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Chapter 1

CHALLENGES IN INTEGRATED PEST MANAGEMENT FOR MASSACHUSETTS CRANBERRY PRODUCTION: A HISTORICAL PERSPECTIVE TO INFORM THE FUTURE

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ABSTRACT

Integrated pest management (IPM) was formally introduced to the cranberry industry in 1983 through support of a scouting program by the University of Massachusetts-Amherst. In that year, 6.5 ha of commercial cranberry were scouted by an IPM specialist. IPM has been successfully adopted by cranberry growers. In 2007, estimates indicate private consultants, company personnel, and individual growers combine to scout more than 80% of Massachusetts' cranberries (>4,050 ha). During the past 25 years, IPM has come to mean much more than simply sweep netting for insect pests and installing pheromone traps. Successful modern cranberry growers must have a working knowledge of insect biology, weed ecology, plant physiology, and disease life cycles. They must know how to apply products with novel chemistry, have proficiency with several pesticide-delivery systems, integrate traditional cultural practices into modern horticulture, select new varieties, cost-effectively renovate out-dated farms, and adjust to the pressures stemming from the encroachment of urbanization. In the 1980's and 1990's, growers primarily determined their response to reaching economic and action thresholds based on the current price of cranberry and the cost of the product they had chosen to apply. Over the past few years, the decision tree has changed. Growers must truly weigh their chosen management strategies in terms of social and environmental costs in addition to the simple economics of product and commodity price. Research by scientists at the UMass Cranberry Station, in collaboration with their colleagues across North America, has been addressing the current and future needs of the cranberry industry. This paper describes the history of IPM in Massachusetts, the challenges of managing a dynamic and

expansive pest complex in a suburbanized environment, and the research that has supported and promoted sustainable cranberry production in Massachusetts.

OVERVIEW

The American cranberry (*Vaccinium macrocarpon* Ait.) is one of three fruits native to North America. Cranberry production has a long history in Massachusetts, and the state is considered to be the birthplace of the industry. Cranberries are found in peat bogs and the sand dune swales of Cape Cod, Nantucket, Martha's Vineyard and Southeastern Massachusetts. Although Captain Henry Hall of Cape Cod is acknowledged as the first to successfully cultivate cranberries (ca. 1810), native Indians had already incorporated the cranberry into their culture, recognizing its nutritional value as well as its usefulness as a dye long before the first European settlers arrived [Eck 1990].

The majority of U.S. cranberries are produced in Massachusetts, Wisconsin, New Jersey, Oregon and Washington; the contributions of Quebec, British Columbia, and the Atlantic Maritime Provinces comprise the substantial remainder of the North American production. Recent assessments estimate that there are approximately 16,200 producing hectares in the U.S. [Farrimond 2005] and about 4,000 hectares in the Canadian provinces (S. Fitzpatrick and K. MacKenzie, pers. comm.). Historically, Massachusetts had the greatest number of hectares and the greatest production in North America. However, as Massachusetts' holdings have remained basically stable (ca. 5,670 ha) since the early 1900's [Mason 1926], Wisconsin's properties have increased from 4,050 to 7,050 hectares (74%) during the years 1992 to 2004. Due to the industry's high production efficiency and low pest pressure, Wisconsin currently produces more than half of the total U.S. cranberry crop [Farrimond 2005].

Contributions to cranberry research have been made by scientists from every growing region. However, one of the earliest horticultural bulletins and research publications was written by a plant pathologist working in the United States [Shear 1907]. Many scientists were affiliated with universities and some worked with the United States Department of Agriculture (USDA). H.F. Bergman, who worked at the UMass Cranberry Station, provided early research on various responses of cranberry to flooding [Bergman 1921; Bergman 1925]. C.S. Beckwith, who worked for Rutgers University in New Jersey, produced an illustrated text on weeds of the cranberry farm [Beckwith and Fiske 1925] and a bulletin on an insect-vectored disease [Beckwith and Hutton 1929]. C.L. Shear, N.E. Stevens, and H.F. Bain were USDA pathologists who collaborated to write a classic treatise on cranberry diseases [Shear et al. 1931]. E.L. Eaton and I.V. Hall worked in Nova Scotia [Eaton 1957; Hall 1959] and G.W. Eaton, from the University of British Columbia, produced well-referenced papers on reproductive traits and yield components [Eaton 1978; Eaton and Kyte 1978].

