Wisconsin Cranberry School proceedings. Volume 3 1992

Madison, Wisconsin: Wisconsin State Cranberry Growers Association, 1992

https://digital.library.wisc.edu/1711.dl/4CDTJQ2IN3R3Z8Z

A SURVEY OF FIELD ACTIVITY AND INFLUENCES OF COMMERCIALLY REARED BUMBLEBEE (*BOMBUS* SP.) ON POLLINATION, FRUIT SET AND PRODUCTIVITY IN CRANBERRY.

Elden J. Stang[1], Christopher Plowright[2] and Daniel L. Mahr[3]

INTRODUCTION

Cranberry fruit set under field conditions typically ranges from 25 to 40% of potential. Up to 28% of fruit failing to set and develop in 'Searles' cranberry is a result of lack of pollination by honey bees and other native pollinators (Birren-kott and Stang, 1989). Several species of bumblebees (Bombus) are recognized as highly effective in pollinating cranberries.

The ability to effectively rear bumblebees under laboratory and commercial conditions is a recent and promising development. Commercially reared bumble-bees have been demonstrated to be highly effective in providing pollination for various greenhouse crops including cucumbers and tomatoes. Our objectives in this study were to assess reared bumblebee activity and potential effects on cranberry fruit set and productivity in the field.

Eighteen colonies of bumblebees including three separate species, *Bombus impatiens*, *B. terricola* and *B. ternarius* commercially reared by Bees Under Glass Pollination Services, Inc. were obtained in mid June, 1991. These species are native to Wisconsin with *B. impatiens* more common in southern areas of the state. Reared colonies consisted of a queen and variable numbers of workers estimated at 10 to 30 per nest. Individual colonies were maintained in specially constructed individual nest boxes. Bee populations were much lower than normally would be expected as a result of some delay in funding commitments for the study and unusual earliness of the blossoming season in 1991. Reared colonies at full strength would contain 200 to 300 worker bees. In 1991 blossoming occurred up to ten days earlier. Hence a major portion of the research was done in northern Wisconsin cranberry marshes to coincide with the blossoming period.

---

[1]University of Wisconsin-Madison, Dept. of Horticulture

[2]Ph.D, Bees Under Glass Pollination Services, Inc., Cantley, Quebec, Canada J0X 1L0

[3]University of Wisconsin-Madison, Dept. of Entomology

Experiment I

Two separate insect cages (2 x 2 x 6 meter) were placed over established 'Searles' cranberry beds at Cranberry Lake Corporation, Phillips, WI on 24 June, 1991 at 5 percent blossoming stage. Within each cage, 5 screened frames were placed over plants to control bee access to flowers during the experiment. Individual active, larger colonies of *B. impatiens* and *B. terricola* were placed in the separate cages on 25 June. Rapid blossoming occurred with full bloom on 28 June. For 3 to 6 hours each day on 25, 26, 27, 29 June and 1 July, the small frames inside the cages were removed and individual flower visits by bees were monitored. Single flowers visited once, twice or three times by bees were labeled. The experiment was terminated 3 July. On 21 September, all labeled upright shoots and fruit were harvested from the caged plots. For comparison, upright shoots with fruit were randomly harvested from the uncaged plot in the same bed and from plants within the cage not covered by screens. Individual berry length, diameter, and weight were recorded. Each berry was cut and seeds were removed, separated into large (fertilized, presumably viable) and small (unfertilized, nonviable) groups and counted.

Experiment II

To examine unrestricted field behavior of reared bumble bees, single bumble bee colonies (queen plus 20 to 30 workers) were placed in the center of producing 'Searles' cranberry beds at four locations in Wisconsin. Locations included R.S. Brazeau, Inc. and Gottschalk Cranberries, Inc., Wisconsin Rapids, Alder Lake Cran-berries, Inc. and Koller Cranberries, Inc., Manitowish Waters. At Cranberry Lake Corporation, ten remaining small colonies of *B. impatiens*, two *B. ternarius* and one colony of *B. terricola* were placed next to each other in 'Searles'. At Alder Lake (A), Koller (B) and Cranberry Lake (C) paired comparisons between beds containing reared bees and not containing bees (control) were established.

Plant sampling locations within paired beds were established from the centrally located bee colony or bed center of the control. Five concentric circles beginning 3 meters from the bee colony or center point and 3 meters apart were marked. On each circle a total of sixteen points were located, starting from the cardinal direction points. Ten flowering uprights were selected for each sample and labeled to identify the radial location and direction. The number of flowers, number of fruit and fruit weight for each upright were recorded for determination of percent fruit set and mean fruit weight.

Observations: Reared bumblebee behavior

Reared bumblebee colonies were observed from dawn to dusk and at shorter intervals on separate days for numbers of flights and approximate duration of flights. Similarly, numbers of flowers visited per unit time were recorded.

RESULTS

Experiment I

In the caged study, *B. terricola* did not pollinate cranberry flowers during the periods of observation from 25 June to 1 July. This lack of activity is unexplained since the colony was otherwise healthy and active. Thus no results were obtained from the caged experiment with this species. *Bombus impatiens* was highly active beginning 26 June, the day after the colony was placed in the cage. In most instances during observation periods two to five bees were outside the next box and active in pollen or nectar collection within the cage. In four plots in the cage a total of 44 fruit were obtained, 36 resulting from one bee visit, 8 from two bee visits to the same flower (Table 1). No fruit were obtained from the few flowers visited 3 times by bees. Except for one berry, all fruit occurred on the 1st or 2nd (basal) flower position on the upright. Where one or two bee visits occurred, fruit set was low but within percentages normally obtained in the field under open pollinated conditions (Table 2). Fruit weight and size were comparable to both control comparisons, either caged open pollinated or uncaged open pollinated fruit. Direct fruit set comparisons are not possible since the open pollinated samples consisted only of fruiting uprights. Despite substantially lower viable seed counts in fruit pollinated once or twice, results suggest single pollinations by effective "buzz" pollinators such as *B. impatiens* are adequate to result in economic fruit size. Slight increases in fruit weight and size occurred with two bee visits to flowers, although increases in viable seed set as a result are not apparent with the limited data obtained in this test.

Experiment II

At the three locations where paired comparisons of beds containing a colony of reared *B. impatiens* and a control not containing a colony occurred, none showed distance effects from the central point within the concentric circles for either control or treated plots (data not shown). Except for a slight increase in berry weight at location C, no effect of location (control vs bee plot) was measured (Table 3).

At locations A and B, directional effects (East-West, North-South) were not noted in flowering or fruiting responses. At location C a directional response was noted. Percent fruit set and total fruit weight per upright were slightly increased along either the western or eastern axis in comparison to north or south directions from the colony in the treated plot (Table 4). Only fruit bearing uprights were selected in sampling thus fruit set percentages are substantially higher than typically occur when all flowering uprights are sampled.

Observations: Reared bumblebee behavior

Projecting from counts of bee trips in the smaller colonies used in this test and numbers of flowers visited per minute, it is possible to estimate the numbers of flowers a full sized colony (250 workers) might visit in one day (Table 5). High values indicated for daily trips are actual counts from a full colony of *B. impatiens* in another study.

Assuming that an 8% deficit exists in pollination (30% vs 38%) and that the entire deficit could be recovered by bumble bee pollination, the estimated returns to a colony purchase for a 2 week pollination season can also be projected. Cur-rent costs for a colony in this projected scenario do not appear to be economically feasible under ideal field pollination conditions. Under less favorable pollination conditions, results might be dramatically different, since bumble bees are known to be highly efficient, able to pollinate for longer daily periods and under less favorable weather conditions than alternate pollinators.

Because of the presence of honeybees and other native pollinators, it is impossible in this study to document either that the addition of reared bumblebees can increase fruit set to the maximum potential or to determine how many bees are necessary to achieve that goal.

That reared bumble bees are as highly efficient and effective as wild native bumblebees in pollination in the field is however clearly established.

Acknowledgement

This research was supported by the College of Agricultural and Life Sciences, UW-Madison and in part by the Cranberry Institute. We also gratefully acknowledge the support of the Wisconsin cranberry producers cited herein for generously allowing use of their facilities and plantings.

Table 1. Number of fruit obtained from one or two bee visits (*B. impatiens*) to flowers in caged trails with 'Searles' cranberry.

Replicate	No. of tagged flowering uprights	No. of fruit (1 visit)	No. of fruit (2 visits)	No. of uprights with 1 fruit	No. of uprights with 2 fruit
1	25	7	6	11	2
2	24	10	0	10	0
3	18	8	1	8	1
4	18	11	1	11	1
Total	85	36	8	40	4

Table 2. Fruit set, fruit size and seed numbers under caged, controlled bee visits vs caged, open pollinated and non-controlled field conditions in 'Searles' cranberry, 1991.

Treatment	Fruit set (%)	Fruit weight (g)	Fruit length (mm)	Fruit diameter	No. of viable seed	No. of nonviable seed
Caged, screened (1 visit)	-	1.15	15.6	12.1	7.1	18.4
(2 visits)	-	1.20	16.6	12.3	5.9	18.2
Mean	28	1.18	16.3	12.4	6.6	18.3
Caged, open pollinated	63	1.13	16.8	13.7	15.1	12.4
Uncaged, open pollinated	57	1.15	17.8	14.4	11.7	16.7

Table 3. Flowering and fruiting in 'Searles' cranberry in beds containing one (location A, B) or multiple (location C) colonies of reared bumble bees vs native pollinators and honeybees.

Treatment	No. of fruit/ upright	No. of flowers/ upright	Fruit set (%)	Fruit weight/ upright (g)	Mean fruit weight (g)
Location A					
Control	1.4	2.9	51	1.55	1.07
Bee plot	1.4	2.9	51	1.66	1.10
significance	ns	ns	ns	ns	ns
Location B					
Control	1.5	2.8	55	1.74	1.13
Bee plot	1.5	2.8	54	1.74	1.16
significance	ns	ns	ns	ns	ns
Location C					
Control	1.3	2.3	57	1.43	1.09
Bee plot	1.2	2.2	58	1.59	1.25
significance	ns	ns	ns	*	**

ns, *, ** = nonsignificant; significant at P = .05, P = .01 respectively.

Table 4. Directional effects on flowering and fruiting in 'Searles' cranberry in beds containing multiple small colonies of reared bumblebees.

Treatment (direction)	No. of fruit/ upright	No. of flowers/ upright	Fruit set (%)	Fruit weight/ upright (g)	Mean fruit weight (g)
West	1.3	2.3	59	1.77	1.29
East	1.3	2.1	62	1.62	1.26
South	1.2	2.4	51	1.42	1.22
North	1.2	2.1	56	1.40	1.18
significance	ns	ns	**	*	ns

ns, *, ** = nonsignificant; significant at P = .05, P = .01 respectively.

Table 5. Estimated responses to reared bumblebee activity and potential economic returns in cranberry.

Reared bumblebee activity and economic returns	Estimated Responses		
	Low	Medium	High
No. of trips per day (250 workers)	862	1325	1788
Length of trip (minutes)	5.3	10.2	15.1
No. of flowers visited per minute	14	14	14
No of flowers per colony per day	63,915	189,075	377,713
Economic value of colony (2 weeks)*	$114	$339	$677

*Assuming full recovery of 8% pollination deficit, fruit averaging 1.2 g/berry and $0.60 per pound of fruit.

CROP FORECASTING
PAST - PRESENT - FUTURE

Jayne Sojka, Lady Bug IPM
Jack Crooks, Ocean Spray Cranberries, Inc.

In the fall of 1989, Ocean Spray launched a program to improve the accuracy of cranberry crop estimates. The objective was to supplement the traditional visual survey methods with quantitative measures of key crop characteristics. For the past three years, in the fall and in the spring, the density of reproductive and vegetative uprights of four varieties was determined to indicate crop potential for the following harvest. In addition, in early August, the number and weight of fruit per square foot was sampled.

Upright density has not yet provided a usable indication of the size of the coming Wisconsin harvest. However, for individual growers, beds with low numbers of reproductive and total uprights relative to the state average consistently produced the lowest crops. The relationship between fruit number per square foot and actual yields in 1990 was used to accurately predict the 1991 crop from fruit number per square foot sampled in August 1991. The predicted Ocean Spray crop was 1,284,000 barrels compared to an actual crop of 1,308,665 barrels, a 2% difference. This same approach employed in Massachusetts, but with half as many observations, underestimated the large 1991 crop by 15%. The relationship between fruit size in August and final size at harvest is not clear, and therefore not yet used in the estimates.

Future improvements include the development of a more comprehensive forecasting system combining critical yield factors and conditions with information from research reports, crop literature, growers, and others with special expertise. A forecasting framework of this kind can improve the accuracy of crop estimates and identify research gaps relevant to understanding yield.

Key components from our experience of crop estimating are discussed below. Note that the procedures described were designed to estimate the entire State's cranberry crop, although individual farms can apply the same principles.

SITE SELECTION AND SAMPLING

Choose Indicator Beds

Within one Management Area, select individual beds of the same variety and age which yield about the same as the average for the entire area. The number of these "Indicator Beds" needed varies with the number of acres and the uniformity of production. The higher the number of acres and variability, the more indicator beds required.

Select Sample Number and Location

The more samples taken per Indicator Bed, the more accurate the estimate will be. Six samples per Indicator Bed are good, four are acceptable.

To select sample locations, first walk and observe the entire Indicator Bed. Mark with flags those areas that appear average. Avoid both barren and unusually productive areas. The skill of selecting average yielding areas is the most important component of the entire crop estimating process.

Harvest Samples

Next, walk the same path again and revisit flagged areas. Harvest samples only from flagged areas that you still feel are representative of the entire bed. Being consistent in site selection is critical to accurate results.

Hand pick all healthy fruit that have obviously grown since bloom and should make it to harvest; no pinheads.

PREDICTING NUMBER AND SIZE OF FRUIT AT HARVEST

Count and Weigh

Fruit number per square foot is the most important number. Fruit size in August may indicate fruit size at harvest, but we have not yet been able to confirm this relationship. Therefore, August fruit weight is not used to estimate now, but may be in the future.

For each sample, count and then weigh all fruit. When finished, calculate average berry number and the average sample weights for each Indicator Bed. To determine the average berry weight, divide the average berry number by the average sample weight.

Summarize Data

Calculate the average overall berry number and weight per berry averages for each Management Area.

CROP ESTIMATION CALCULATIONS

Calculated Estimates

Method 1: For each Management Unit, calculate the projected change in yield from the previous year.

$$\frac{\text{(last year's yield in bbl/acre)}}{\text{(last year's fruit/sq.ft.)}} \times \text{(this year's fruit/sq.ft.)} = \text{this year's est. yield in bbl/acre}$$

Example: From Table 1, using Ben Lear

$$\frac{\text{(155 bbl/acre in 1990)}}{\text{(153 berries/sq.ft. in 1990)}} \times \text{(189 berries/sq.ft. in 1991)} = \text{191 bbl/acre est. yield (24\% increase)}$$

If you do not have any data from a previous year, use the numbers from Method 1. Each Management Unit may be different, so calculate separately.

