding flowers more rapidly than bumble bees **3.** Honey bees forage freely from a wider range of flowers than the short tongued bumble bees. Hence competing pollen sources are more important for honey bees than bumble bees. Put another way the main bumble bee species visiting cranberry flowers have a better preference for cranberry flowers.

In Washington, there was no consistent relationship between honeybee populations and the no of hives used per acre. The rates were an average of 3 (range 1 - 6.8) colonies per acre for the early flowering 'Stevens' compared to 2.3 (0.9 - 5.6) at the final stages for 'McFarlin'. Despite the higher initial rate on 'Stevens' the overall rate of honey bee populations measured on 'Stevens' was lower than for 'McFarlin'

By contrast, responses in the bumblebees densities from commercial hives were apparent, although in three seasons data had been accumulated for 10 bogs. The ability of commercial bumble bee colonies to deliver bees onto cranberry bogs has been derived as an initial reference for stocking at up to 4.5 hives per acre. Recommended changes to the timing of introduction of bumble bee hives may change this initial guideline.

Irrigation, weather and bee activity

On cranberries, honey bee populations were reduced to 10 % of normal levels while the bog remains wet, but bumble bee populations remain at 80 % of normal on wet crops. Wetting the crops can discourage bee foraging by diluting the nectar and making the pollen temporarily unavailable for collection. Honey bee populations decline by more than a half once winds exceed 6 - 7 mph. Bumble bee foraging is not so readily affected by these winds, but declines beyond 7 mph.

Honey bee populations increased 70 fold on cranberries between the onset of foraging at 59 - 60°F and 71°F. Medium and high bumble bee populations increase 9 fold from about the onset of foraging at about 54 - 55°F and 71°F. At about 80°F bumble bee populations will level off and then decline in the middle of the day as temperatures extend into the 80's. Partly this is because honeybees deplete the nectar resource of the crop faster at high temperatures. In addition, bumblebees can only cool their colonies by fanning, which diverts workers from foraging. If the wax melts and larvae are exposed then bumblebee workers throw the larvae out, so overheating can be a problem. Bumble bee colonies try to keep at around 86-90°F. Honeybees bring water in to evaporate, which controls high temperatures better.

Consequently honey bee populations using cranberry flower are volatile to changes in the weather. As well only a few hours per day produce most of the foraging.

Most (80 %) honey bee foraging occurred between 11 am and 4 pm, while for bumble bees 85 % of the foraging occurred between 10 am and 7 pm. Foraging of bumble bees and honey bees on cranberries is a best low before 10 am even when temperatures above 65°F allow for adequate flight. This is presumably due to the time needed to replenish nectar in for new pollen to become available from newly opened flowers. With honey bees the relative percentage of cranberry pollen being gathered during six parts of the day was examined with the pollen traps over two days. Over 80 % of the weight of cranberry pollen was collected by honey bees between 12 am and 4 pm. This implies that much of the pollination done by honey bees is actually achieved during only four hours per day in the Pacific North-West.

Honeybee pollen collection

Honey bees collect cranberry pollen freely for about 7 - 10 days. There is steady decline in the percentage of pollen collecting honey bees on cranberry bogs as the season progresses. Hence better honey bee pollination should be achieved with early flowering varieties compared to later flowering varieties. Honey bees took 5-10 days to start to collect pollen freely after introduction to the bogs. The variation may depend partly on the attractiveness of other flowers close to the bogs. Honey bees were relatively slow to come onto a bog, where the colonies had been resident for all the year and learnt about their environment. This indicated that they were collecting pollen more from other sources such as scotch broom before the mass of cranberry flowers provided an attractive enough source of pollen to foragers. The effect of shifting hives in 10-12 days later for bogs with mainly late flowering areas should be investigated judging from the seasonal trend in pollen collection. Final pollen gathering from cranberries was low while the majority of pollen come from blackberry (increased to 60 %). Catsear (false dandelion) with 15 - 30 % of the pollen, which was mainly gathered around mid day, was another major competing flower for honeybees. In British Columbia, white sweet clover seemed to be an important competing pollen source.

REARED BUMBLEBEE FIELD MANAGEMENT

The advent of extensive (100,000 colonies per year) commercial production of bumblebee colonies (*B. terrestris* - Europe, New Zealand; *B. impatiens, B. occidentalis* - North America) primarily for pollination of glasshouse tomatoes between 1987 and 1992 opened up new avenues for their field use and the resultant new queen progeny. However, the three large and at least seven lesser firms in all these areas have only just begun the sale of colonies for field crops. For North America, sales began in 1993/1994. To be frank these firms tend to be a "little green" at the best in dealing with colonies in the field. In a few years you should get better pollination service from more professionally handled colonies.