The most definitive historical works on insects were authored by H. J. Franklin, the first director of the UMass Cranberry Station [Franklin 1948; Franklin 1951]. Franklin wrote during the time of rapid development of new chemistries for pesticides and his writings do include discussions of chemical management. Franklin was a keen observer of insect behavior. Many of his observations relating to cultural practices and water management of insects provide insights and support for current cranberry pest management [Franklin and Cross 1948; Franklin 1951]. Through his writings, Franklin provided the baseline knowledge and research for the development of the integrated management of cranberry insects.

In the same decade as the publication of Franklin's pioneering observations, the term integrated control was defined by B.R. Bartlett in 1956 as the blending of biological control agents with chemical controls [Metcalf and Luckman 1975]. Since then, IPM has been described as an ecological approach to pest control, based upon sound biological knowledge and principles [Metcalf and Luckman 1975] and the intelligent selection and use of pest control actions that will ensure favorable economic, ecological, and sociological consequences [Rabb 1972]. The philosophy of IPM hinges upon the integration of biological, cultural, and chemical control practices to manage pest problems. As in many other commodities, an integrated approach to cranberry pest management is based upon dynamic principles rather than a definitive set of rules for control of a particular pest situation.

In Massachusetts cranberry production, IPM involves pest monitoring by using sweep nets, pheromone traps, and visual inspection. Cultural, chemical, and biological control strategies are used to develop a broad-based approach to controlling the most economically threatening pests. Cultural practices, such as flooding, the application of a thin layer of sand, and the use of resistant varieties, can reduce the severity of a pest problem. Pesticides remain a vital part of cranberry IPM programs, tempered by their compatibility with other control measures and their consistency with IPM philosophy. Although economical and logistical constraints often hamper wide-scale adoption, biological controls can be successfully utilized to manage pests in specific situations [Mahr 1999].

Historically, many cranberry farmers who used IPM could reduce the number of spray applications made in a growing season. More recently, applications of broad-spectrum organophosphates have declined and the use of target-specific, reduced risk compounds has become more prevalent. To achieve efficacy with these newer chemicals, multiple applications are often needed. Thus, the traditional benchmark of success in IPM - reduction in the number of pesticide applications - is no longer appropriate. Success in cranberry IPM in the 21st century will likely be measured by such parameters as seasonal and long-term reduction in pest pressure and damage, promotion of sustainable vine health and crop yield performance, and promotion of environmental stewardship.

THE MASSACHUSETTS CRANBERRY INDUSTRY

To be competitive in the global market, cranberry growers and manufacturers must produce fruit and processed products that meet or exceed national and international quality standards. Consistently harvesting saleable crops depends upon managing pest damage to vines and fruit. To appreciate the history and the challenges of pest management in the cranberry industry, a brief description of cranberry production and cranberry culture in Massachusetts is provided here.

Cranberries are low-growing evergreen perennial vines that typically grow in acidic peat soils, often with a water table that is fairly close to the surface. Agricultural bogs constructed in upland settings and natural bogs that occur in swales have vines that grow in sandy soil [Johnson 1985; Shumway 1996; Turenne 2002]. The vines have vertical stems (uprights) that can be either vegetative or reproductive, and horizontal runners that bear the uprights. Reproductive uprights may have three to seven flowers that produce one to five fruits [Baumann and Eaton 1986; Brown and McNeil 2006]. Many varieties of cranberry have uprights that are biennial bearing [Eaton 1978]. Optimally, the vine cover is continuous across the production area yielding vine densities of 4,300-6,500 uprights per m^2 [DeMoranville 2007]. The farm area is typically the lowest part of the landscape and is comprised of perimeter and interior drainage ditches and dikes that can readily contain water (Fig. 1). Due to the periodic need of flooding, farms are always associated with nearby water bodies such as ponds, rivers, or man-made reservoirs. Irrigation systems consisting of flood gates, flumes, lift pumps, piping, and sprinkler heads are critical components of the working farm.