To obtain total production figures for each Management Unit multiply the estimated yield times the number of acres in the Unit.

Method 2: More complicated and no obvious advantage over Method 1. Included for your information only.

Actual Yields

Finally, be sure to complete the estimation process by adding actual harvest data this fall for each Management Area.

UPRIGHT DENSITY DATA (Table 2)

Although not yet an accurate method to predict yield potential, Fall upright data gives valuable feedback on the impacts of cultural practices and the general reproductive potential of these marsh. Trends over several years showing increasing or decreasing upright density, fewer numbers of reproductive uprights or decreasing proportion of reproductive uprights can provide early warning signals that should not be overlooked. Study will continue on how to incorporate these fundamental cranberry characteristics into future estimates.

Table 1. 1991 Wisconsin Crop Estimation
Based on Sample Group Extrapolation to All Growers

Method 1. When weighted by acres, the average % difference in berry numbers between 1991 and 1990 indicates a 6.5% increase. Therefore, the Wisconsin crop is estimated to 1,284,000 barrels in 1991.

Cultivar	Actual Yield	1990 No. Berries	No Obs.	Berry Wt.	1991 No. Berries	No. Obs.	Berry Wt.	Berries % Diff.
Ben Lear	155	153	18	0.69	189	25	0.88	+24
McFarlin	167	144	15	0.61	156	17	0.63	+8
Searles	178	155	37	0.54	154	45	0.7	0
Stevens	200	168	22	0.68	180	29	0.89	+7

Average % increase weighted by acres per cultivar = +6.5

Method 2. 1990 Actual Yield and berry numbers were used to formulate the regression equations below. The 1991 number of berries were plugged into the equations to estimate 1991 yields. The estimated yields were compared to 1990 yields and a weighted average difference calculated as done above for numbers of berries. Using the regression method, the 1991 Wisconsin crop is estimated to be up 4.8% or 1,263,620 barrels. The results are very close to the estimates above based only on numbers of berries. However, the fit of the regression lines (R^2) does not allow for a high degree of confidence in the regression estimates.

Cultivar	Regression equations Yield = M(# berries) + b	R^2	1991 Est. Yield	1990 Est. Yield	Yield % Diff.
Ben Lear	Y = 1.21 (189) - 33	0.75	196	155	+26.0
McFarlin	Y = 1.17(156) - 0	0.59	182	167	+9.0
Searles	Y = 1.03 (154) + 19	0.51	178	178	0
Stevesn	Y = 1.06 (180) + 10	0.24	201	200	+.05

Table 2. Wisconsin cranberry crop estimate data.

Cultivar	1989 Fall Uprights/sq. ft. # beds	Repr.	Veg.	Total	1990 Aug Fruit/ft^2	1990 Actual Yield Bbl/A
Searles	18	173	225	398	169	211
Stevens	12	264	174	438	196	309
McFarlin	6	220	170	390		
Ben Lear	9	192	189	381	166	201
Overall Mean		212	190	402	177	240

	1990 Fall Uprights/sq. ft. # beds	Repr.	Veg.	Total	1991 Aug Fruit/ft^2	1991 Actual Yield Bbl/A
Searles	14	141	212	353	159	153
Stevens	8	200	157	357	176	242
McFarlin	4	136	237	373	118	143
Ben Lear	4	203	158	361	220	246
Overall Mean		170	191	361	168	196

	1991 Fall Uprights/sq. ft. # beds	Repr.	Veg.	Total
Searles	16	172	171	343
Stevens	9	201	118	319
McFarlin	4	195	172	367
Ben Lear	4	167	104	271
Overall Mean		184	141	325

August Fruit/ft^2 = 4 samples per bed.

NUTRIENT STATUS OF WISCONSIN CRANBERRIES

Teryl R. Roper and Sherry M. Combs
University of Wisconsin-Madison

Many fertilization programs over the years in an effort to increase cranberry yields. Some have resulted in increased yields in some years and some marshes. Others have not. Many factors are at play in producing a high yield including soil type, site, water availability, temperature, sunlight, management practices, and general vigor of the vines. What works well for your neighbor won't necessarily work for you. Mineral nutrition is only one piece of the total yield puzzle.

Plant analysis is the quantitative determination of the essential elements in plant tissue. Elements included by the University of Wisconsin Soil and Plant Analysis Lab include: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), and boron (B). Sodium (Na) and aluminum (Al) are also included though they are not essential. Sodium improves the quality of some crops and aluminum can be toxic in some low pH soils.

If properly used, results of plant analysis and a soil test can be a guide for efficient crop production. Soil tests provide estimates of nutrient needs but not all pieces of the production puzzle are supplied by just a soil test. Plant analysis allows you to evaluate your fertilizer and management practices by providing a nutritional "photograph" of the crop. These "photographs" can be used to help identify nutritional disorders, evaluate fertilizer efficiency, and determine availability of elements for which no reliable soil test exists.

Between 1981 and 1989 the Soil and Plant Analysis Lab at the University of Wisconsin-Madison analyzed about 400 cranberry plant and soil samples. While this is not a great number it may be representative of the cranberry marshes in the state as a whole. We have plotted some test results for the major nutrients for cranberry plants and soil in figures 1-9. In each figure the proposed critical tissue level has been identified at the top. Below this number the tissue sample would be considered deficient in that nutrient. Additions of nutrients to deficient vines should result in a positive response. Samples containing more than the critical level are considered to have sufficient nutrition for good yield. Addition of nutrients above yearly maintenance doses probably will not result in a yield response.

First lets look at nitrogen (N) (Fig 1). Over the past several years, 75% of the samples were sufficient in nitrogen. These levels are reasonable as too much nitrogen can cause rank vine growth and lead to decreased yields. This suggests that most marshes have enough nitrogen and adding large quantities of nitrogen may be counterproductive. However, the 25% of samples that are below 0.9% N may profit by having more N added. In these beds it likely won't matter what form of N is provided (liquid, granular, organic, or foliar). These vines should show improvement given any N. However, during hot days beds established on peat may release enough nitrogen from mineralization processes to supply significant amounts of usable nitrogen.

Phosphorus (P) is also important to cranberry production (Fig. 2). About 75% of the samples were in the sufficient range (0.14% or higher). A few samples were in the high range (above 0.19%). Adding large amounts of phosphate fertilizer to these vines already having sufficient tissue P levels will probably not increase yields. However, the vines represented by the 25% deficient samples may profit by additions of phosphate fertilizer. Phosphate is relatively immobile in soils because it is fixed very tightly to specific soil adsorption sites. Availability of fixed phosphate to plants is affected by soil pH and soil potash content. Plants should have adequate levels of available P if soil test levels are maintained at 25 ppm (50 lbs/acre) with a pH less than 6.5.

The other major element of interest is potassium (K) (Fig 3). Ninety four percent of the samples had tissue potassium at or above the critical level of 0.5%. Only 6% of samples had tissue K levels below critical. Although potassium deficiency may occur in Wisconsin cranberries, the likelihood is extremely low because beds have adequate natural K reserves.

Magnesium (Mg) is an important element for plant growth. The vast majority of our samples (88%) were sufficient for Mg (Fig. 4). Only 12% of the beds would profit from remedial applications of Mg. A good source of magnesium is dolomitic lime. If a change in soil pH is not desirable, Epsom salts ($MgSO_4$) may be applied. Magnesium deficiency symptoms in Wisconsin cranberries should be rare.

Levels of micronutrients are of concern to many growers. These elements are required in very small amounts (parts per million) yet are critical to normal plant growth. Our understanding of the critical levels of micronutrients is limited, and in some instances is based on greenhouse work which may not apply well to field conditions.

With the exception of zinc, virtually all the plant samples analyzed were sufficient in all microelements. Roughly 10% of the samples were below the critical level for zinc (Fig. 5). However, as soil pH decreases, zinc availability increases. So, if a bed has zinc deficiency it may be solved be applying a small amount of sulfur to reduce the soil pH.

Boron is known to be an important micronutrient for flower formation and function. The mechanics of the function of B are not known. Boron is quite immobile in plants and may not be in sufficient concentration in rapidly growing tissues such as floral meristems. Our data show that virtually all of the tissue samples had adequate boron (Fig. 6). Boron application has been shown to be beneficial when applied to other fruit crops. No definitive data are yet available for cranberries, however. We are suggesting a tentative critical level of 10 ppm. At this time there is no scientific data to suggest cranberries will benefit from further boron application. Because plants have a very fine line between enough and too much micronutrient, potential toxicities can occur with indiscriminate applications.

Soil pH is another important factor for cranberry production. The optimum pH for cranberry growth is between 4.0 and 5.5. The bulk of the samples tested (80%) were in that range (Fig. 7). The beds represented by the remaining 20% of samples could benefit from soil pH adjustment. Caution should be taken to not overadjust. Decreasing high pH will increase availability of phosphorus and most micronutrients. Having soil very acidic (pH < 4.0) may create increases in the soluble forms of aluminum and cause toxicity.

There is also some confusion in the relationship between soil element concentration and tissue element concentration. We like to think that if more fertilizer is applied to the soil that the tissue content of the applied elements will also increase. However, when we plot the relationship between available soil nutrient and tissue nutrient analysis the result is not definitive.

The plots for available soil P and K and leaf potassium and phosphorus (Figs. 8 & 9) illustrate the point. For both elements there is a broad range of soil concentrations, yet the tissue concentrations are very narrow. This suggests that other factors beyond soil availability control the content of the elements in tissues. Apparently, having enough of an element in the soil is important, but adding more will not necessarily increase the tissue concentration of that element. Furthermore, higher tissue nutrient levels do not necessarily result in a corresponding yield increase.

The cranberry industry in Wisconsin has followed many individual fertilizer programs on the quest for the holy Grail of high yields. Some programs have called for frequent applications of small amounts of fertilizer at great expense. In some instances the cost of application was higher than the cost of materials. These data suggest that other factors may be at work in determining yields and tissue nutrient content; and that tissue sampling for sufficiency of mineral elements is a good way to help choose the specific elements your beds may need.

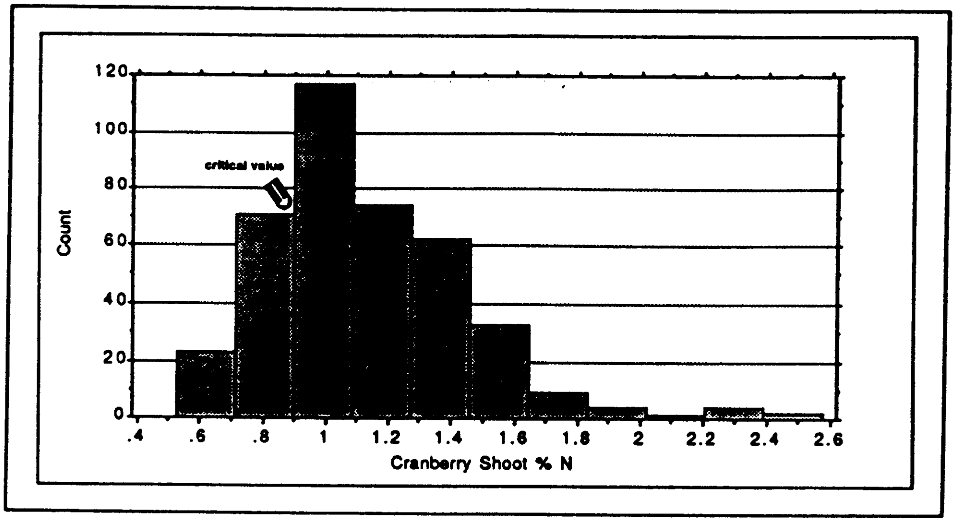

Figure 1. Above, cranberry tissue nitrogen levels from Wisconsin between 1981 and 1989. The critical level for tissue nitrogen is 0.9%.

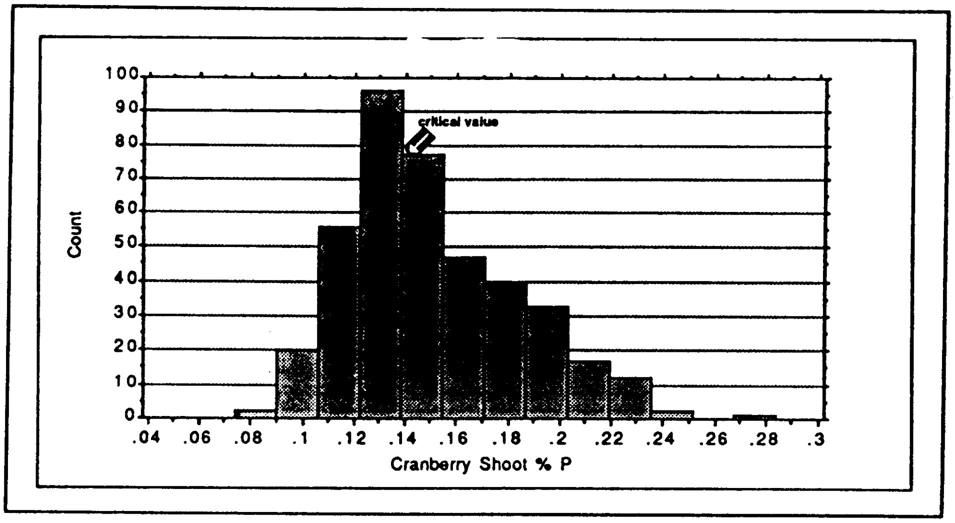

Figure 2. Above, cranberry tissue phosphorus levels from Wisconsin between 1981 and 1989. The critical level for tissue potassium is 0.5%.

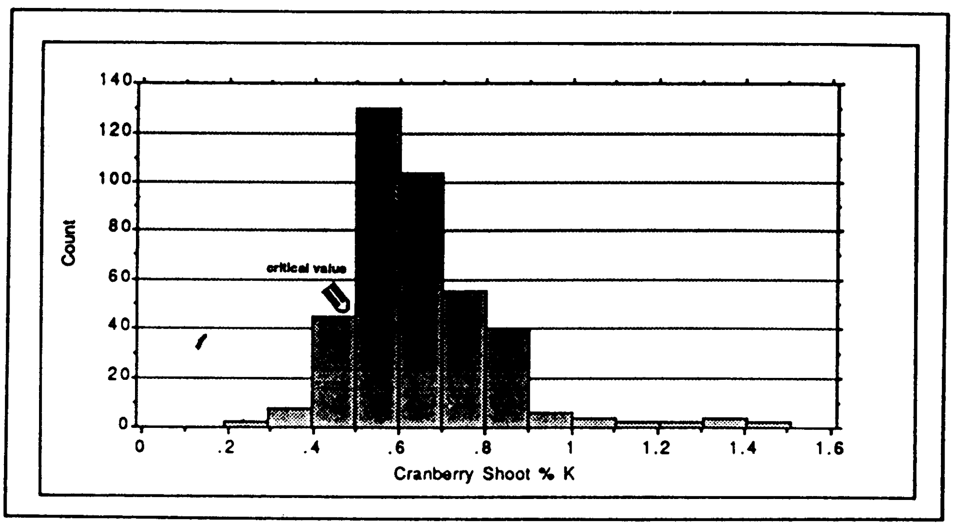

Figure 3. Above, cranberry tissue potassium levels from Wisconsin between 1981 and 1989. The critical level for tissue potassium is 0.5%.