In Washington and British Columbia colonies not protected by an electric fence were eaten by bears even when placed on a high solid pole. The continued supply of sugar to foraging colonies is dubious or probably the wrong approach. I consider, the feeder should be shut off during pollination of the crop to ensure surplus nectar is used up within the colony. Only mature colonies accumulate food stores beyond daily use. Bumblebees are diligent foragers, because each day they must replenish food stores daily or temporarily starve, and they start foraging each day before honeybees can reduce the amount of accumulated nectar per flower. So far nobody has measured how much effect this contrast in feeder management has on foraging from the entrance, but perhaps extra food cuts foraging by half at least initially. The feeder can be reapplied along with the closing of the entrance for a day if harmful insecticides are applied, where any cranberry crop within 0.5 miles still has more than a trace of flowers. The feeder provides handy food for any colonies taken into a screen cage for new queens to be extracted for overwintering. No provision of a small (0.5 -1 inch wide) entrance landing and with entrances in the same direction caused workers to drift into lower colonies. Bumblebees and their social parasites (cuckoo bumblebees, *Psithyrus* spp) at least use a marking pheromone (virtually distinct for different *Bombus* subgenera) to assist females to find the colony entrance. The colonies produced by one of the major firms for tomatoes pollination are great for inspection and rapid control of wax moth operations. However, these hives have insufficient space for the largest colonies and inadequate ventilation and drainage for the fecal output. This tends to accentuate overheating problems and cause more ejection of larvae to make enough space for the bees. Colony foraging from commercial hives will benefit from shaded hives in old pumphouses, sheds, special shelters. Hives within 2 feet of each other should have the entrances facing in different directions to aid orientation.

Few bumblebees forage beyond 1/3 of a mile and with commercial colonies at least in the first 2 weeks foraging was concentrated within 1/6-1/10 of a mile (100-200 m). This is based on limited measurements on foraging from feral colonies in Nebraska, and hived colonies in New Zealand and Washington. Hence, when commercial bumblebee colonies are used in combination with honeybees, then place the commercial bumble bee colonies in the more central bog locations about 50 yards or more away from honeybee colonies. Keeping the bees apart and shutting of the feeders will lessen the risk of the honeybees robbing the bumblebee colonies. Let the honeybees and feral bumblebees look after the marginal flowers on bog complexes.

FERAL POPULATION MANAGEMENT

Management options

Management of field populations of bumblebees has barely extended beyond the planning stage anywhere in the world. In theory, more bumblebees may be obtained from the collection of overwintered queens or colonies started in field hives from a "wild or suburban area", where bumblebees are not needed and then shifted to the grower. Trapping of colonies in field hives in a suburban setting in Christchurch, New Zealand and the sale of colonies over 60 miles away began the commercial use of bumblebees in the world in 1982. Eventually these sales to red clover, kiwifruit and alfalfa growers stimulated the European implementation of extensive commercial colony production by *Biobest* in 1987. In practice, release of bumblebee queens in two contrasting areas of Canterbury in New Zealand lead to population increases during that season at a dry cool continental area. Where queens have been consistently released since 1982, populations have increased even although hives placed out on the farm did not encourage any colony formation. This grower has planted strategic small corners of bee forage and has increased his range of nectar bearing crops so it now includes *Phacelia,* chicory and lotus in addition to Dutch and red clover.

In early summer, some urban dwellers especially need colonies removed when the owners come across them in their gardens, garages, sheds and house walls. However, only some of these colonies merit collection. Some are unavailable (in or under concrete, structural walls, roofs - that can not be reassembled). Others are too small or too far spent (tunnel activity less than 0.5 per minute) or with are species with a fierce temperament (mainly long tongued species) or have significant parasites (mainly the small parasitic wasp *Melittobia acasta* or many *Psithyrus*). Colonies with *M. acasta* have to be destroyed (put in a freezer, and hives treated with pyrethroids to kill residual parasites). Collection of large colonies from such sites with a net, cooler box and ice pads, tubes or canisters during the day takes about an hour before all bees return (foragers make up 30-50 %) of workers in growing and mature colonies. Removal of pupae of the bumblebee brood flies *Brachicoma* and adult moths *Vitula edmandsae* can in badly infected colonies take about 30 minutes. Readily accessible, medium sized colonies can sometimes be transferred to hives at night within a few minutes with only bee gloves for protection. The use of CO_2 as soon as the first of the brood clump of enclosed underground colonies is exposed may speed up collection. In practice, collection of colonies is used with some care to provide queens for bumblebee rearing. Eventually some suburban areas may provide limited amounts of colonies for crop pollination once "underemployed" bee keen youths can take advantage of this opportunity. Before this happens growers need to know the value of these colonies, which should be kept separate from commercial colonies to minimize the risk of spread of colony enemies.