Figure 1. Aerial view of a commercial cranberry farm in Southeastern Massachusetts showing interior and exterior ditches, perimeter roads, and proximity to nearby water resources. Photograph courtesy of C. DeMoranville.

Three normal agricultural practices in cranberry production deserve specific mention: the use of water, the application of sand, and chemigation. Water is used for irrigation, insect and disease control, frost and heat protection, the application of sand, harvesting, and protection from winter desiccation and cold injury [DeMoranville and Sandler 2000]. The production area is routinely flooded for harvest and winter protection. Flooding to a depth of 30-40 cm of water can usually be achieved within 24 hours and can be maintained for days or even weeks without additional pumping. Holding a flood is so crucial to successful cranberry farming in Massachusetts that if a property is unable to maintain a flood, the long-term commercial success of the farm is compromised. Water is frequently re-used because the irrigation system and water storage resource are usually interconnected (Fig. 1), thus water usage in cranberry production is not always consumptive [DeMoranville and Sandler 2000].

In the early 1800's, Henry Hall noticed that the growth of his wild vines improved when sand from an adjacent beach was deposited on them; subsequent research confirmed the observation [Tomlinson 1936]. Since then, the application of a thin layer of sand to the production surface every three to five years has become one of the most common horticultural practices in cranberry. Sanding encourages the production of vertical stems that bear the fruit and promotes rooting by anchoring long runners. Sanding also has pest management benefits including burial of insect pupae [Tomlinson 1937] and weed seeds [Sandler et al. 1997]. It is desirable to have a sand resource on-site as the delivery of screened sand has been recently reported to cost $14 U.S. per cubic meter (approximately $3,600 per ha for a depth of 2.5 cm sand) (P. Beaton, pers. comm.).

Chemigation, the delivery of pesticides through the sprinkler system, is the most common method of chemical application utilized by Massachusetts cranberry growers. Typical chemigation systems contain many components including injection ports, displacement pumps, and back-flow prevention devices [DeMoranville et al. 1996]. Chemicals can also be applied by helicopter, ground rigs, boom sprayers or hand-held devices, but chemigation is the industry standard for chemical delivery. For sprinkler systems to reliably deliver the chemical to the target pests, a level of uniformity and precision must be obtained. For cranberry farms in Massachusetts, efficiency is gauged by achieving high coefficients of uniformity [Christiansen 1942] and low rinse-out times [DeMoranville et al. 1996].

The cranberry industry is important economically and aesthetically to Massachusetts. Cranberries recently accounted for $47 billion U.S. (12%) of the cash farm receipts in the state [National Agricultural Statistics Service 2006]. Cranberry production is the third largest agricultural commodity in Massachusetts, following greenhouse plants and dairy farms. Data from the mid-1990's indicated that cranberry accounted for 5,500 jobs and $2 million U.S. in payroll to Massachusetts residents [Buzzards Bay National Estuary Program 2006]. Although cranberries are produced on approximately 5,800 ha, growers own more than 24,000 ha of land. These additional holdings are comprised chiefly of upland areas that surround the cranberry farm. Cranberry growers play a very important role in the maintenance of the open space that contributes to the appealing character of Southeastern Massachusetts (Fig. 1).

The cranberry industry has secured a niche with its products, both fresh market and processed in state, national, and international market economies. The demand for high quality fruit compels the industry to maximize yield. In addition, cranberry growers must confront increasing public pressure to reduce pesticide use. Balancing environmental concerns and consumer demands for safe and consistent products against pest and market pressures becomes a delicate and intricate enterprise. Cranberry growers continue to take the challenge of delivering a dependable commodity in the midst of mounting environmental pressures. IPM is the process by which growers can strive for sustainability and profitability while maintaining a commitment to environmental stewardship.