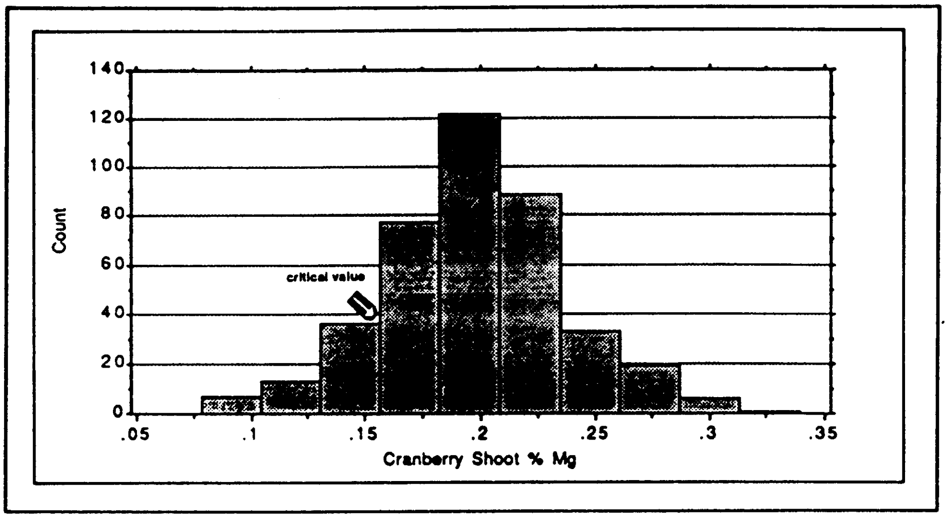

Figure 4. Above, cranberry tissue magnesium levels from Wisconsin between 1981 and 1989. The critical level for tissue magnesium is 0.15%.

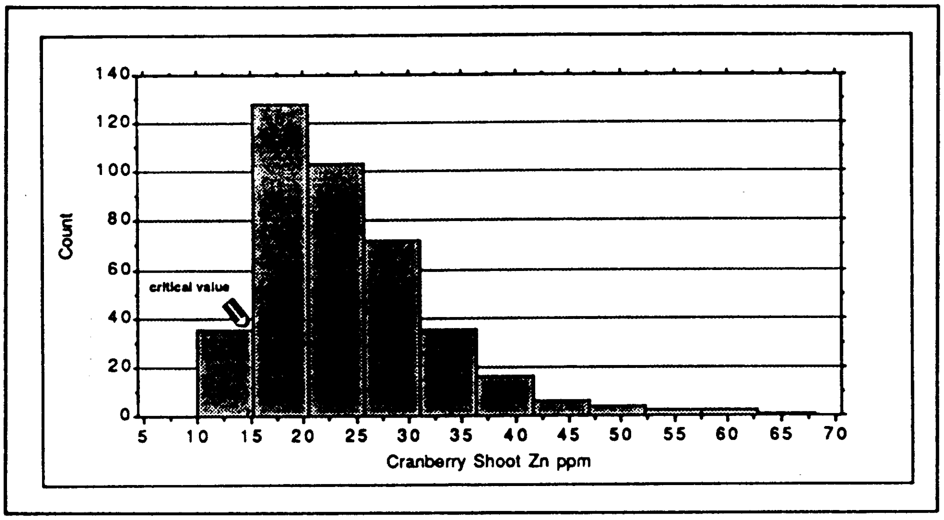

Figure 5. Above, cranberry tissue zinc levels from Wisconsin between 1981 and 1989. The critical level for tissue zinc is 15 ppm.

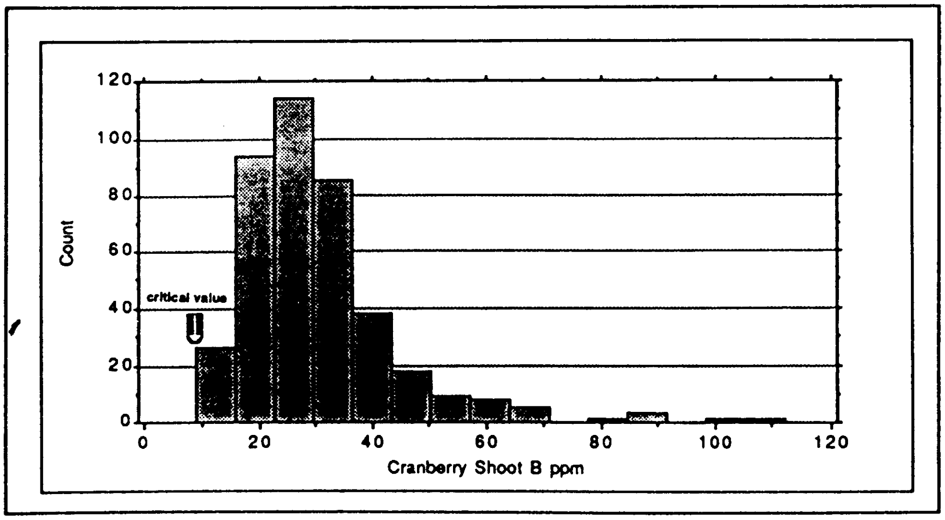

Figure 6. Above, cranberry tissue boron levels from Wisconsin between 1981 and 1989. The critical level for tissue boron is 10 ppm.

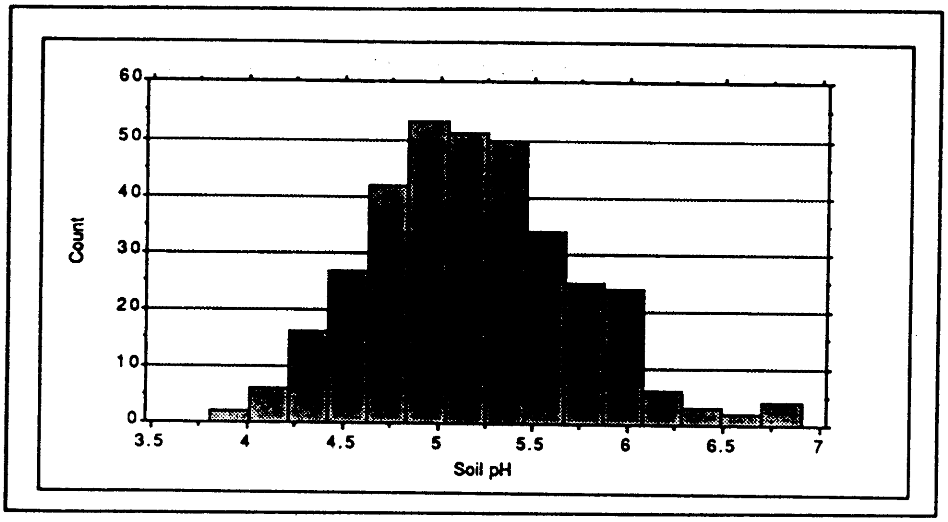

Figure 7. Above, soil pH for Wisconsin cranberry beds sampled 1981-1989. Optimum soil pH is 4.0 tp 5.5.

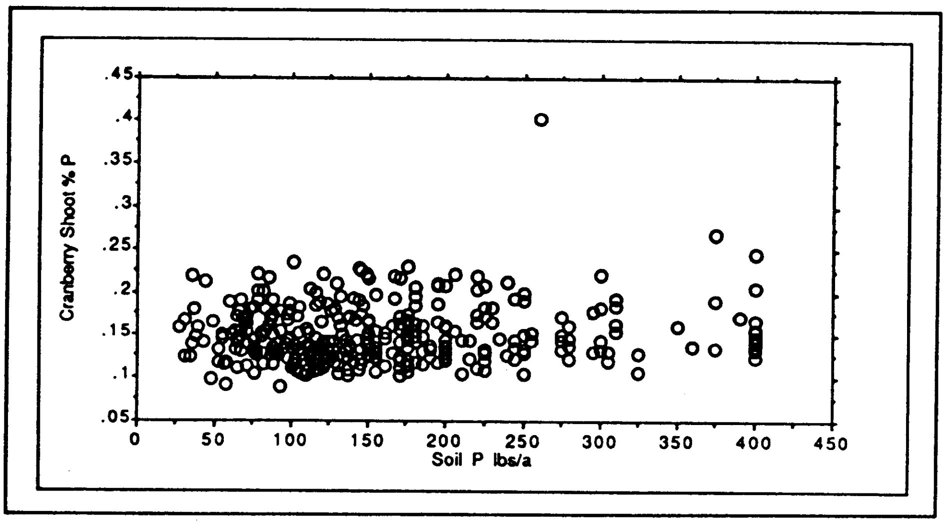

Figure 8. Above, the relationship between Wisconsin cranberry tissue phosphorus levels and available soil phosphate between 1981 and 1989.

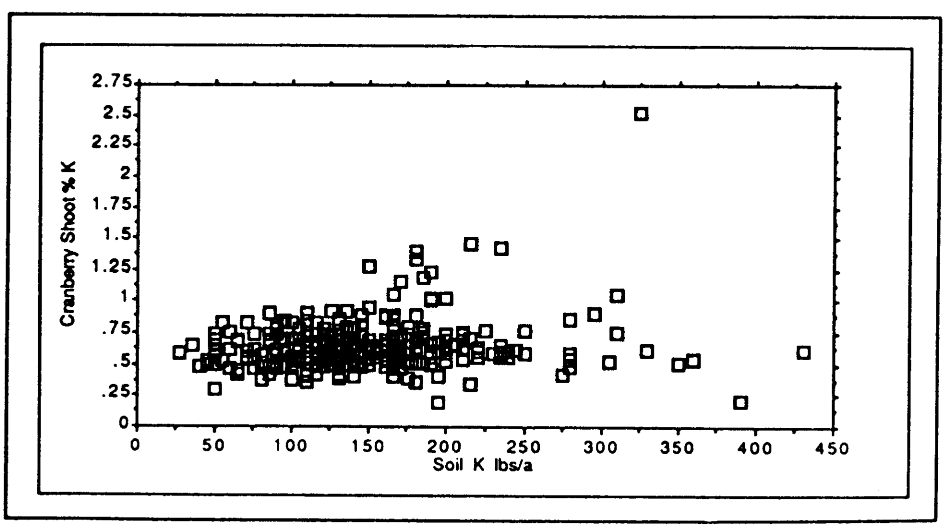

Figure 9. Above, the relationship between Wisconsin cranberry tissue potassium levels and available soil potash between 1981 and 1989.

Nutrient Deficiencies in Cranberries

Lloyd A. Peterson
Department of Horticulture
UW-Madison

Plant Nutritionists have identified 16 elements that are essential for plants to grow and develop. Of these 16 elements, 2 are supplied by air, carbon (C) and oxygen (O), and 1 from water, hydrogen (H). Carbon dioxide (CO_2) in the air is the source of C. Oxygen comes from air as O_2. In the photosynthetic process, water (H_2O) is split releasing H which along with C and O is metabolized to form carbohydrates, etc. Of the dry matter content of cranberry plant, C, H, and O make up over 90% of that content. Under field conditions, it is assumed that these 3 elements are adequate for normal plant growth.

Thirteen of the 16 elements are referred to as either macro or micronutrients and are supplied by the soil and absorbed into the plant by the roots. The macronutrients are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S). This group is required in relatively greater quantities by the plant, and the concentrations in the tissue are expressed as a percentage. The 7 micronutrients are zinc (Zn), copper (Cu), manganese (Mn), boron (B), iron (Fe), chloride (Cl), and molybdenum (Mo). They are required in very small amounts by the plant and are expressed as parts per million (ppm) in the tissue. Even though the amounts of these nutrients needed by the plants are different, they all are essential for the crop plants, cranberries included.

The soil with supplemental fertilization is the primary supplier of the macro and micronutrients. The survey data for Wisconsin Cranberry Bogs previously discussed by Dr. Roper illustrate that a majority of these bogs are in the sufficiency range. However, if nutritional problems are present, diagnostic tools are available to assist in solving the problem.

There is a close relationship between the available nutrient supply in soil and concentration of that nutrient in the plant. Therefore, a chemical analysis of a plant tissue sample from a bog is a good way to assess the nutritional status of a plant-soil system primarily because a plant analysis provides a relatively complete picture of the essential plant nutrients. To make this evaluation, a comparison between the sample analyses and standards for the cranberry crop is used.

It is important to have a good set of standard values for comparison to nutrient concentrations of field samples. These standards are developed by growing cranberry plants in controlled conditions which allows for careful measurement of growth response to nutrient composition. From a deficiency standpoint, the nutrient concentration that is most important to define is the concentration above which the plant grows normally and below which a growth reduction occurs. We define this concentration as the critical concentration for each plant nutrient. In the deficiency zone, plant growth is reduced and this reduction becomes more severe as the nutrient concentration decreases. Besides a growth reduction, an abnormal plant appearance will usually be present. Abnormalities become more severe as concentration of a particular nutrient decreases. We have observed nutrient deficiency symptoms on cranberry plants; however the symptomatology associated with a number of nutrients is difficult to differentiate for one and another. We find that visual symptoms do not define a specific nutrient deficiency as well in a cranberry crop compared to other horticultural crops. To be sure, tissue analysis is suggested for making a correct determination in nutrient associated problems.

The tissue analysis standards for cranberries are as follows:

MACRONUTRIENTS

	Proposed Levels		
Nutrient	Low	Sufficiency Range	High
	---------- % ----------		
Nitrogen	<0.90	0.90 to 1.00	>1.00
Phosphorus	<0.13	0.13 to 0.18	>0.19
Potassium	<0.50	0.50 to 0.90	>0.91
Calcium	<0.30	0.31 to 0.60	>0.60
Magnesium	<0.15	0.15 to 0.20	>0.20
Sulfur	<0.07	0.08 to 0.20	>0.20

MICRONUTRIENTS

	Proposed Levels		
Nutrient	Low	Sufficiency Range	High
	---------- ppm ----------		
Iron	<40	40-80	>80
Boron	<10	10-20	>20
Copper	<5	6-10	>10
Zinc	<15	15-30	>30
Manganese	<10	10-200	>200

Evaluating Perennial Fruit Crop Nutrition with Plant Analysis

S.M. Combs
Soil & Plant Analysis Lab, Dept. of Soil Science
UW-Madison

Perennial crops are ideally suited to evaluating nutritional needs by plant analysis. Fertilizer programs can be monitored by sampling leaves midseason and making nutrient adjustments the following year. Plant analysis can also be important for the diagnosis of acute nutritional problems that may occur during the growing season. It is also a useful and sometimes the only tool for evaluating the adequacy of elements for which no good soil test exists (i.e. N, Fe, Cu).