A SUMMARY OF THE BIOLOGIC AND ECONOMIC ASSESSMENT OF PESTICIDE USAGE ON CRANBERRY

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This assessment attempts to provide a critical evaluation of the impact and importance of pesticides in the production of cranberries in the United States. The report contains detailed information and general conclusions regarding the use of insecticides, fungicides, and herbicides used in cranberry production in the United States during the period of 1987-1992. It provides an overview of the uses of the major chemicals and describes the economic and social benefits of those uses to the cranberry industry. This information may be useful for decision making regarding pesticide registrations, for designing improved, environmentally sound pest control programs, and in establishing goals for reducing or eliminating certain pesticide inputs in cranberry production.

Numerous insects, plant pathogens, and weeds must be controlled to produce a quality cranberry crop. Most of the current pest control strategies in cranberry include the use of pesticides, although there is an attempt to reduce pesticide use through the implementation of IPM programs and research on non-chemical control measures.

"Currently, growers rely mainly on about a dozen pesticides of the 27 still labelled for use on this crop."

The use of pesticides in the different cranberry growing regions is dictated by the pest complex and intensity of pest pressure, the time of year and weather conditions, specific management objectives, and the properties of the pesticides. The loss of registration of even a few pesticides would have a severe impact on the cranberry industry. In some cases satisfactory control of certain pests could be achieved with alternative chemicals; however, more applications of less effective and sometimes less environmentally sensitive pesticides would be required to produce a quality cranberry crop. Also, growers would have reduced flexibility in timing and choice of materials and diminished capacity for pesticide resistance management with fewer alternative materials available to rotate.

Acreage, production and value of cranberries, United States, 1987-1992a.

Year	Area Harvested (acres)	Total Production (barrels[b])	Value
1987	26,700	3,391,000	$150,906,000
1988	27,300	4,080,000	$186,340,000
1989	27,500	3,747,000	$164,720,000
1990	27,800	3,391,000	$156,365,000
1991	28,300	4,219,000	$206,783,000
1992[c]	28,700	4,080,000	$213,292,000

[a] Source : USDA Agricultural Statistics, 1993.
[b] Barrels of 100 pounds
[c] Preliminary

Cranberries are grown commercially in the United States in Massachusetts, New Jersey, Oregon, Washington, and Wisconsin on over 28,000 acres. Fruit production exceeded 400 million pounds in 1992, with a value of approximately $213 million. Most of the cranberry crop today is used for processed products, with 10 percent or less sold as fresh fruit.

There are many species of insects that affect the roots, shoots, and fruit of the cranberry plant. Most of these pest are native to North America. Most are indirect pests, feeding on the foliage or roots, reducing the vigor of the plant. A few feed directly on the blossoms and developing berries, causing significant reduction in yield and quality.

Although insecticide use fluctuates each year depending on pest pressure, insecticide use in Massachusetts and Wisconsin is relatively high, while use in other States is considerably lower. The decrease in parathion use did not result in a dramatic increase in use of other insecticides, perhaps because of the implementation of IPM programs. The two biological insecticides, Bt and nematodes, have only been available for use on cranberry since 1989 and 1988, respectively. Their use has increased, although they have not been adopted yet in New Jersey.

"Of the insecticides currently registered for use on cranberry, chlorpyrifos, diazinon, and azinphos-methyl have predominant use in cranberry production, although parathion was the most extensively used insecticide in all areas prior to its cancellation."

Insecticides are extremely important, especially to prevent damage from direct fruit pests in the East Coast growing areas where there is heavy insect pressure. Insects cause up to 40% berry damage in Massachusetts if beds are left untreated. Yield is also indirectly affected. Fewer insect problems exist in Wisconsin and on the West Coast; however insecticides are still necessary to produce a crop. In most places yields would be significantly reduced since the remaining insecticides are not as effective and cultural or biological alternatives do not provide as good or as fast control as the chemicals. At least half of the crop could be lost to direct pests alone the first year in East Coast beds, with yield reductions of 15-50% estimated elsewhere. In subsequent years, pest pressure would be higher and losses more severe, enough to drive many growers out of business. Expected substantial yield reductions due to regional insect problems will produce important short-run economic losses.

"Without insecticides, yields would be reduced 15-50 percent the first year. In subsequent years pest pressure would be higher and losses would be more severe."