HISTORY OF CRANBERRY IPM IN MASSACHUSETTS

Accepted techniques of IPM, such as crop rotation or use of resistant cultivars, have long been unofficially part of farmers' routine approach for producing saleable crops. However, use of these techniques under an IPM program differs from their traditional use by the acknowledgment that the grower has an understanding of the philosophy of pest management. After the creation of the Environmental Protection Agency (EPA) in December 1970, momentum was generated in the Federal government to encourage farmers to manage pests within the context of a philosophy that integrated biological, chemical, and cultural practices.

Significant federal support for IPM extension, research and field programs began in 1972, with major contributions coming from the EPA, USDA, and the National Science Foundation [National Research Council 1989]. Since 1973, IPM administered through the Extension

Service has focused primarily on promoting the implementation and development of workable programs among growers' organizations, consultants, and private industry. The IPM program for the Massachusetts cranberry industry was initiated in 1983 at the UMass Cranberry Station, which is part of the College of Natural Resources and the Environment at the University of Massachusetts-Amherst. Subsequently, the Cranberry Station has been looked upon as a leader in the development and dissemination of IPM techniques and information by the cranberry producing regions in the United States, Canada, and other countries.

In its first year, approximately 6.5 ha were scouted under the UMass IPM program. The number of hectares covered by the program peaked in 1985 at just over 240 ha, hovered around 160 ha through the 1989 season, and returned to the initial year's coverage through the early 1990's. Prior to the economic collapse of the cranberry industry in 1999, as many as six private scouting businesses (IPM consultants) provided services for Massachusetts cranberry growers. One of the primary goals of any University-based IPM program is to encourage the adoption of IPM programs by the private sector and to slowly withdrawal from providing scouting services. Progressing along this continuum, the UMass Cranberry Station discontinued its fee-for-service program in 1995. The total number of cranberry hectares managed using IPM philosophy has increased in the last two decades from several hundred hectares to more than 4,000 ha. Most growers, in Massachusetts and other growing regions in the U.S., scout their farms themselves [Weber 1997]. A small segment of growers pay private IPM consultants to scout their farms; costs vary but typically fall between of $185-250 U.S. per ha. Persons employed by individual cranberry companies scout the remainder of the acreage.

A basic cranberry IPM program consists of: sweep net sampling for 6-10 weeks; use of pheromone traps for *Sparganothis* fruitworm (*Sparganothis sulfureana*), cranberry girdler (*Chrysoteuchia topiaria*), and black-headed fireworm (*Rhopobota naevana*) moths to aid in the timing of insecticide sprays; inspection of berries in July-August for cranberry fruitworm (CFW; *Acrobasis vaccinii*) eggs; scouting for dodder (*Cuscuta gronovii*) seedlings to time management strategies; use of soil and plant tissue analyses to determine fertilizer applications; determination of crop phenology for fungicide and insecticide applications; and mapping of weeds. Maintaining proper sanitation, judicious use of irrigation, planting resistant varieties, and use of various cultural techniques are additional examples of the many components found in an integrated management program for cranberries [Lasota 1990].

A grower survey conducted in 1999 indicated that 80% of Massachusetts cranberry growers identified themselves as frequent IPM practitioners and 16% as occasional practitioners [Blake et al. 2007]. Practices frequently used by >75% growers included scouting with sweep net, inspecting fruit for cranberry fruitworm eggs, calculating % out-of-bloom activities (important for CFW management), scouting for dodder seedlings, raking dodder, mowing weeds, sanding, cleaning ditches, and scheduling irrigation to minimize leaf wetness. Most growers practiced IPM because they agreed with IPM philosophy (80%) and believed it had environmental benefits (73%). More than half of all growers who returned surveys were satisfied with its effectiveness and believed that IPM saved money. More than 90% agreed that the use of IPM could reduce pesticide residue in food and the environment and protect beneficial insects.

Although many growers surveyed in 1999 held the perception that IPM can pose measurable economic risk (and subsequently act as a barrier to adoption), growers felt more strongly about the potential environmental benefits that come from using IPM than the risks they might incur [Blake et al. 2007]. Implementing IPM did not increase the amount of time spent managing pest problems. In addition, cost of pest control products and services were not seen as barriers to adoption. Most growers felt current IPM methods for controlling major pests were very adequate, but also felt that adoption of IPM practices could be improved with an increase of funds for further development of IPM methods.