Plants require sixteen elements for growth (C, H, 0, N, P, K, Ca, Mg, S, B, Zn, Fe, Mn, Cu, CI, Mo). In Wisconsin soils, usually the elements N, P, K, Ca, Mg, S, B, Zn, Fe, Mn and Cu may be of concern depending on soil type, and crop grown. Growth is normal if all elements are present in adequate levels and correct proportions. Growth is restricted when there is not enough, too much or an imbalanced supply of one or more nutrients. Plant analysis is the quantitative chemical determination of many of these essential elements. Results from lab analyses are compared to known levels in plant populations of known yields to determine adequacy. The actual concentration of nutrients is a "snapshot" and reflects all the cultural and environmental factors that have influenced growth up to the date of sampling. In some respects, therefore, plant analysis is more "precise" than a soil test for determining nutrient availability. A soil test gives an index of the amount of nutrient that is potentially available to the crop. However, a plant analysis tells how much of that "potentially available" nutrient actually got taken up by the plant.

If leaf nutrient concentrations are low or deficient, a fertilizer application or increasing current fertilizer application rates will probably give substantial plant response (Table 1.). Decreasing fertilizer applications is suggested when nutrient levels are above sufficiency levels. However, factors such as seasonal conditions, irrigation, plant vigor, crop load, pruning, etc. need to be considered when making these decisions.

The analysis and interpretations are of little value without the use of standard, consistent sampling procedures. Time of sampling during the growing season and plant part sampled can greatly affect mineral content. In general, sample perennial fruit crop leaves at midseason. Table 2 lists several diagnostic plant parts and number of plants to sample for the most reliable results. Do not include plants affected by insect, disease, or pesticide damage. If an area is showing acute problems, sample healthy and unhealthy plants separately at any time during the growing season.

Soil testing can help supplement leaf analysis for nutrient evaluation. Soil tests can confirm low nutrient levels and indicate that additional nutrients will be beneficial. If soil tests are high while leaf nutrient levels are low, other problems are likely limiting plant uptake. Low nutrient levels in plant tissue may be the secondary result of insect or disease damage, soil compaction or low soil pH.

Plant analysis may not be the best approach for every field on every farm, but for trouble shooting, monitoring, and confirming suspected nutrient deficiencies, it can be an important tool.

Table 1. Nutrient concentrations for cranberry shoots

Element	Plant Nutrient Status		
	Low	Sufficient	High
	---	% ---	
N	< 0.90	0.90-1.00	> 1.00
P	< 0.14	0.14-0.18	>0.18
K	< 0.50	0.50-0.90	> 0.90
Ca	< 0.30	0.30-0.60	> 0.60
Mg	< 0.15	0.15-0.20	> 0.20
	---	ppm ---	
Fe	< 40	40-80	> 80
B	< 10	10-20	> 20
Cu	< 5	6-10	> 10
Zn	< 15	15-30	> 30
Mn	< 10	10-200	> 200

Table 2. Plant tissue sampling for perennial fruit crops.

Crop	Stage of Growth	Plant Part	Number of Plants to Sample
Apples, Cherries Pears, Plums	current season's shoots July 15-Aug. 15	fully developed leaves at midpoint on new shoots	4 leaves from each of 10-20 trees
Cranberries	current season's shoots Aug. 15-Sep. 15	newest terminal growth	35-50 leaves
Raspberries	midseason	youngest mature fully developed leaves on laterals or "primo" canes	2 leaves from 20-40 plants
Strawberries-new planting	current season's shoots Aug. 15-Sep. 15	youngest mature fully developed leaf blade and petiole	2 leaves from 10-20 plants
Strawberries-old planting	May 25-June 5, before picking Aug. 15-Sep. 15 after picking	youngest mature fully developed leaf blade and petiole	2 leaves from 10-20 plants

NOTES

PHYTOPHTHORA ROOT AND RUNNER ROT OF CRANBERRY IN WISCONSIN- THE CURRENT SITUATION

Michael J. Drilias and Steven N. Jeffers
Department of Plant Pathology
University of Wisconsin-Madison

Root and runner rot of cranberry has been recognized in Wisconsin since 1987 (4). This disease is present in all cranberry-growing regions of the state and affects all common commercially-grown cultivars. Affected plants usually are located in low-lying or poorly drained areas of beds. To date, *Phytophthora* spp. have been recovered from necrotic roots or runners collected in 46 of 63 (73.0%) beds at 26 of 34 (76.5%) marshes. *Phytophthora* spp. have also been recovered from apparently healthy vines collected in 10 of 11 (90.9%) beds where symptoms of root and runner rot were not evident. In addition, a baiting bioassay was developed to detect *Phytophthora* spp. in cranberry field soils (2). Phytopththora spp. were detected in 16 of 17 (94.1%) beds where the disease was present and in 5 of 6 (83.3%) beds where disease symptoms were not evident. Water collected in irrigation and drainage canals at five marshes were assayed for the presence of *Phytophthora* spp. *Phytophthora* spp. were recovered from water samples collected in both the spring and fall at four marshes where root and runner rot was present but were not detected in water samples collected at a marsh where symptoms of the disease were not evident.

Six distinct morphological types of isolates in at least two species (tentatively identified as *P. cryptogea* and *P. megasperma*) have been isolated from necrotic roots and runners, cranberry field soils, and irrigation and drainage water. *Phytophthora* cinnamomi, a cause of root and runner rot of cranberry in Massachusetts and New Jersey (1), has not been detected in Wisconsin cranberry beds. Pathogenicity of P. cryptogea, the most frequently isolated species of *Phytophthora*, was determined in the greenhouse with cuttings grown from dormant 1-year-old upright stems (cv. Searles) planted in a pasteurized mixture of sand and peat (5:1,v/v) that was artificially infested with inoculum (pooled from three isolates) at rates of 0, 2, 5, or 10% (v/v) (3). Plants were grown for 13 weeks and received four biweekly flooding periods of 0, 2, 4, or 6 days. At the end of the experiment, fresh shoot weight was determined. Shoot growth was related inversely to both inoculum rate and flooding duration (Figures 1 & 2). However, flooding duration had a greater negative impact on shoot growth than did incoculum rate. Young plants (5-6 weeks of age) were affected more severly than were older plants (19-21 weeks of age). Relative virulence of four of the six morphological types from Wisconsin and *P. cinnamomi* from Massachusetts was compared with 0 and 5% inoculum and 0 and 2 days of flooding. Shoot growth was reduced by three of the four morphological types from Wisconsin but only when plants were flooded (Figure 3). However, *P. cinnamomi* reduced shoot growth both with and without flooding. In the absence of inoculum, flooding also reduced shoot growth.

Currently, no fungicide is registered to control *Phytophthora* spp. on cranberry. However, fungicides that are selectively effective against these fungi are known (5), and some are commercially available for use on other crops. During 1990 and 1991, the fungicides metalaxyl (Ridomil), fosetyl-Al (Aliette), and oxadixyl (San-371) were evaluated in field trials conducted at two commercial cranberry marshes in separate geographical areas of Wisconsin. At each site, plots were established in an area of a bed devoid of vines where plants had died from root and runner rot. Each plot consisted of 20 rooted cranberry cuttings (cv. Stevens) planted inside a 30-cm-diameter plastic PVC ring embedded in the soil. Fungicides were applied monthly from June through October (total of five applications) during 1990 and from June through September (total of four applications) during 1991. The plants were subjected to normal cutural practices and naturally occurring inoculum. In October 1991, plants were collected and shoot weights were determined. Plants also were assayed for infection by *Phytophthora* spp. There was a significant difference in plant survival at one of the two locations (Table 1), but mean shoot weight did not differ significantly among treatments at either location. However, there was a significant difference in the number of plants infected with *Phytophthora* spp. at both locations. Infection by *Phytophthora* spp. was reduced by metalaxyl and oxadixyl but not by fosetyl-Al.

In a companion trial conducted at only one of the grower locations, metalaxyl and fosetyl-Al were applied to established vines for two seasons. Plots (2 X 2 m) were located at the periphery of an area of a bed where vines had died from the disease. These treatments also were evaluated in October 1991. Yield from untreated plots was greater than yields from plots treated with either fungicide, although the difference in yield was not statistically significant (Table 2). The number of flowers in untreated plots was significantly greater than the number of flowers in fungicide-treated plots. There was a significant reduction in percentage of uprights flowering in plots treated with fosetyl-Al and a significant reduction in the number of flowers per flowering upright in plots treated with metalaxyl. It appears that under the application schedule used, these fungicides may adversely affect differentiation and development of cranberry flowers.

Information on the relative resistance of cranberry cultivars to *Phytophthora* root and runner rot is inadequate. In Wisconsin, the disease affects all common commercially-grown cultivars (4). In research conducted in Massachusetts (1), differences in susceptibility to root rot caused by *P. cinnamomi* were identified among cultivars commonly grown in that region. Six cultivars commercially grown in Wisconsin (Ben Lear, Crowley, McFarlin, Pilgrim, Searles, and Stevens) currently are being evaluated in field trials initiated June 1991 at two commercial cranberry marshes in separate geographical areas. At each site, the trial is located in an area of a bed where vines had died from disease. Each plot consists of 10 cranberry cuttings planted inside a 15-cm-diameter plastic PVC ring embedded in the soil. The plants are subjected to normal cultural practices and naturally occurring inoculum. During 1991, few plants died at either location and preliminary results are inconclusive. At one location, there was a significant difference ($P<0.005$) in percent plant survival (based on 100 plants): Ben Lear - 98.0, Crowley - 98.0, McFarlin - 97.0, Pilgrim - 90.0, Searles - 98.0, and Stevens - 99.0. However, at the other location there was no significant difference ($P>0.750$) in plant survival: Ben Lear - 99.0, Crowley - 98.0, McFarlin - 100.0, Pilgrim - 99.0, Searles - 99.0, and Stevens - 99.0. In October 1992, plants will be evaluated for mortality and total shoot length of surviving plants will be measured.

______*Phytophthora* spp. isolated from Wisconsin cranberry fields are pathogenic. Thus, it is important that effective disease management strategies be identified if the productivity of Wisconsin's cranberry industry is to be increased. An integrated approach to disease management--involving fungicides, host resistance, and cultural practices--should provide the most effective and consistent means for control.

LITERATURE CITED

1. Caruso. F. L, and Wilcox, W. F. 1990. *Phytophthora* cinnamomi as a cause of root rot and dieback of cranberry in Massachusetts. Plant Disease 74:664-667.

2. Drilias, M. J., and Jeffers, S. N. 1990. Detection of *Phytophthora* species in cranberry field soils. (Abstr.) Phytopathology 80:1025.

3. Drilias, M. J., and Jeffers, S. N. 1991. Influence of flooding on pathogenicity of *Phytophthora* spp. to cranberry. (Abstr.) Phytopathology 81:1163 .

4. Jeffers, S. N. 1988. *Phytophthora* species associated with a cranberry decline syndrome in Wisconsin. (Abstr.) Phytopathology 78:1572.

5. Schwinn, F. J., and Staub, T. A. 1987. Phenylamides and other fungicides against oomycetes. Pages 259-273 in: Modern Selective Fungicides. H. Lyr, ed. Longman Scientific and Technical, Essex, England.

Table 1. Effect of fungicides on growth of cranberry (cv. Stevens) and infection by *Phytophthora* spp.[w]

		Treatment[y]				
Fungicide efficacy parameter[x]	Location	Control	Fosetyl-Al	Metalaxyl	Oxadixyl	P[z]
Plants surviving (%)	1	86.7	81.0	93.5	88.6	<0.005
	2	98.0	98.5	96.9	97.9	>0.750
Shoot weight/plant (g)	1	0.656	0.751	0.773	0.701	0.648
	2	0.418	0.359	0.363	0.453	0.143
Plants infected with *Phytophthora* spp. (%)	1	10.8	11.8	0.0	2.6	<0.005
	2	17.0	13.3	0.5	5.7	<0.005

w. In June 1990, plots were established in an area of a bed where vines had died from disease. Each plot consisted of 20 rooted cranberry cuttings planted inside a 30-cm-diameter PVC ring embedded in soil. Treatments were replicated ten times in a randomized complete block design.

x. In October 1991, plants were collected and oven-dried weights of shoots were measured. Plants were assayed for infection by *Phytophthora* spp. by plating rooted stems onto a medium selective for *Phytophthora* spp. Values of percent plant survival and percent plant infection are based on approximately 200 plants. Values of shoot weights are the means of ten replicate plots.

y. Fungicides were applied monthly from June through October (five applications) in 1990 and from June through September (four applications) in 1991. Fosetyl-Al was applied at a rate of 4 lbs/acre (5 lbs Aliette 80 WP/acre). Metalaxyl was applied at a rate of 1.75 lbs/acre (7 pints Ridomil 2E/acre). Oxadixyl was applied at a rate of 1.75 lbs/acre (7 lbs SAN-371 25 WP/acre).

z. Signifance level. Plant survival and plant infection data were analyzed with a Chi-square test for independence. Shoot weight data were analyzed with analysis of variance.

Table 2. Effect of fungicides on yield, yield components, and productivity variables of cranberry (cv. Ben Lear)[w]

Yield and productivity variable[x]	Treatment[y] Control	Fosetyl-Al	Metalaxyl	P[z]
Yield (g)	35.41	15.43	13.36	0.071
Number of uprights	248.0	205.6	226.6	0.403
Weight (g) of uprights	57.59	48.80	53.03	0.518
Individual upright weight (g)	0.23	0.24	0.23	0.845
Uprights flowering (%) (no. flowering uprights/no. uprights)	14.6 a	4.3 b	8.1 ab	0.016
Number of flowers/flowering upright	3.1 a	3.3 a	2.2 b	0.003
Number of flowers	119.5 a	32.4 b	48.9 b	0.015
Number of berries	29.2	13.4	11.6	0.077
Fruit set (%) (no. berries/no. flowers)	22.9	50.8	23.2	0.634
Fruit retention (%) (no. marketable berries/no. flowers)	18.6	24.8	18.8	0.934
Individual berry weight	1.57	1.06	1.18	0.195

w. In June 1990, plots (2 X 2 m) were established along the periphery of an area of a bed where vines had died from disease. Treatments were replicated eight times in a completely randomized design.

x. In October 1991 (before harvest), all upright shoots and fruit were removed from four 106-cm2 areas in the center portion of each plot. The four subsamples were combined to provide a single composite sample. Values are the means of eight replicate plots.

y. Fungicides were applied monthly from June through October (five applications) in 1990 and from June through September (four applications) in 1991. Fosetyl-Al was applied at a rate of 4 lbs/acre (5 lbs Aliette 80 WP/acre). Metalaxyl was applied at a rate of 1.75 lbs/acre (7 pints Ridomil 2E/acre).

z. Signifance level from an analysis of variance. Values in a row followed by the same letter do not differ significantly according to Fishers LSD (P=0.05).