There are numerous plant pathogens that cause disease on cranberries under the proper conditions. Some cause injury only to the vines or roots, but the majority infect berries, causing direct damage. Fruit rots, all caused by fungi, are the most important disease problem in cranberry. In East Coast beds, most berry damage is due to fruit-rotting fungi, rather than insects or mechanical injury; losses to fruit rots in both the field and in storage can be very high. Fungal diseases tend to be the most serious in regions with long growing seasons and relatively high summer temperatures, such as are encountered in New Jersey. In Wisconsin and the Pacific Coast region, disease pressure is usually low and field rots other than cottonball are rarely encountered. Storage rots are usually considered together as a group because the symptoms produced by most of the fungi on the berries are so similar that it is practically impossible to visually distinguish fruit rots caused by different fungi.

The most fungicides are used in Massachusetts, where fruit rot disease pressure (both field and storage) is most severe. New Jersey and Wisconsin treat close to the same acreage with fungicides, but a much larger percentage of the total acreage in New Jersey in treated because of higher disease pressure. Much of the fungicide use in Wisconsin is triforine for cottonball control rather than fungicides for fruit rot control. On the smaller acreages on the West Coast, where disease pressure is less severe, less fungicide is used.

"The most important fungicides for cranberry production are clorothalonil and the EBDC, mancozeb."

"Without fungicides for fruit rot and vine disease control, overall yield reductions of 20 percent would be common (although it would range from 0 to 100 percent in individual beds); the incidence of storage rot would increase; and it is questionable whether growers in areas of high disease pressure would be able to continue to produce a crop of high enough quality to justify harvesting."

Fungicides are applied to prevent direct damage from fruit rots and indirect effects on yield and vigor from diseases of the leaves, shoots, and roots. In general, recommended fungicide spray schedules provide good control of fruit rots and allow production of a high quality crop. Chlorothalonil and mancozeb provide good control of field and storage rots, while copper products are less effective. Timing of applications affects the incidence of field and storage rot, with earlier schedules providing better control. Growers in areas of high disease pressure would have difficulty producing a quality crop for fresh fruit without fungicides.

Many native and introduced plant species are considered weeds when they invade managed cranberry marshes. Most of the weeds affecting cranberry production are adapted to a wet, marshy environment and grow directly in the beds. Others tend to be found mainly in the ditches or edges of beds. In cranberry beds under dry cultivation, upland weed species cause more problems.

Herbicides are generally applied either in the fall or spring as pre-emergence broadcast applications or as a post-emergence wipe during the summer to weeds above the vine level. Glyphosate is used only for wiper-application spot treatment. Approximately 48% of all growers use glyphosate in any one year. New Jersey used very little herbicide other than glyphosate. Dichlobenil was used on the greatest acreage. Herbicide usage was highest in Massachusetts, and then in Wisconsin.

"Dichlobenil, napropamide, and glyphosate are the most commonly used herbicides."

The herbicides registered for use on cranberry are effective and generally selective to cranberries when used according to recommendations, but none of the herbicides available will control all weed species. A combination of herbicides applied in sequence is normally used because of the great variety of weeds that infest cranberry beds. Yield reductions of 50-60% are likely based on the fact that growers with poor weed management practices currently have significantly lower yields than average. Without some selected herbicides or any herbicide, up to half of the growers would eventually go out of business because it would no longer be profitable to farm when their beds become overwhelmed by weeds in 5 to 10 years. Mechanical weed control would be a poor replacement for herbicides in terms of yield, and although the use of bog renovation would help prevent devastating yield reductions in the Northeast, expected per acre impacts are still significant. The short-run economic impact of loss of herbicide availability is expected to be especially important to Wisconsin producers and also to have major deleterious consequences for producers in the Northwest.

"Without the major herbicides more herbicides that are less efficacious would be used, but yields would decline significantly. Many weeds would have no effective alternative controls. The major impact on yields would not be seen for several years as bogs would be gradually overwhelmed by weeds."

Pesticide use is a major issue. There is considerable concern by growers and the general public over the use and fate of pesticides. Although cranberry is a small crop in terms of acreage, it is a high value crop where future pesticide regulation may be critically important. Because of the wetlands habitats where much of the cranberry production areas occur, and the extensive usage of water in cranberry culture, protection of water quality and wildlife is a major concern. The potential for movement of pesticides to groundwater is very low because of the high organic matter content of most cranberry bogs; stratification that facilitates the horizontal movement of water while downward penetration into lower soil layers is inhibited; the dense fibrous root system of the cranberry vines in the upper 2 to 4 inches of the bed that slows the downward movement of water; and because water is generally flowing into, rather than out of, most wetland type cranberry bogs. Retaining potentially toxic compounds on the bog where they are degraded to insignificant amounts by the biological and chemical properties of the cranberry ecosystem reduces the possibility of surface water contamination.