Quantifying IPM the level of adoption and success is challenging as many farmers choose to engage selectively in particular aspects of an IPM program [Musser et al. 1986; Ridgeley and Brush 1992]. Measurements of IPM adoption and success have ranged from reliance on self-reporting by farmers to the evaluation of farmer knowledge and decision-making criteria with regards to pest management strategies [McDonald and Glynn 1994; Nowak et al. 1996]. Several indices have been developed to evaluate pesticides in terms of their risk to the environment and nontarget organisms [Higley and Wintersteen 1992; Penrose et al. 1994; Levitan et al. 1995]. Only when linked to other economic and environmental criteria, could risk indices be used to more completely evaluate the success of an IPM program.

One pesticide-risk index, the Environmental Impact Quotient (EIQ), is defined by a weighted equation that relates toxicity and environmental fate data to three main components: the farm worker, the consumer, and the ecological component [Kovach et al. 1992]. The EIQ can then be used as a tool to characterize the potential risk associated with a particular pesticide. The cranberry EIQ [Frantz and Sandler 1994] modified several weighted multipliers in the EIQ to reflect exposure conditions in the cranberry industry. The impact of picker exposure was reduced (reflecting the minimal pesticide exposure during harvest), groundwater risks were increased, and the importance of the aquatic environment was increased. Using the adjusted factors, cranberry EIQ values were calculated for pesticides used in the cranberry industry. The EIQ is limited in evaluating IPM success in that it does not address the efficacy of a product, only its risk [Dushoff et al. 1994]. Since IPM crosses many disciplines and is classically defined by its dynamic nature, measuring its success will also require a multifaceted approach.

MANAGING CRANBERRY PESTS IN MASSACHUSETTS

The principal challenge for managing pests in cranberries is simply the vast number of organisms that can cause damage to the vine or the fruit or both (see Tables 1-3). Over 20 insects cause injury to the cranberry and three are direct fruit pests [Averill and Sylvia 1998]. Fruit rot is the most serious yield-limiting disease problem for Massachusetts and is associated with more than 10 causal agents [Oudemans et al. 1998; Caruso 2007]. The large number of infectious agents makes understanding the biology of this disease complex challenging. Thirty-three different plants species are highlighted in the table, but more than 80 species of weeds have been described by several cranberry researchers [Beckwith and Fiske 1925; Demoranville 1984; Demoranville 1986; Sandler 2004].

Management of these numerous pests must combine knowledge of the biology of pest complex with practical application of control strategies. In practice, IPM is the implementation of pest control strategies founded on ecological principles and biological data that capitalize on natural mortality factors (e.g., natural enemies, unfavorable soil conditions, etc.) while minimizing the disruption of these factors. Pest management revolves around optimizing control, rather than maximizing it. Consequently, current control tactics are aimed at the suppression of a cranberry pest rather than its eradication.

Table 1. Common and latin names of insect pests in Massachusetts cranberry production

Direct fruit pests	
Cranberry fruitworm	*Acrobasis vaccinii*
Cranberry weevil	*Anthonomus musculus*
Sparganothis fruitworm	*Sparganothis sulfureana*
Early season cutworms and other caterpillars	
Blossomworm	*Epiglaea apiata*
False Armyworm	*Xylena nupera*
Gypsy moth	*Lymantria dispar*
Humped green fruitworm	*Amphipyra pyramidoides*
Brown spanworm	*Ematurga amitaria*
Green spanworm	*Itame sulphurea*
Black-headed fireworm	*Rhopobota naevana*
Yellow-headed fireworm	*Acleris minuta*
Soil insects	
Cranberry root grub	*Lichnanthe vulpina*
Cranberry white grub	*Phyllophaga anxia*
Hoplia beetle	*Hoplia equina*
Oriental beetle	*Anomala orientalis*
Striped colapsis	*Colapsis costipennis*
Black vine weevil	*Otiorhynchus sulcatus*
Strawberry root weevil	*Otiorhynchus sulcatus*
Cranberry girdler	*Chrysoteuchia topiaria*
Miscellaneous	
Cranberry flea beetle	*Systena frontalis*
Cranberry tipworm	*Dasineura oxycoccana*
Leafminer	*Coptodisca negligens* and *Neptoculid spp.*
Southern red mite	*Oligonychus ilicis*