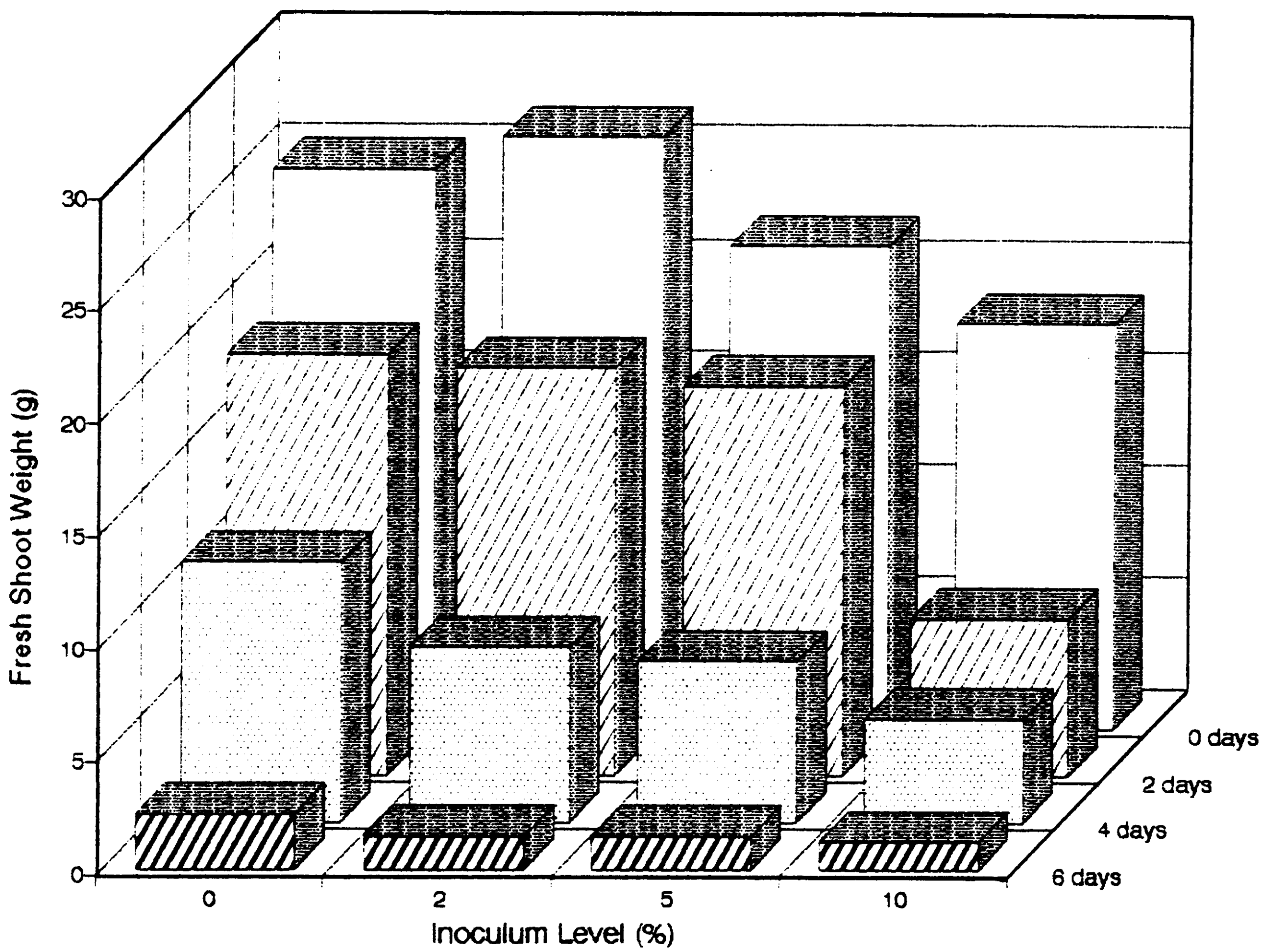

Figure 1. Influence of flooding on pathogenicity of *P. cryptogea* to cranberry (cv. Searles). Rooted cuttings, 5-6 weeks of age, were grown for 13 weeks and received four biweekly flooding periods. Data are the mean of eight replicate plants.

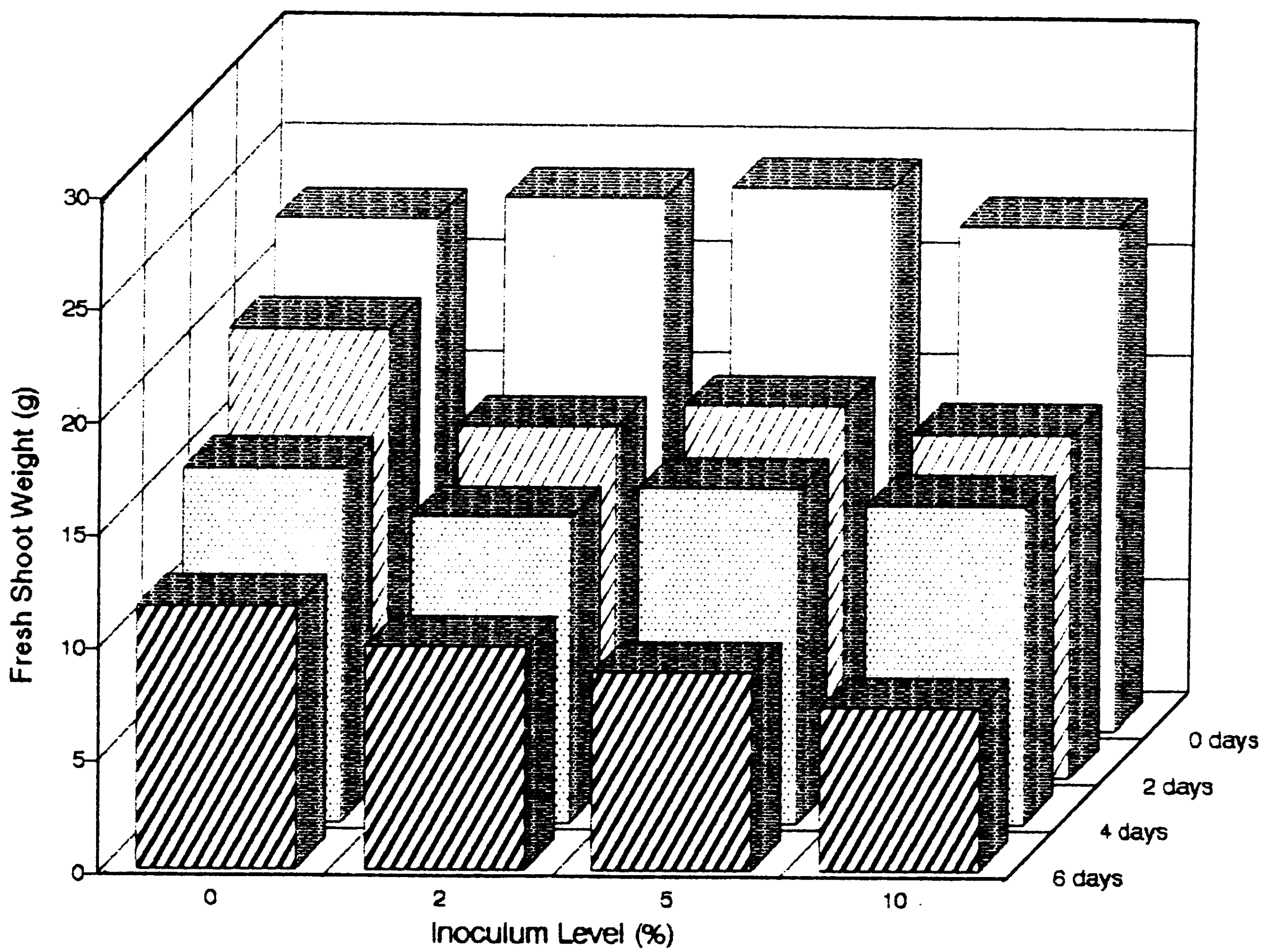

Figure 2. Influence of flooding on pathogenicity of *P. cryptogea* to cranberry (cv. Searles). Rooted cuttings, 19-21 weeks of age, were grown for 13 weeks and received four biweekly flooding periods. Data are the mean of eight replicate plants.

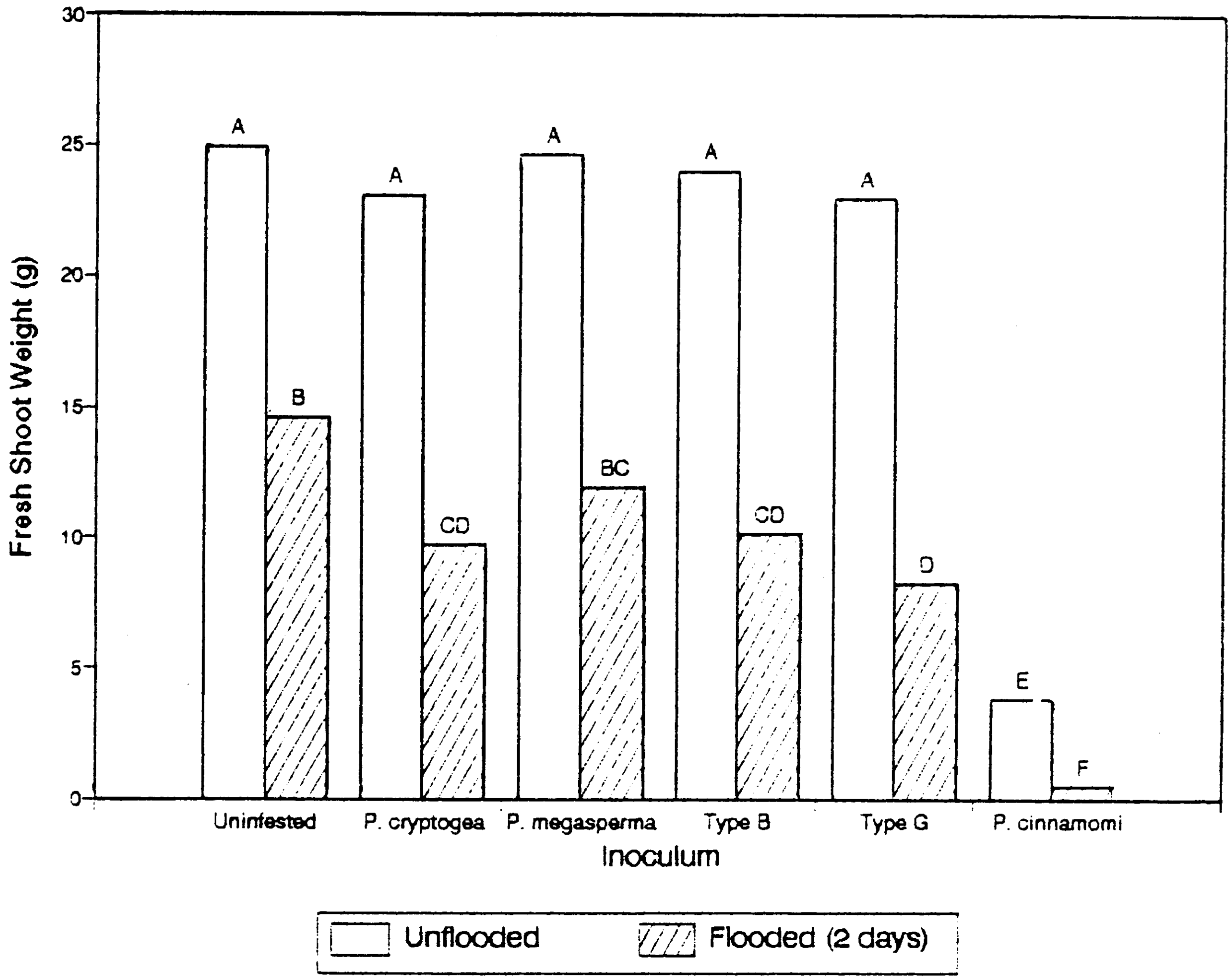

Figure 3. Relative virulence of *Phytophthora* spp. on cranberry (cv. Searles). Rooted cuttings, 7-8 weeks of age, were grown for 13 weeks and received four biweekly flooding periods. Data are the mean of ten replicate plants. Bars labeled with the same letter do not differ significantly according to Fishers LSD (P=0.05).

UNDERSTANDING BIOLOGICAL CONTROL AND ITS POTENTIAL FOR MANAGING INSECT PESTS ON CRANBERRY IN WISCONSIN

Daniel L. Mahr
Department of Entomology
University of Wisconsin - Madison

INTRODUCTION

Five major issues facing agriculture into the 1990s include (1) insuring food safety, (2) increasing agricultural sustainability, (3) improving farm profitability, especially for family farmers, (4) improving the health and safety of farm workers, and (5) reducing negative environmental impacts of traditional agricultural practices. Pest management is a component of each of these issues. Other specific pesticide related issues of importance include loss of effectiveness of products because of development of pest resistance and loss of specific products through the reregistration process. Whenever possible, traditional broad spectrum insecticides and other high input pest management practices should be replaced with low input, non-polluting, and self sustaining methods of pest control. A frequently mentioned alternative to chemical control is biological control.

Biological control can be a very successful approach to pest management, but unfortunately it is poorly understood by farmers, environmentalists, policy makers, and the general public. Attempts at biological methods of insect control have met with both fabulous success and dismal failure. The differences in result can be attributed to (1) the specific target pest and the type and extent of damage done to the crop, (2) the efficiency of the natural enemies available for the target pests, (3) the type, value, and use of the crop, (4) the amount of research conducted on the biological control of the target pests, including studies of the natural enemies involved, and (5) the level of knowledge and the degree of commitment of the biological control user. The last factor may very well be the most crucial for the success of biological control.

Biological control is the active utilization of natural enemies to regulate the numbers of pests. Biological control is the logical extension of natural control, and a knowledge of natural control is helpful in the development of an understanding of biological control.