> "Most pesticides are applied through chemigation systems, aerially, or with ground spray units. The use of pesticides in the different cranberry growing regions is dictated by the pest complex and intensity of pest pressure, the time of year and weather conditions, specific management objectives, and the properties of the pesticides."

Cranberry IPM programs started by the University of Massachusetts, and later by the University of Wisconsin, have been extremely successful and were turned over to and adopted by the industry. Now 80% of the cranberry acreage in these states is scouted regularly. Similar programs have been instituted by the national grower cooperative in other States, and there are also private consultants that offer IPM programs. The pest management procedures developed in these programs to improve timing of pest controls to coincide with crucial parts of the pest and/or plant life cycle, result in better choice of control methods based upon the pest populations detected through regular scouting and reduce usage of pesticides when pests were not present.

> "In most cases, good alternatives are not available for control of important pests."

Economically, the short-run impacts of the loss of availability of selected pesticides would be substantial and long-run impacts may be much more significant, especially for herbicides. Without insecticides, yields would be reduced up to 50 percent the first year and losses would be more severe in subsequent years. Without fungicides, overall yield reductions of 20 percent would be common, storage rot would increase, and growers in areas of high disease pressure may not be able to produce a crop worth harvesting. Without the major herbicides, more herbicides that are less efficacious would be used, but yields would decline significantly and many weeds would be uncontrolled. After several years many bogs would be overwhelmed by weeds. The short run economic welfare changes due to the loss of availability of individual pesticides is relatively small, because the remaining pesticides are reasonable substitutes in most cases. However, loss of availability of any group of pesticides is expected to impose large reductions in yield and quality, with the largest impact resulting from the loss of herbicides.

> "Loss of the major herbicides, fungicides, and insecticides is expected to result in short-run economic welfare changes of at least $65 million, $39 million, and $21 million, respectively. Consumers and producers of cranberries are expected to share these losses approximately equally."

> "Without chemical pesticides fruit quality would be drastically reduced and it would be virtually impossible to economically produce a cranberry crop."

North American Tissue Test Standards

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The "standard" ranges for mineral nutrient content of cranberries has been published as different values for different growing areas. Many of the ranges being expressed are the result of research in a growing area. However, at the 1993 North American Cranberry Research and Extension Workers Conference, in Richmond, BC, the research scientists who work on cranberry mineral nutrition agreed that it was time to come up with uniform standards. Looking at the different regional research, we recognized that the values from region to region or by variety are not different enough to suggest different standards.

In November 1994, the Cranberry Mineral Nutrition Working Group met again and worked together to establish the standards. These are resultant from research on the major cultivars and in all of the growing areas. Work done by retired researchers was also considered. The values listed in the table below are the normal ranges for cranberry tissue nutrient content in a mid August to mid September sample, where only this years growth is taken. Please note that the ranges are expressed relative to normal. This does not mean that above or below normal means an excess or a deficiency - but that some attention to these levels should be given in planning future fertilizer practices. A fact sheet with these numbers and some guidelines on sampling will be printed and made available during the late spring or early summer of 1995.

In looking to use these guidelines, here are a few things to keep in mind:

- ♦ The guidelines are for producing beds.
- ♦ The guidelines are for a tissue sample taken in the late summer/early fall. We recommend tissue sampling between 15 August and 15 September.
- ♦ Tissue samples taken during this time period should be this year's growth only and not include any fruit, flower or pinhead material.
- ♦ Sample throughout the bed to adequately represent the entire bed in the sample.

There are a few things to bear in mind when looking at these values and the results of a tissue test. If you have used any pesticides which contain plant nutrients, you may see elevated levels of the nutrients in your results. For example, the fungicide KOCIDE contains copper, and late season use of this material may show up as high copper in the tissue. If you are trying to troubleshoot a problem, it is better to take samples from the area in question and a "good" area in the same or an adjacent bed and compare the results - this way you will get a better indication of what the status quo for the bed should be. Another problem situation that often occurs is that tissue samples from areas with vine overgrowth may show up as low. DO NOT assume that the plants need more fertilizer. Overgrowth may "dilute" the nutrient content in the plant and extra fertilizer will only serve to make this situation worse.

CRANBERRY TISSUE NUTRIENT CONTENT GUIDELINES FOR PRODUCING BEDS

NUTRIENT	BELOW NORMAL	NORMAL	ABOVE NORMAL
Nitrogen (%)	< 0.90	0.90 - 1.10	> 1.10
Phosphorus (%)	< 0.10	0.10 - 0.20	> 0.20
Potassium (%)	< 0.40	0.40 - 0.75	> 0.75
Calcium (%)	< 0.30	0.30 - 0.80	> 0.80
Magnesium (%)	< 0.15	0.15 - 0.25	> 0.25
Sulfur (%)	< 0.08	0.08 - 0.25	> 0.25
Boron (ppm)	< 15	15 - 60	> 60
Iron (ppm)	< 20		
Manganese (ppm)*	< 10		
Zinc (ppm)	< 15	15 - 30	> 30
Copper (ppm)	< 4	4 - 10	> 10

* Manganese content over 300 ppm may be an indication of poor drainage. If tissue MN is at or above this value, please check soil drainage conditions and if it is poor or there are numerous wet spots, you may want to consider improving soil drainage through ditching or tile drains.