For the 21st century, the use of chemicals within an IPM context represents a significant departure from the pest control knowledge base needed with the use of broad-spectrum pesticides available in the middle to latter parts of the 20th century. The choice of pesticides has shifted, especially within the last 10-20 years, from broad-spectrum organophosphates to reduced risk compounds and growth regulators for insect control and from the use of petroleum-based products and whole-farm preemergence herbicide applications to spot-application of plant growth regulators for control of very specific plant groups (Fig. 2). More accustomed to considering insect resistance issues, growers must now also consider judicious use of new classes of fungicides (e.g. strobilurins) to prevent the development of resistant fruit rot fungi. The modern cranberry farmer must know the biology of the pest, understand the chemistry of the chosen chemical, and incorporate horticultural and nonchemical knowledge and experience to make appropriate management decisions.

Table 2. Common and latin names of weed pests in Massachusetts cranberry production

Weeds of zero tolerance	
Dewberries	*Rubus hispidus, R. flagellaris*
Dodder	*Cuscuta gronovii*
Poison ivy	*Rhus radicans*
Sawbrier	*Smilax glauca*
Wild bean	*Apios americana*
Serious weeds	
Asters	*Aster ericoides, A. novi-belgii*
Common sawbrier	*Smilax rotundifolia*
Narrow-leaved goldenrod	*Euthamia tenuifolia*
Upright bramble	*Rubus allegheniensis*
Yellow loosestrife	*Lysimachia terrestris*
Weeds of less importance	
Black chokeberry	*Pyrus melanocarpa*
Nutsedge	*Cyperus dentatus*
Leatherleaf	*Chamaedaphne calyculata*
Perennial sedges, grasses	
Red maple	*Acer rubrum*
Rushes	*Juncus spp.*
Sheep laurel	*Kalmia angustifolia*
White clover	*Trifolium repens*
Weeds of minor concern	
Annual sedges, grasses	
Arrow-leaved tearthumb	*Polygonum sagittatum*
Blue-eyed grass	*Sisyrinchium spp.*
Cinquefoil	*Potentilla canadensis*
Fireweed	*Erechtites hieracifolia*
Ferns	
Hardhack	*Spiraea tomentosa*
Horsetail	*Equisetum arvense*
Joe pye weed	*Eupatorium dubium*
Meadow beauty	*Rhexia virginica*
Meadowsweet	*Spiraea latifolia*
Mosses	*Polytrichum spp., Sphagnum spp.*
Pitchfork	*Bidens frondosa*
Ragweed	*Ambrosia artemisiifolia*
Sheep sorrel	*Rumex acetosella*
Sweet pepper bush	*Clethra alnifolia*
White violet	*Viola lanceolata*

Table 3. Common and latin names of diseases in Massachusetts cranberry production

Berry rot, various pathogens include:
Apostrasseria lunata (black rot) = *Allantophomopsis lycopodina + A. cytisporea*
Botryosphaeria vaccinii (Botryosphaeria fruit rot)
Coleophoma empetri (ripe rot)
Glomerella cingulata (bitter rot)
Godronia cassandrae (end rot) = *Fusicoccum putrefaciens*
Penicillium spp. (Penicillium rot)
Phomopsis vaccinii (viscid rot)
Phyllosticta vaccinii (early rot or bull's eye rot)
Physalospora vaccinii (blotch rot)
Strasseria geniculata (black rot)
Fairy ring, *Psilocybe agrariella* var. *vaccinii* (suspected); exact causal agent unknown[*]
False blossom, mycoplasma-like organism = phytoplasma
Leaf spots, *Pyrenobotrys compacta* and *Protoventuria myrtilli*
Phytophthora root rot, Phytophthora cinnamomi
Red leaf spot, Exobasidium rostrupii
Ringspot virus
Upright and runner dieback, *Phomopsis vaccinii* and *Synchronoblastia crypta*

[z] Work ongoing to identify causal agent (F. Caruso, pers. comm.)