NATURAL CONTROL

Natural controls consist of various environmental factors that have a negative impact on the population of a species, thereby limiting its capacity to build up to large numbers. There are many different environmental factors that can have this influence, and these factors are usually divided into two groups: (1) biotic factors and (2) abiotic factors. Biotic factors ("bio" referring to life) are those environmental factors involving living organisms, and include such things as predators and disease organisms, and starvation caused by competition when the food supply is inadequate. Abiotic factors ("abiotic" meaning without life) are those environmental factors not related to living organisms, and

Note: Much of this paper has been derived from a University of Wisconsin-Extension publication on biological control which is currently in preparation. The author and the University of Wisconsin would appreciate appropriate citation and acknowledgement for reproduction or use of information in this paper.

include such things as drought, freezing, flooding, and topographic features such as high elevation or desert.

The size of every population of every type of organism is regulated by natural environmental factors. These factors differ by location and change through time. At some times various factors combine to dramatically reduce a population, and that species becomes uncommon in that location. At other times the environment is more favorable resulting in greater survival and reproduction of the species, and consequently the population increases, sometimes dramatically. Pests respond to environmental factors just as do non-pest organisms, and the relative impact of natural controls influences when pest numbers are going to be high or low.

Natural control is a very important but often overlooked form of pest control. It is overlooked because the actions of nature are often subtle and not always apparent, and because humans are not directly involved in applying natural controls. However, as we continue to reduce our reliance on pesticides and other preventive forms of pest control, it will be necessary for pest managers to become more knowledgeable about natural controls. This will mean increasing our knowledge in the following areas:

1) being able to distinguish pests from non-pest species;
2) better understanding the life cycle of the pest and the severity and type of damage done;
3) understanding how populations of a pest respond to abiotic and biotic factors in the environment;
4) being able to recognize the beneficial organisms ("natural enemies") that help naturally control the pest;
5) understanding and conscientiously utilizing sampling practices to routinely monitor for pest and natural enemy activity; and
6) using effective and environmentally safe methods of controlling a pest when natural and biological controls are not being effective; such methods should not interfere with the natural and biological controls of other pest species in the system.

NATURAL ENEMIES

A natural enemy is an organism which kills, seriously debilitates, reduces reproduction of, or otherwise interferes with individuals of another species. All species, including all types of cranberry pests, have natural enemies. Some natural enemies affect many different species, and these are referred to as **generalist natural enemies**. Other natural enemies may affect one or a very few closely related species, and these are called **specialists**. Specialist natural enemies are better suited to find their prey and cause it injury, and therefore are usually more efficient in biological control programs. Natural enemies of pest insects fall into three main categories: predators, parasites, and insect pathogens.

Predators.

Although predators include such things as birds, rodents, and frogs, all of which are important in natural regulation of many types of insects, the most important predators in insect pest management are other insects. Two major factors characterize predators: (1) they are usually free-living and often very mobile, and (2) they consume many prey (pests) during their lives. Predators are often generalist natural enemies although a few types are highly specialized. A large percentage of insects are predators and many are beneficial natural enemies in crop settings. It is not possible here to discuss all types of predators and their importance in natural and biological control. A few common examples include ladybird beetles, lacewings (aphid lions), mantids, syrphid flies, assassin bugs, minute pirate bugs, spiders, and predatory mites.

<u>Parasitic insects</u>.

Parasitic insects, often simply called "parasites" or "parasitoids", belong primarily to two major groups of insects, the flies and the wasps. Parasites have a more complex life cycle than most predators. The general life cycle consists of the following stages: egg, larva, pupa, and adult. The adult is a free-living insect such as a fly or tiny stingless wasp. It seeks out the **<u>host</u>** insect (prey or pest) and deposits one or more eggs in, on, or near it. The egg hatches into the larval stage, which is often maggot-like in appearance. The larva feeds on the host insect, consuming and eventually killing it. Most parasite larvae actually feed and develop <u>within</u> the body of the host insect. Once the larva is fully grown and done feeding, it changes into the pupa, which is a transitional stage between the larva and adult fly or wasp which eventually develops from the pupa. Depending on the species of parasite, the adult stage has various foods, including flower nectar, pollen, other sugar and carbohydrate sources such as rotting fruit, or other insects (in which case, the adult can be classified as a predator). A parasite larva is very closely tied to its individual host insect, is generally incapable of much movement on its own, and kills only one host insect during its development. Many parasites are very specialized natural enemies with phenomenal abilities to locate and kill their particular host species. Parasites are generally considered more efficient natural enemies than predators against many types of pests.

Most plant-feeding insects (as well as many other types of insects) are attacked by one or more species of parasites. Indeed, there are many thousand different species of parasites in North America. Most are small (some are extremely tiny, less than 1 mm when fully grown) and rather non-descript, and it is often difficult to differentiate them from other small insects. Most belong to one of the following groups: tachinid flies, ichneumonid wasps (ichneumons), braconid wasps (braconids), and chalcid wasps (chalcids). The parasitic wasps are small and mostly incapable of stinging, differentiating them from their larger relatives such as hornets and yellowjackets.

<u>Insect pathogens</u>.

Insects, like other organisms, are subject to diseases. There are many types of insect pathogens which are very important in natural and biological control. **<u>Insect viruses</u>** tend to be fairly host specific and often work very rapidly when host population levels are high. Some **<u>bacterial pathogens</u>** are host specific while others are more general. The pathogen in commercial insecticides containing *Bacillus thuringiensis*, used for controlling some cranberry caterpillars, is a bacterium. **<u>Fungal pathogens</u>** usually require high humidity to be effective and are fairly common in the Midwest, especially during periods of higher moisture. **<u>Insect protozoans</u>** are also common but often debilitate their host rather than killing it outright. **<u>Insect parasitic nematodes</u>**, such as those available for controlling cranberry girdler, are often grouped with insect pathogens, and are highly effective for controlling certain soil insects and other insects living in moist habitats. Most insect pathogens are not harmful to plants, humans, or other types of organisms. However a few have a relatively broad host range that includes beneficial insects.

Some insect pathogens, such as *Bacillus thuringiensis*, have been mass-produced and made commercially available for pest management. Such products are called **<u>microbial insecticides</u>**. The use of these is an excellent example of the biological control method called **<u>augmentation</u>** which will be discussed below.

BIOLOGICAL CONTROL

As stated earlier, biological control is the human extension of natural control, specifically, the use of natural enemies. The primary difference between natural control and biological control is the human role in manipulating the natural enemies of the pest. As will be shown below, such intervention may be relatively brief and the results relatively permanent, a situation approaching natural control. In other cases the human input may need to be fairly frequent and routine, a situation more similar to other forms of traditional pest control such as sanding cranberry beds or use of pesticides.

Biological control has been used successfully against certain pests in every major pest group, including insects, mites, nematodes, plant pathogens, weeds, and even vertebrate animals such as rabbits. The specific methods of biological control vary somewhat depending upon the type of target pest. This paper will focus on the biological control of insects.

Biological control scientists and practitioners recognize three approaches to insect biological control: (1) **importation** of exotic natural enemies which do not currently exist in the area of interest, (2) **conservation** of existing natural enemies, and (3) **augmentation** of natural enemies to bolster those that naturally occur. Background information on these three general approaches is given below. My outlook for using each of these approaches on cranberry pests is presented later in this paper.

IMPORTATION of exotic natural enemies.

This method is based, in part, on the knowledge that many serious crop pests have been accidentally introduced from other parts of the world. It is also based on the fact that the most efficient natural enemies of a pest are often found in the native home of the pest, or in the home of a closely related insect species. "Exotic" natural enemies are then sought out by USDA and university scientists, evaluated for their potential benefits and risks, and then imported, released, and, hopefully, permanently established in the area of the non-native pest. There are many examples of outstanding success using this approach, such as the complex of imported parasites which controls alfalfa weevil. Unfortunately, there are also many cases where effective exotic natural enemies simply haven't been found or haven't been successfully established in the target area. When fully successful, this method of biological control approaches natural control in that once the new natural enemy is established it can be sufficiently effective so that further human inputs may be unnecessary, other than assuring that the activities of the natural enemy are not hampered. Although importation of exotic natural enemies will not solve all pest problems, there are still many pest species that could be subjects for this approach. USDA and university scientists are on continuous exploration in foreign lands for potentially useful beneficial natural enemies. However, federal and state funds for these activities are limited and major successes are relatively slow in coming.

CONSERVATION of existing natural enemies.

Natural enemies, like all other organisms, are subject to biotic and abiotic environmental factors that influence their populations. Negative influences should be reduced and positive influences should be encouraged. When humans are actively involved in improving environmental conditions to favor natural enemies, this is referred to as **conservation** of natural enemies. Probably the single most important factor in conservation of natural enemies is to avoid utilization of broad spectrum insecticides that are known to kill them. Not all pesticides are equally harmful to natural enemies. Some beneficial insects are naturally tolerant of certain pesticides, while other natural enemies have, through many generations of repeated exposure, developed resistance to certain pesticides. In some situations it will be necessary to utilize pesticides for pest control, especially where no other methods are effective and the pest numbers are so great that serious economic damage will result if chemical controls are not applied. In many such cases it will be possible to use chemical controls in conjunction with natural enemies, and this fact gave rise to the concept of "integrated control" or **Integrated Pest Management** (IPM). But in these situations, proper choice of materials and correct timing and method of application are usually very important to conserve natural enemies.

AUGMENTATION of natural enemies.

Because of various environmental factors, some natural and others created by humans, natural enemies often occur in inadequate numbers to provide satisfactory pest control. In these situations, there are two options: (1) do nothing and suffer significant losses, or (2) provide human input in the form of some control method. One of the possible control methods is to artificially increase the natural enemy population by releasing additional natural enemies that have been raised at insect farms called **insectaries**. (Actually, insectaries are fairly sophisticated indoor laboratories and some of the natural enemy rearing techniques are quite advanced.) The natural enemies that are released may be the same species that already exist at the site, or they may be other species that may have greater or lesser effectiveness than those occurring there naturally. This type of artificial input of natural enemies is called **augmentation**.

Generally, plant communities with greater complexity (more species of plants) have greater numbers of plant-feeding insects, which, in turn, support a greater number of species of generalist and specialist natural enemies. By growing our crops in a monoculture (even on a relatively small scale, such as in cranberry beds), and by eliminating competing weeds, we reduce the numbers of plant feeders with a resulting reduction in the number of types of natural enemies. Under these conditions, there are often inappropriate types or inadequate numbers of natural enemies to suppress an increasing pest population. Disruption of the agroecosystem also can have a negative impact on natural enemies. Therefore, we see more natural enemies and a greater diversity in a perennial crop, such as a cranberry bed, Christmas tree plantation, orchard, vineyard, or alfalfa field than we do in an annual crop such as corn, soybeans, or cabbage, where the entire field is completely cultivated or cleared at least once each year. These factors have formed the basis for the augmentation approach to biological control.

Augmentation of natural enemies can be subdivided into two approaches: (1) **inundative releases** and (2) **inoculative releases**. Inundation involves releasing massive numbers of natural enemies for immediate reduction of a damaging or near-damaging pest population. In this way it is analogous to a corrective insecticide application; the expected outcome is for immediate pest control. Because of the nature of natural enemy activity, and the cost of purchasing them, this approach using predaceous and parasitic insects is rarely recommended. However, the utilization of microbial insecticides (such as *Bacillus thuringiensis*) and insect parasitic nematodes are excellent examples of inundative releases of natural enemies. **Inoculation** involves releasing small numbers of natural enemies at prescribed intervals throughout the pest period, starting when the pest population is very low. The expected outcome of inoculative releases is to keep the pest at very low numbers, never allowing it to approach an economic injury level. In this way, inoculative releases are analogous to preventive insecticide applications. When using inoculative releases you assume that a pest problem is going to develop. In some ways inoculative releases go against the dictates of integrated pest management programs, which discourage pest management inputs (other than a routine monitoring program) until a pest problem becomes evident. The utilization of inoculative natural enemy releases is neither low input nor sustainable; it requires a relatively high input of time, labor, and money and must be repeated at least annually and usually several times per growing season. However, these negative aspects of the augmentation approach to biological control are fairly minor in comparison to the problems which are sometimes associated with the use of broad spectrum insecticides and other disruptive methods of pest control.

TYPES OF NATURAL ENEMIES COMMERCIALLY AVAILABLE

There are over thirty types of natural enemies commercially available in the United States. Although this seems like a relatively large number, consider that there are over 700 species of serious arthropod pests (insects and mites) in North America; and most of these have a complex of generalist and specialist natural enemies. Commercially available natural enemies fall into two categories: (1) those that are generalists in what they attack (such as ladybird beetles, lacewings, and *Trichogramma*) and therefore have a potentially wide market, and (2) those that are specialist natural enemies (such as predatory mites or the whitefly parasite *Encarsia*), for which there are major markets on high value crops. The production of natural enemies requires highly specialized equipment and methods and is relatively labor intensive. Often, years of university, federal, and private research are necessary to sufficiently understand the biological needs of a natural enemy to be able to mass produce it. Therefore, producers will continue to supply generalist natural enemies of proven abilities, or specialized natural enemies for major markets. It should be realized that many if not most cranberry pests will not be appropriate targets for those natural enemies currently available, and other types of control practices may be necessary, especially against the most damaging pests. However, it is likely that the list of commercially available natural enemies will continue to slowly increase as long as producers have acceptable markets for their new products.

The following is a brief discussion of the major natural enemies currently available that might be considered for use on cranberry.

Predatory insects.

Ladybird beetles. The most commonly available ladybird beetle is the convergent lady beetle, *Hippodamia convergens*. It is native to much of the United States, including throughout the Midwest. The convergent lady beetle is not commercially produced. Instead, it is mass collected, literally by the bucketful, from amazingly large hibernating congregations in the hills and mountains of central and southern California. The natural behavior of the lady beetle in California is to fly out of the coastal and inland valleys in the fall into higher cooler elevations, and then congregate in spectacular masses to spend the winter. In spring, their normal behavior is to fly back down to lower elevations, where aphids and other prey have started to develop, before they start feeding. This has posed problems with the field collected lady beetles because they naturally rapidly disperse some distance after release. Lady beetles now are preconditioned by the commercial suppliers by temperature treatment and feeding to reduce the normal dispersal behavior. However, many users are still somewhat disappointed by the rapid decline in numbers after release.

Another problem related to this is the need for lady beetles to feed. If aphids or other appropriate foods are not abundant, this will also cause rapid dispersal to more productive hunting grounds. For these reasons, release of convergent lady beetle is more efficient when large areas are treated as compared to smaller areas such as home gardens.

Both the adults and the larvae of convergent lady beetles are predaceous. The preferred food is aphids, but in the absence of these they will also feed on other small, slow moving, soft bodied insects and mites.

Because of their limitations, use of convergent lady beetles on cranberry is **not** recommended.