Worker Protection Standard for Agricultural Pesticides

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The federal Worker Protection Standard (WPS) for Agricultural Pesticides took effect January 1, 1995. Its purpose is to reduce the risk of employee exposure to pesticides. You are subject to the WPS if you have at least 1 employee who is involved in the production of agricultural plants in a nursery, greenhouse, forest, or farming operation.

This handout cannot provide the precise worker protection details that are specified under the rule. If you have employees handling pesticides or workers performing tasks in pesticide-treated areas, you'll need to get a copy of EPA's *How to Comply* manual. This manual and its supplementary handbooks are available from your county Extension office. They have a limited supply but, GEMPLER'S, an agricultural supply warehouse in Mt. Horeb, WI, carries the complete line of WPS training materials and aids. Their phone number is 800-382-8473.

Affected Pesticides

The pesticide products covered under the WPS include those that are involved in the production of agricultural plants in nurseries, forests, greenhouses, and on farms. Some pesticides not included in the above definition are those used: on pastures and rangelands; for vertebrate pest control; as attractants and repellents; on animals or their premises; and on harvested portions of plants.

All pesticide products which are used in the production of agricultural plants will have a restricted-entry interval (REI). Check the *Agricultural Use Requirements* section on the label for the specific reentry interval for your product.

Affected Employees

Any employee who handles an agricultural plant pesticide or who enters a treated site during an application, an REI, or the 30 days after an REI has expired. The following individuals are covered under the WPS:

- Agricultural workers -- those who perform tasks relating to the production and harvesting of agricultural plants.
- Pesticide handlers -- those who handle agricultural plant pesticides or assist in their application (e.g., mixers, loaders, applicators, flaggers) or clean or repair application equipment. Crop advisors are considered pesticide handlers.

Exemptions

- When performing the tasks of an agricultural worker or a pesticide handler, the owner of an agricultural establishment and his/her immediate family are exempt from many WPS requirements except: restrictions during applications (monitoring is not required), early-entry restrictions (pesticide safety training is not required), and wearing personal protective equipment.
- When hiring a professional application or consulting service, the owner and his/her immediate family are exempt from the WPS requirements except for the employer information exchange provision.

Requirements for Workers & Handlers

Information at a Central Location

The following 3 types of information must be displayed in a central location where workers and handlers (except handlers employed by a commercial application business) are able to read them. This information must remain posted for 30 days after an REI for the applied pesticide has expired.

- A WPS pesticide safety poster or its equivalent which conveys basic pesticide safety concepts;
- Name, address, and phone number of the nearest emergency medical facility; and
- Specific information about the application before it is made, including the location, date, and time of intended application; restricted-entry interval; and product name, EPA registration number, and active ingredient(s) of the pesticide.

Pesticide Safety Training

Employer responsibility. The employer is responsible to ensure that each noncertified employee who handles pesticides or who enters treated sites during an application, an REI, or the 30 days after an REI has expired is trained on general pesticide safety principles every 5 years. The employer can accomplish this by:

- Providing training,
- Verifying that the worker is already trained, or
- Determining whether the worker is a certified pesticide applicator.

Trainer Responsibility. The employer may do the actual training or contract others to perform such training. In either case, the trainer:

- May present information either orally or audiovisually (EPA has developed a *How to Comply* manual and other training aids to assist trainers),
- Must provide training in a language workers can understand, and
- Must be a certified pesticide applicator or, to train workers, a trained handler.

Worker Training Information. The training program must include the following:

- The effects of pesticide exposure on human health;
- Routes of pesticide entry into the body;
- Symptoms of pesticide poisoning;
- First aid for pesticide injury or poisoning;
- How to obtain medical care;
- Decontamination procedures, including flushing of eyes;
- Warnings about taking pesticides or containers home;
- Where pesticides may be encountered during work activities;
- Hazards from chemigation and drift;
- Hazards from pesticide residues on clothing; and
- Entry restrictions, oral warnings, posting, availability of specific information about applications, and protection against retaliatory acts.

☞ Early-entry workers who will contact surfaces treated with a pesticide must receive WPS training (unless he/she is certified) before entry; wear PPE and be instructed on its proper use; be trained to prevent and recognize heat-related illness; and be informed of other precautions relating to early entry.