Although many other factors come into consideration, monitoring continues to be the tool by which growers collect information to determine when control decisions should be made. The use of sweep nets, pheromone traps and visual inspections are the main methods by which growers monitor insect populations. Action thresholds (AT) are available for many cranberry insects. The action threshold is a practical estimate of the economic threshold, the density at which control measures should be applied to prevent an increasing pest population from reaching the economic injury level [Stern et al. 1959]. AT are typically based upon the average number of insects gathered at a particular sampling time. Examples of AT currently established for insect pests in cranberry production include: 4.5 cutworms, 4.5 cranberry weevils, and 18 spanworms per set of 25 sweeps [Averill and Sylvia 1998].

AT do not exist for weed and disease pests. However, cranberry growers use phenology and other biological indicators to make pest management decisions. For example, weeds are prioritized based on their ability to spread, reduce yield, and susceptibility to control measures [Else et al. 1995]. Growers can then make decisions based on the assigned priority level. Weed mapping provides a historical catalogue of weed location, growth, and control over the years. Mapping can help identify populations of weeds that serve as points of invasion into the farm [Sandler et al. 2006]. For fruit rot management, growers make fungicide applications based on the percentage of open bloom as well as the keeping quality forecast (KQF). A strong relationship between various weather factors and the quality of fruit was documented in the late 1940’s [Franklin 1948] and the KQF procedure has been used to recommend fungicide applications ever since [DeMoranville et al. 1997].