Lacewings. Green lacewings also are somewhat specialized for feeding on aphids, but will also feed on quite an assortment of other small insects and mites. Because they are usually released as eggs or young larvae, they do not fly away. The larval stage, called the aphid lion, is the most important stage for pest control. Although the adults also feed on insects, they require other food sources, and if any necessary type of food is not available, they will fly elsewhere to lay eggs. Two species of green lacewings are commercially available. *Chrysoperla* (or *Chrysopa*) *carnea* is usually considered best for row or field crops, while *C. rufilabris* is better adapted for orchards.

We occasionally find green lacewing larvae occurring naturally in cranberry beds, where they probably feed on small caterpillars such as fireworms and spanworms, and other small insects. We suspect that they may also feed on tipworm larvae, but this has not been demonstrated. No research has been conducted on augmentative releases of lacewings in cranberry beds, so any use should be considered experimental. Typical release rates on other crops are in the range of 10,000-20,000 eggs per acre at a price of about $25-50 per acre. Application to small areas is usually done by hand, but mechanical devices are available for hand, tractor, and even aircraft application.

Spined soldier bug *(Podisus maculiventris)*. This member of the stink bug family feeds on a variety of slow-moving, soft-bodied insects that live on plants, such as caterpillars and the larvae of Colorado potato beetle. It is a native insect which is often very important in natural control and holds promise for augmentative releases. However, it has been in commercial production for only a couple of years and it has yet to be fully evaluated. No research has been done to measure the potential benefit of this predator in cranberries.

Praying mantids. Some suppliers sell mantid egg cases. Each egg case will give rise to many young mantids. Mantids are very general predators which make no distinction between pests and beneficial insects. Their numbers usually decline rapidly after hatching and they provide little if any significant value in pest control. The use of purchased mantid egg cases is **not recommended** for commercial agriculture, including cranberry production.

Parasitic insects.

Trichogramma. *Trichogramma* is the most commonly used parasitic insect in augmentation programs world wide. Millions of acres in the former USSR and China are treated annually with this tiny wasp. The entire genus *Trichogramma*, indeed, the entire family *Trichogramma*tidae, consists of insects that parasitize the eggs of other insects. The tiny adult *Trichogramma* wasp, less than 1 mm long, lays one or more of its own eggs within the egg of its host insect. The *Trichogramma* egg hatches and the larva consumes the inside of the host egg. The *Trichogramma* then pupates, and eventually the next generation adult emerges, leaving the host egg killed. Because the pest is killed in its egg stage, the damaging stages do not develop.

Some species of *Trichogramma* are specialized parasites whereas others are more general in their acceptance of host eggs. Eggs of moths and butterflies are most frequently attacked, although some species also attack eggs of beetles and other insects. There are three or four species commercially available in the United States, all of which are used primarily against the eggs of various types of moths. *T. pretiosum* is most suited for use in field and row crops; *T. minutum* is better suited for use in orchards and other tree crops; and *T. evanescens* is used primarily against European corn borer. A fourth species is used against avocado pests in California. Research is currently being conducted on other species of *Trichogramma* which may be more efficient parasites of the eggs of various types of pests. We have found both *T. minutum* and *T. pretiosum* capable of parasitizing blackheaded fireworm eggs in cranberry beds, where we have found *T. pretiosum* to also occur naturally.

Release of *Trichogramma* should coincide with the earliest flights of moths of the target pest. For example, releases should be made within a few days of first pheromone trap catches of blackheaded fireworm. Additional releases should be made at one to two week intervals through the flight period.

Although we are not currently able to recommend *Trichogramma* releases on cranberry, typical release rates on other crops are about 50,000-100,000 per acre, at a cost of $1020 per acre. Various manual and mechanical application methods have been developed.

Insect pathogens (microbial insecticides).

Although several insect pathogens have received approval from EPA for use as microbial insecticides, few types are actually commercially available. Most microbial insecticides have several advantages over traditional chemical insecticides in IPM programs. They combine ease of application with human and environmental safety. Also, they tend to be fairly specific, and generally are not directly harmful to beneficial predatory and parasitic insects.

Products containing the bacterium *Bacillus thuringiensis* ("Bt") are by far the most widely used microbial insecticides. There are several varieties of Bt, each of which has somewhat different properties. *Bacillus thuringiensis* var. *kurstaki* is the variety most frequently used in commercial preparations for caterpillar control. It is exempt from federal residue tolerances and can be used up to the time of harvest. It is registered for use on many types of crops. Bt varieties *tenebrionis* and *san diego* are effective against larvae of certain beetles, including Colorado potato beetle and elm leaf beetle. The variety *israelensis* is effective for control of larvae of mosquitoes, black flies, fungus gnats, and other fly relatives.

Another bacterium, *Bacillus popilliae* causes milky disease of white grubs. It is especially effective against Japanese beetle grubs and is not effective against the larvae of June beetles (*Phyllophaga* sp.), which are the most important white grubs in Wisconsin. Commercial products containing this bacterium **are not recommended** for use on cranberry in Wisconsin. However, research is being conducted on other types of milky disease bacteria, and one may ultimately be found that is effective against *Phyllophaga* grubs.

Nosema locustae is a protozoan which is effective against grasshoppers, crickets, and related groups. It is slow in acting and often decreases vitality of the insect and reduces reproduction rather than outright killing the insects. It has greatest application in rangeland, where some feeding injury can be tolerated. It is sold as a bait formulation which is attractive to, and fed upon by the grasshoppers.

There is much interest in the commercialization of insect parasitic nematodes (also called "entomogenous" nematodes) for biological control. Such nematodes are safe to use and do not affect plants. They are primarily used against soil insects, and they may be detrimental to some groups of beneficial predatory insects that live in the soil, such as predaceous ground beetles. Parasitic nematodes require moisture for survival and movement, and will be most effective in moist habitats, such as moist soil. Nematodes have three advantages in pest management: (1) the living worms move through the habitat and actually seek out their host insects, (2) they reproduce in their hosts and tend to persist in the environment as long as some hosts are present, and (3) they are viewed by EPA to be higher animals, more similar to beneficial insects, and are not currently regulated by federal agencies. *Steinernema carpocapsae* is the most commonly available nematode for biological control. There is also interest in *Heterorhabditis* nematodes and other groups, which may eventually become commercially available. Thus far, production costs are high, and application costs may be as high as $300 per acre. Therefore, current use is restricted to high value crops. However, as mass production technology improves, prices are expected to decline considerably. Storage and application are not as straight forward as other microbial insecticides, but application technology is also improving.

THE OUTLOOK FOR BIOLOGICAL CONTROL OF CRANBERRY INSECTS IN WISCONSIN

Certain approaches to biological control are already in use by the cranberry industry. There is great potential for the development of many other specific biological control methods.

Outlook for IMPORTATION of new natural enemies of cranberry pests.

Historically, the north central states have been relatively neglected in the area of new natural enemy introductions. No state departments of agriculture or universities in the Midwest have the types of biological control facilities and programs that are sponsored in leading biological control states such as California, Texas, and Hawaii. Furthermore, USDA importation programs in the Midwest have been minor compared to other regions. Many of our biological control successes, such as alfalfa weevil, have resulted from natural enemy introductions into other areas, with resultant spread into the north central states.

This situation is likely to change. There is increased interest by the USDA to cooperate with individual states and regions in finding, evaluating, and introducing new natural enemies. In addition, individual states in the Midwest are making a greater commitment to biological control. Several Department of Entomology faculty at the University of Wisconsin - Madison are actively involved in biological control programs. However, Wisconsin does not have the facilities necessary for natural enemy importation activities, and the state does not fund foreign exploration. Therefore, most activities in our department have focused on the conservation and augmentation approaches to biological control. This situation could easily change if facilities and resources for importation programs became available.

Because cranberry is a native North American crop, and because most cranberry pests are also thought to be native to North America, the importation approach to biological control on cranberry may be somewhat limited. Significant opportunities do exist, however. For example, blackheaded fireworm and some of our spanworm species are also considered to be native to the Old World, especially Europe and Asia, where more efficient natural enemies may exist. Also, there are species of the egg parasite *Trichogramma* which occur in Europe and Asia but not in North America; one of these species may be more effective at killing the eggs of cranberry pests than our native *Trichogramma*. Our recent research on the Wisconsin natural enemies of blackheaded fireworm demonstrated very little native parasitization and it is likely that more effective natural enemies could be found elsewhere. Virtually no research has been conducted to determine potentially important natural enemies of cranberry pests, and this would likely be a productive area of work.

Outlook for CONSERVATION of natural enemies of cranberry pests.

The use of broad spectrum insecticides is one of the greatest impediments to successful biological control. Frequent use of such insecticides in a preventive approach to insect control will never be compatible with most biological controls. Usually, the routine utilization of pest scouting to make decisions about control has significantly reduced the use of insecticides, helping to preserve natural enemies. Pest monitoring should continue to be the cornerstone for IPM program.

The widespread acceptance by the cranberry industry of the University's IPM program has provided many benefits, including reduced usage of broad spectrum pesticides except where actually needed. There is no doubt that such reduction increases the abundance of native natural enemies. For example, our research has shown that there are over twice as many beneficial natural enemies inhabiting the soil surface under cranberry vines in unsprayed vs. sprayed beds. Further, cranberry girdler egg predation rates were over twice as great in the unsprayed bed. We believe that there have been similar increases in natural enemies of foliage and fruit pests where insecticide usage has declined, although no research has yet been done on this.

IPM is not just using scouting procedures to determine pest levels, and then spraying accordingly. More importantly, it is the integration of all effective, economic, and environmentally safe pest management procedures. Cultural insect controls, such as sanding and flooding, and biological controls such as the use of *Bacillus thuringiensis* sprays, will be less detrimental to natural enemies than will be traditional insecticides. As the cranberry industry continues to implement IPM practices, more natural enemies will be conserved, resulting in more effective natural pest control.

As biological control becomes more important in cranberry pest management, IPM scouts must learn to identify natural enemies and assess their impact. In a fully developed IPM program, it will be just as important to monitor the natural enemies in a bed as it will to monitor the pests.

Outlook for AUGMENTATION of natural enemies of cranberry pests.

The use of biological control by augmentation of natural enemies has become an accepted and established practice. However, historically and currently relatively few types of natural enemies are commercially available in the United States, and these are targeted against a relatively small number of pests. Natural enemy augmentation programs have had their greatest impact in western Europe in glasshouse crops, and in Eastern Europe and China where *Trichogramma* is used for control of various caterpillar species on millions of acres of field crops, row crops, and orchards.

Specific types of natural enemy releases are currently being developed and evaluated for use on cranberry. At least three companies are marketing *Bacillus thuringiensis* (Bt) formulations: Abbott Labs (DiPel), DuPont (Biobit), and Mycogen (MVP). Although not currently labeled specifically for blackheaded fireworm, laboratory and field studies indicate that Bt can effectively control this pest, but use pattern and timing of applications are critical. Research continues in this area. Bt is also effective against spanworms if properly timed. Currently, Bt is the material of choice for eradicating gypsy moth from forest areas in eastern Wisconsin, and it is already registered for use against this pest on cranberry should this become of concern here. Applications of Bt for all target pests should be made as soon as possible after egg hatch. If the egg hatch period is prolonged, two or three applications at 5-7 day intervals may be necessary for optimum control.

Although Bt is the only microbial insecticide currently available for use on cranberry, there is good potential for others. We recently discovered an insect virus which is quite active against blackheaded fireworm, resulting in as much as 100% natural mortality in some of our 1992 research samples. We will be cooperating with an insect pathologist at the University of Illinois to characterize this virus, and will then determine its potential as a microbial insecticide. We are also conducting laboratory studies of a virus of codling moth that is being registered as a microbial insecticide by the University of California. This virus may also have potential for controlling blackheaded fireworm. Further, there is a variety of *Bacillus thuringiensis* that may be effective against cranberry tipworm larvae; we will be doing laboratory evaluations of this as well. Finally, several agrichemical and genetic engineering companies are working to register other insect pathogens for control of various insects; some of these may have benefit against cranberry pests.

The use of insect parasitic nematodes for cranberry pest control was first seriously studied on the West Coast where black vine weevil is a pest of unflooded cranberry plantings. Studies in Washington showed that these nematodes also gave good control of cranberry girdler larvae and applications have been made for girdler control in

Wisconsin. Most studies on cranberry have been against soil insects, using the nematode *Steinernema carpocapsae*. OceanSpray entomologists have done considerable work trying to kill *Phyllophaga* grubs with this nematode, but without good success. I consider the use of nematodes still somewhat experimental but as more research is developed on production, formulation, and application technologies, I believe the consistency of results will increase and cost per acre will decrease. There are many species of insect parasitic nematodes known but which are not currently available commercially. Some of these may have a future place in cranberry insect management. For example, we will be conducting laboratory studies this year to determine if tipworm may be a potential target of nematodes. Currently, insect parasitic nematodes are not considered by the Environmental Protection Agency to be microbial insecticides. Therefore, they are not regulated, either from the perspective of assuring efficacy, or for the need of establishing pesticide residue tolerances.

Of the commercially available predatory and parasitic insects, only the egg parasites *Trichogramma* currently have potential for use on cranberry, the targets being the egg stages of various moth pests such as blackheaded fireworm, cranberry fruitworm, sparganothis, and spanworms. Limited research in Massachusetts has shown that cranberry fruitworm eggs can be killed by *Trichogramma* releases, but the degree of control was often not sufficient. In small scale caged field studies here in Wisconsin, we have successfully parasitized blackheaded fireworm eggs with two commercial species of *Trichogramma*, *T. minutum* and *T. pretiosum*, but parasitization rates were too low to be effective. However, large scale, late summer field releases of *T. minutum* conducted by Canadian workers in 1991 resulted in over 60% control of overwintering blackheaded fireworm eggs. Use of *Trichogramma* has great potential on cranberry, but much more research is necessary.

I have one further thought on the use of augmentative releases of natural enemies for control of cranberry insects. Much of my discussion has focused on purchasing natural enemies from commercial suppliers. Such suppliers must be able to make a profit from a given natural enemy or will not be willing to produce it. Further, availability of a particular natural enemy may be subject to production schedules and unpredictable levels of orders from customers. An alternative approach has been taken in the California citrus industry, which heavily (in some cases, exclusively) relies upon biological control. In the Fillmore region north of Los Angeles, a cooperative "citrus protection district" has for many years operated a non-profit insectary for producing and distributing, in a timely manner, natural enemies to its member growers. If, through research, we can find effective natural enemies for use against cranberry pests, I see the potential for the cranberry industry doing something similar in each region of the country. This seems a very logical future step in the evolution of cranberry pest management.

CONCLUSION

The U.S. Department of Agriculture has recently indicated that, where the technology exists and can be used economically, biological control should be the focus of integrated pest management programs. In the past few years, biological control methods have become available for use in cranberry pest control. These methods include the conservation of natural enemies by (1) pest scouting, (2) reduced pesticide use, and (3) use of non-chemical control methods. In addition, specific types of natural enemy augmentation have been used, specifically, the use of microbial insecticides based on *Bacillus thuringiensis* and insect parasitic nematodes. Preliminary research within the Department of Entomology at the University of Wisconsin - Madison shows promising avenues of additional biological control methods for cranberry insect management.