Handler Training Information. The training program for handlers includes the first 7 items for worker training plus:

- The meaning of pesticide label information and precautionary statements;
- Appropriate use of personal protective clothing and equipment;
- Prevention and recognition of heat-related illness;
- Safety requirements for handling, transporting, storing, and disposing of pesticides;
- Environmental concerns such as drift, runoff, and wildlife protection; and
- Other provisions of the WPS that must be followed by the handler.

Decontamination Sites

A decontamination site (water for routine washing and emergency eye flushing, soap, and single-use towels) must be available:

- Whenever workers perform activities in a treated area during an REI or within 30 days after the REI.
- Whenever anyone handles pesticides (for handlers, a clean pair of coveralls also must be at the decontamination site and enough water for washing the entire body in case of an emergency).
- Within 1/4 of a mile of all workers and handlers, or at the nearest place of vehicular access to the site where employees are working. The decontamination site for handlers mixing pesticides must be at the mixing/loading site. Water for washing, soap, and clean towels must also be available at the site where handlers and early-entry workers remove their PPE.

Additionally, at least 1 pint of emergency eyeflush water shall either be carried on person or otherwise immediately accessible (per EPA, within very few seconds; per WDATCP, within 10 feet) to each handler (and to each early-entry worker who contacts pesticide-treated surfaces) and for which the pesticide labeling requires protective eyewear.

Employer Information Exchange

Handler's Employer. Before a handler makes an application for hire, the handler's employer must inform the client (i.e., the agricultural employer) of:

- The location of the treated site.
- The time and date of application.
- The product name, active ingredient, and EPA registration number.
- The restricted-entry interval.
- Whether posting of the treated area and oral notification to workers is required.
- Any other product-specific requirements concerning worker protection.

The operators of agricultural establishments must have this information to protect their employees. See *Information at a Central Location* and *Notice About Applications*.

Agricultural Employer. Similarly, the owner hiring the application or consulting service must inform the handler's employer of the location of any area that may be treated or be under an REI while the commercial handler is at the agricultural establishment, and if there is a likelihood that the handler may be in or walk within 1/4 of a mile of such areas.

The operators of commercial pesticide handling establishments must have this information to protect their handlers while at the agricultural establishment.

Emergency Assistance

If a worker or handler has become poisoned or injured by exposure to pesticides, the employer must promptly make transportation available to an emergency medical facility. The pesticide label and information about pesticide activities must be made available to the medical personnel.

Further Requirements for Workers

Notice About Applications

The employer must give notice of pesticide applications to all workers who will be in a treated area, or walk within 1/4 of a mile of a treated area, during the pesticide application or an REI. Notification may either be oral warnings or posting of warning signs at entrances to treated sites; both are required if the label specifies.

Oral warnings. The employer is responsible for providing oral warnings to workers in a manner that the worker can understand. The warnings shall consist of the location of the treated area, the period of time entry is restricted, and instructions not to enter the treated area until the REI has expired.

Posting. The employer also is responsible for posting warning placards that are visible from all usual points of worker entry to the treated area including each access road, footpath, or other established walking route leading to the area. Sites subject to posting must be placarded within 24 hours before the application. The placards must be removed or covered within 3 days after the REI has expired.

Restrictions During and After Applications

- During application -- no person, except a trained and protected handler, may be in the area being treated.
- After application -- with the exception for early-entry workers, keep all workers out of an area during the REI.

Early-Entry Workers with No Contact

Entry into the treated area is allowed immediately after an application provided workers will not touch or be touched by any pesticide residue on plants, on or in soil, in water, or in the air. Examples of 'no contact' activities include: wearing footwear and walking through a treated area in aisles or on pathways; operating an enclosed cab; or operating an open cab where plants or other treated surfaces cannot brush against or drip pesticide onto the worker from overhead. Such workers must be given all the protections discussed thus far, except for decontamination sites.

Early-Entry Workers with Contact

Entry into the treated area to perform tasks that involve contact with pesticide residue (e.g., moving or repairing irrigation equipment) is allowed provided:

- Entry does not occur until any inhalation exposure level or ventilation criteria have been met,
- Entry does not occur during the first 4 hours after an application,

- Tasks do not exceed more than 1 hour per 24-hour period, and
- Tasks do not involve hand labor (tasks performed by hand or with hand tools).

Early-entry workers with contact must be given all the protections discussed thus far, plus wearing of PPE. preventing heat stress, and labeling information.

☞ More stringent restrictions exist for applications in nurseries and greenhouses.

Further Requirements for Handlers

Restrictions During Applications and Monitoring

- Handler employers and pesticide handlers both must make sure that pesticides do not contact, either directly or through drift, anyone except trained and protected handlers.
- All handlers applying a pesticide with a skull and crossbones symbol on its label must be monitored visually or by voice contact at least every 2 hours. See *Exemptions*.

Specific Instructions

A handler must be provided with access to the pesticide label and be given labeling information on the signal word, human hazard statements, PPE required for the handling task, first aid, environmental precautions, and any other precautions about the handling task.

They also are to be informed about sites on an agricultural establishment that may be treated or under an REI. See *Employer Information Exchange*.

Equipment Safety

Employers must make sure that handlers:

- Are instructed in the safe operation of application equipment.
- Know how to correctly handle, repair, and clean contaminated equipment

Personal Protective Equipment (PPE)

Pesticide labels will list the minimum PPE that employees must wear. Employers are to provide the PPE, train employees how to use them correctly, and keep them clean and in good working condition.

Crop Advisors

Crop advisors are pesticide handlers. They may enter sites during an application or an REI provided they are given the same protections as a handler. When entering treated sites, they are not limited to the time restrictions for early-entry workers. They may enter an area during or up to 4 hours after an application provided they wear the PPE that the pesticide label requires for handling activities. If they wait until at least 4 hours after an application, they may wear the PPE listed for early-entry tasks.

No WPS protections are required for commercial crop advisors after the REI has expired.

Proposed Provisions

(As of this writing, none of these proposals has been enacted)

In January 1995, EPA has proposed five changes to the WPS. These include:

- Pesticide safety training. Require immediate training (0-day grace period with a one-year phase-in period before going into effect) for agricultural workers, and shorten the interval for retraining to 3 years.
- Crop advisors. Exempt certified or licensed crop advisors from WPS requirements.
- Irrigation tasks. Provide an exception for early-entry workers who operate, move, or repair irrigation or watering equipment to wear reduced PPE and remain in the treated

area up to 8 hours per 24-hour period. This exception does not apply to "dual notice" pesticides, i.e., pesticides that contain both oral and posting warnings.

- Limited contact activities. Provide an exception for early-entry workers who perform limited contact tasks (i.e., tasks that result in minimal contact with treated surfaces and where such contact is limited to the forearms, hands, lower legs, and feet) to wear reduced PPE and remain in the treated area up to 3 hours per 24-hour period. Again, this exception does not apply to "dual notice" pesticides.
- Reduction in REI. Allow a reduction in the REI from 12 to 4 hours for certain low risk pesticides (mainly biological or microbial pesticides).

The EPA also proposed in August 1992 requiring employers to provide employees specific hazard information for each pesticide to which they may be exposed. Either a Material Safety Data Sheet (MSDS) or a pesticide-specific fact sheet must be located at a central location accessible to workers and handlers.

WPS Definitions

Agricultural establishment means any farm, forest, nursery, or greenhouse.

Agricultural plant means any plant grown or maintained for commercial or research purposes and includes, but is not limited to, food, feed, and fiber plants; trees; turfgrass; flowers; shrubs; ornamentals; and seedlings.

Crop Advisor means any person who is assessing pest numbers or damage, pesticide distribution, or the status, condition, or requirements of agricultural plants. The term does not include any person who is performing hand labor tasks.

Early entry means entry by a worker into a treated area on the agricultural establishment after a pesticide application is complete, but before any restricted-entry interval for the pesticide has expired.

Farm means any operation, other than a nursery or forest, engaged in the outdoor production of agricultural plants.

Forest means any operation engaged in the outdoor production on any agricultural plant to produce wood fiber or timber products.

Fumigant means any pesticide product that is a vapor or gas, or forms a vapor or gas on application, and whose method of pesticidal action is through the gaseous state.

Immediate family includes only spouse, children, stepchildren, foster children, parents, stepparents, foster parents, brothers, and sisters.

Nursery means any operation engaged in the outdoor production of any agricultural plant to produce cut flowers and ferns or plants that will be used in their entirety in another location. Such plants include, but are not limited to, flowering and foliage plants or trees; tree seedlings; live Christmas trees; vegetable, fruit, and ornamental transplants; and turfgrass produced for sod.

Owner means any person who has a present possessory interest (fee, leasehold, rental, or other) in an agricultural establishment. A person who has both leased such agricultural establishment to another person and granted that same person the right and full authority to manage and govern the use of such agricultural establishment is not an owner for purposes of the WPS. The WPS does not allow any exemptions for owners of commercial pesticide handling establishments or for persons who operate or manage, but do not own, an agricultural establishment.

Restricted-entry interval means the time after the end of a pesticide application during which entry into the treated area is restricted.