Note: Use of company names or brand names is for convenience only and is not an endorsement of these companies or products over others that are similar. Material provided herein is for informational purposes only; the user of pest control products and practices assumes responsibility for safe, legal, and environmentally sound usage.

ADDITIONAL READING

There are many books in your local libraries that will help you become more familiar with insects in general, and pests and their control. For general insect identification, including natural enemies, there are several excellent and inexpensive field guides available in local bookstores. An excellent source of up-to-date information on alternative pest control measures is the "IPM Practitioner" newsletter; this is also often available in local libraries but is well worth the subscription price. The following books are specific references on biological control. Some of these are out of print and available only through libraries. None of these references include specific information on biological control of cranberry insects.

Non-technical books.

DeBach, Paul. 1974. Biological control by natural enemies. Cambridge Univ. Press. 327 p.

Swan, Lester A. 1964. Beneficial insects. Harper and Row. 429 p.

Technical books.

Burges, H. D., and N. W. Hussey. 1971. Microbial control of insects and mites. Academic Press. 861 p.

Clausen, C. P. 1972. Entomophagous insects. Hafner Publ. Co. 688 p.

Clausen, C. P. 1978. Introduced parasites and predators of arthropod pests and weeds: a world review. USDA Agric. Handbook No. 480. 545 p.

Croft, Brian A. 1990. Arthropod biological control agents and pesticides. Wiley. 723 p.

DeBach, Paul. 1964. Biological control of insect pests and weeds. Reinhold Publ. Co. 844 p.

Hoy, M. A., and D. C. Herzog. 1985. Biological control in agricultural IPM systems. Academic Press. 589 p.

Huffaker, C. B., and P. S. Messenger. 1976. Theory and practice of biological control. Academic Press. 788 p.

Ridgway, R. L., and S. B. Vinson. 1977. Biological control by augmentation of natural enemies. Plenum Press. 480 p.

van den Bosch, R., P. S. Messenger, and A. P. Gutierrez. 1982. An introduction to biological control. Plenum Press. 247 p.

Waage, Jeff, and David Greathead. 1986. Insect parasitoids. Academic Press. 389 p.

Flooding Cranberry Beds in the 1990's to Control Blackheaded Fireworm

Stephen D. Cockfield and Daniel L. Mahr
Department of Entomology
University of Wisconsin-Madison

Background and Introduction

Growers have been using deep, brief floods in late spring to control blackheaded fireworm since the mid 1800's. The only alternatives to flooding in the 1800's were kerosene emulsion, Paris green (an inorganic insecticide), and the botanical insecticides tobacco and pyrethrum. Flooding was widely regarded as the best control method.

After the turn of the century up to 1915, bulletins from USDA and Massachusetts Experiment Station recommended waiting until June to reflood, and extending the flood for 4-8 hrs for maximum larval mortality. This severe measure was probably practiced in response to a serious and chronic outbreak of blackheaded fireworm in Massachusetts. In the following decades, agronomists and plant physiologists questioned the safety of the method and investigated the problems caused by excessive flooding. They documented symptoms of stress and correlated the injury with low oxygen content of flood water. Perhaps in response to these concerns, in 1945, entomologists in Massachusetts recommended limiting the duration of a flood to 10 hours twice in June. Although pyrethrum was still in use, DDT was then newly available. When first introduced, DDT was the most effective compound for general insect control and had relatively low toxicity to plants and mammals. For the first time, a compound had been discovered which performed better than flooding.

During the 1950's, and 60's, many new types of synthetic organic insecticides were developed and are still in use today. These compounds controlled fireworm effec- tively without danger to plants, and seemed to be a permanent alternative to flooding.

Management options have changed once again in the 1990's. We are witnessing a decline in the number of synthetic organic compounds registered for cranberry instead of an increase. Reliance on fewer available products increases the possibility of excessive use of particular compounds. Excessive use, in turn, can lead to insecticide resistance. Cultural control methods such as flooding should be reevaluated with the hope of once again increasing pest management options. Since the earliest writing on the subject, there has not been any published quantitative assessment of the technique. The purposes of this investigation are (i) to quantify the effect of water of different temperature and dissolved oxygen (DO) content on survival of submerged blackheaded fireworm larvae, and (2) to evaluate reflooding as a control measure.

Laboratory Experiments

Methods and Materials

Blackheaded fireworm larvae were established on cut cranberry foliage and allowed to construct silken shelters. Samples were submerged in water of high (8.2- 13.1 ppm) DO at two temperatures, 36°F and 50°F, for different lengths of time. Other samples were submerged in water of low (5.1-7.1 ppm) DO at 50°F for different lengths of time. After submersion, the number of living and dead insects were counted.

Results

The trend in survival of larvae over time was similar for the two temperature treatments (Fig. 1). As the time of submersion increased to nine days, survival decreased to approximately 40%.

The effect of DO on survival of larvae is illustrated in Figure 2. About 90% of larvae survived submersion in water of high DO for three days, while only about 10% survived in water of low DO for the same length of time. At low, springtime temperatures, DO concentration had a comparativelY large effect on survival of larvae while temperature had little effect.

Field Experiments

Methods and Materials

Three marshes (designated Marsh A, B, and C) were selected as sites for field trials in 1991 from a total of six volunteer sites. All three were located near Warrens. At each site two beds were chosen based on their proximity to one another, high density of blackheaded fireworm eggs, and the ability to flood one bed independently. In April, 100 eggs in each bed were located and their locations marked. Twenty-four hours prior to and 24 hours after flooding, three 0.1 m2 (about 1 ft2) areas from each bed were pruned to ground level. The foliage samples were examined under a microscope for living and dead larvae.

The beds which could be independently flooded at each site were flooded 3- 1 0 inches above the foliage to kill blackheaded fireworm larvae. Timing of flood was based on maximum hatch of eggs and minimum bud break of plants. Water temperature and DO were monitored at mid-afternoon and dawn each day. Duration of flood was based on dormancy of the plants.

Marsh A was flooded in the morning of 11 May and water withdrawn after 50 hours. Marsh B was flooded in the afternoon on 12 May and water removed after 31 hours. Marsh C was flooded in the evening of 13 May and water withdrawn after 24 Hours. For a summary of DO and temperature measurements during the trials, see Table 1.

Data were analyzed by computing the corrected percentage reduction (CPR) in larval density, which is intended to measure mortality of insects in the treated plots apart from population changes not caused by the treatment. CPR ranges from 0% (no reduction) to 100% (complete elimination of larvae).

Results

The egg hatch patterns and times of treatment are represented in Figure 3. Shoot elongation occurred during the end of hatch, when temperatures rose into the high 80's. The beds were flooded before hatch was completed to avoid greatest damage to the plants.

On Marsh A there was an approximate 90% decrease in larval density in the treated bed but very little change in the untreated bed (Table 2). Larval density was reduced very little on Marsh B whereas density increased greatly on the untreated bed because of continued egg hatch (Table 2). The same pattern was apparent on Marsh C. The CPR was high for all sites indicating a significant mortality of larvae during the flood (Table 2).

Conclusions

The ability of flood water to kill blackheaded fireworm larvae depends on the concentration of dissolved oxygen. The lower the oxygen content, the greater the larval mortality in a certain time period. The longer larvae remain submerged, the greater the mortality.

Although flooding generally will not eliminate fireworm populations, it does cause considerable mortality in the field. Reflooding may be most effective as a preventative treatment when population densities are near or below economic injury level, or as a supplement to insecticides or other control measures. This should result in a reduced need for insecticide applications.

Ideally, modern use of reflooding should be done with full knowledge of its effects on plant health and crop yield. Although there is some information on the tolerance of cranberry plants to flooding, current knowledge does not allow us to predict the effect of flooding on cranberry plant health and fruiting during the transition from late dormancy to early growth. The timing and duration of a flood will need to be based on a balance of risks and benefits: the risk of reduced yield if flooding is attempted, the risk of reduced yield if no action is taken, the expected benefit provided by pest suppression, and the relative cost of control alternatives.

In an era of increased pest and environment monitoring in integrated pest man- agement programs, we believe reflooding can have a role in controlling blackheaded fireworm. In some cases flooding may be adequate by itself; in other cases it may be necessary to combine flooding with other pest management approaches.

Table 1. Flood water temperature (°F) and Dissolved Oxygen concentration (ppm) during field trials.

Day	Time	Measurement	Location Marsh A	Marsh B	Marsh C
1	afternoon	Temp.	72	---	---
		DO	8.5	---	---
2	dawn	Temp.	68	70	61
		DO	6.0	7.2	4.1
	afternoon	Temp.	79	81	81
		DO	8.0	7.2	7.2
3	dawn	Temp.	72	---	---
		DO	4.2	---	---

Table 2. Mean density of blackheaded fireworm larvae found in 0.1 m2 samples and derived corrected percentage reduction (CPR) of larval density resulting from flood treatment.

Site	Bed	Larval Density Before Flood	After Flood	CPR
Marsh A	flooded	36.3	3.7	89.4
	control	7.7	9.7	
Marsh B	flooded	4.0	3.0	93.1
	control	0.7	7.7	
Marsh C	flooded	43.3	12.0	78.7
	control	14.0	31.3	

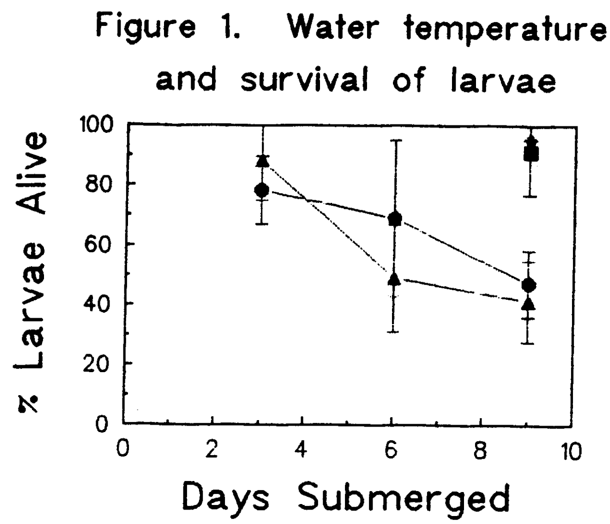

Figure 1. Percent of blackheaded fireworm larvae alive after submergence in water at 36°F (circles) or 50°F (triangles). Percent survival of unsubmerged larvae after 9 days at either temperature is in the top right corner. all symbols are averages and the vertical bars are standard deviations.

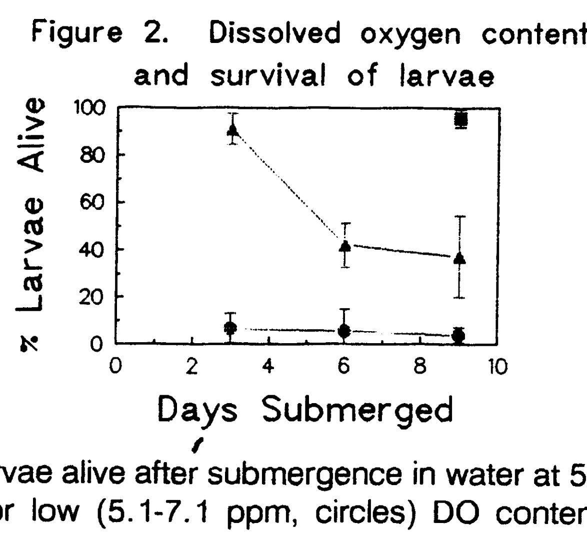

Figure 2. Percent of larvae alive after submergence in water at 50°F and with high (8.2-13.1 ppm, triangles) or low (5.1-7.1 ppm, circles) DO content. Percent survival of unsubmerged larvae after 9 days at 50°F is in the top right corner. All symbols are averages and bars are standard deviations.

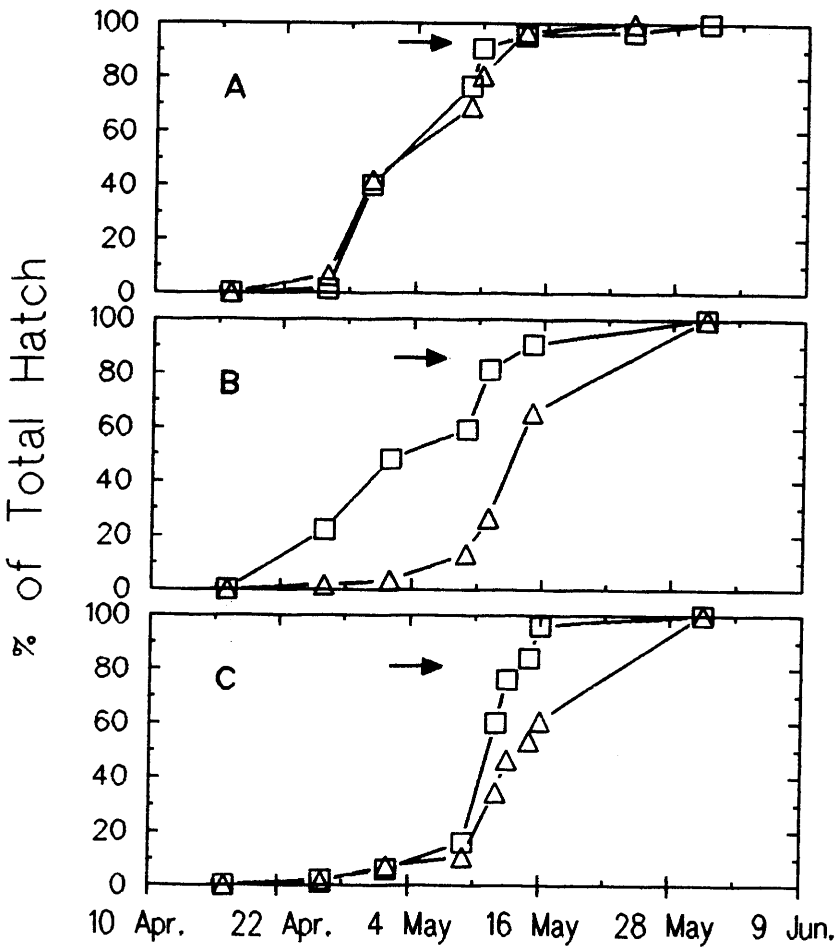

Figure 3. Percent of monitored eggs which successfully hatched in each bed during April and May. A is percent hatch at Marsh A, B at Marsh B, and C at Marsh C. Data from flooded beds are designated by squares, those from unflooded beds by triangles. Arrows indicate percent hatch at the start of reflood.