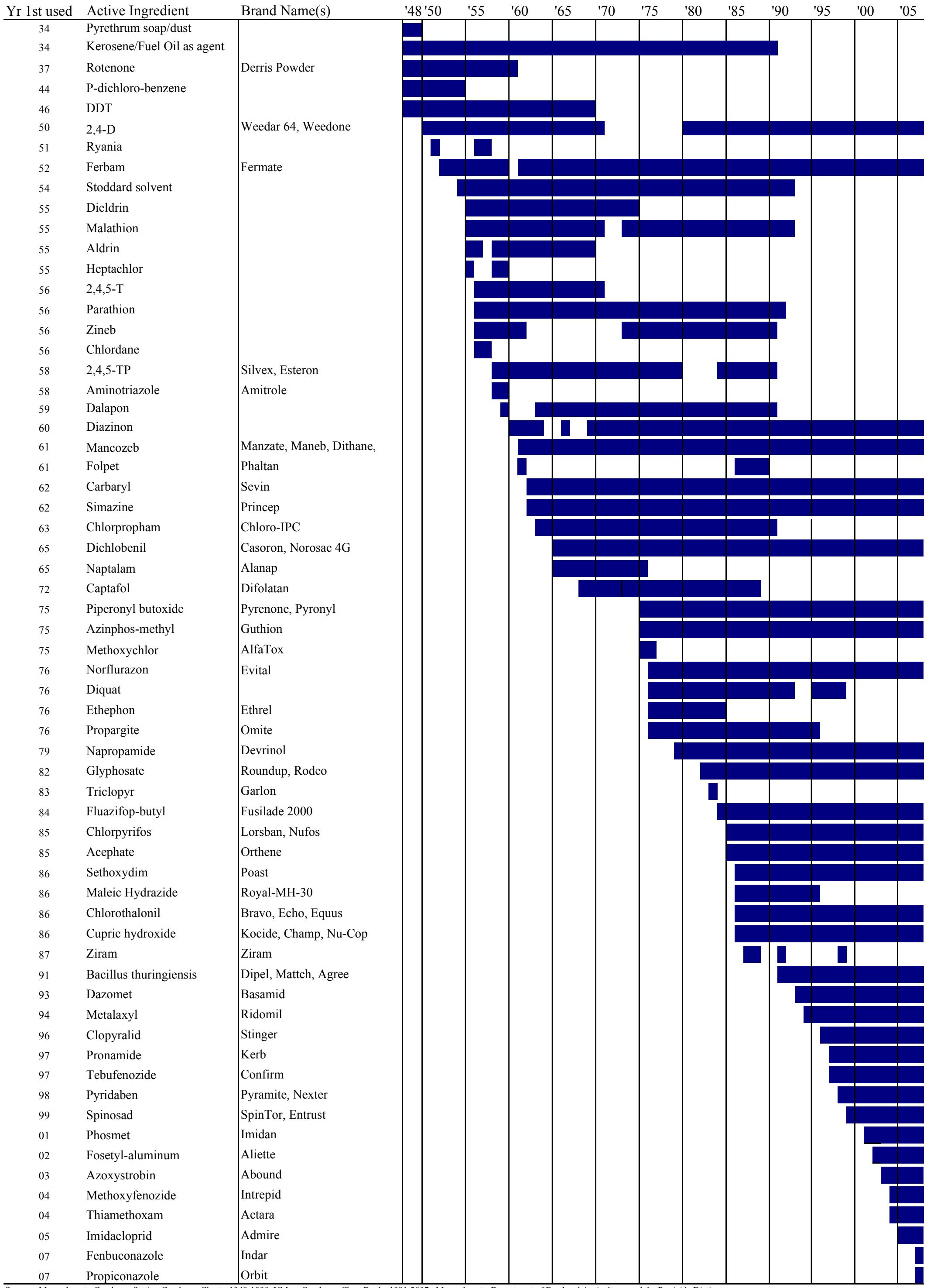


Figure 2. Pesticides approved for use on Massachusetts cranberry farms, 1948-2007.

In a recent 4-year comparison, the efficacy of the KQF (in terms of number of fungicide applications and percentage rot) was compared to the forecast generated by SkyBit [SkyBit 2007] (a fee-for-service company that processes data originating from the National Weather Service). Plots managed by the traditional KQF model received either one less or the same number of fungicide applications than those managed under the SkyBit plan; KQF plots had similar or less field and storage rot in all four years than those that used the SkyBit model (F. Caruso, pers. comm.). The KQF formula developed 60 years ago is generating accurate estimates for the keeping quality of cranberry fruit.

Chemical control is a critical component of pest management for cranberries. According to a recent summary report, 32 different pesticides were used in Massachusetts in 2003. These included seven fungicides, nine herbicides, and 16 insecticides (J. DeVerna, pers. comm.). Chlorothalonil was the most widely used fungicide (in terms of producing hectares that received at least one application), followed by the ethylenebisdithiocarbamate (EBDC) fungicides and the copper fungicides (see Table 4). For postemergence herbicides, glyphosate was applied to 55% of the production area; clopyralid was used on only 8%. The top two preemergence herbicides used were pronamide (46%) and dichlobenil (23%). Diazinon was the most widely applied insecticide (84%), followed by carbaryl (72%) and thiamethoxam (54%).

Table 4. Percentage hectares treated and mean active ingredient of common pesticides applied to Massachusetts cranberry farms, 1996 and 2003.

	Hectares receiving application (%)		Mean active ingredient (kg/ha)	
Pesticide	1996	2003	1996	2003
Chlorothalonil	77	73	7.82	3.80
Copper	22	29	6.59	n/e
EBDC	45	42	4.70	3.46
Azoxybtrobin	n/a	13	n/a	0.20
Glyphosate (post)	80	55	0.56	n/e
Dichlobenil (pre)	67	23	2.30	2.25
Clopyralid (post)	n/a	8	n/a	0.03
Pronamide (pre)	n/a	46	n/a	0.57
Diazinon	75	84	5.12	2.62
Carbaryl	42	72	6.99	2.06
B.t. products	14	1.3	n/e	n/e
Spinosid	n/a	57	n/a	0.13
Thiamethoxam	n/a	54	n/a	0.20

n/a, not available.
n/e, not estimated.

Data from 1996 [Crop Profile 2001] indicated the percentage of fungicide-treated hectares did not substantially change from 1996 to 2003, however growers applied less fungicide per hectare (see Table 4). Mean kilograms of active ingredient (kg a.i.) applied per hectare for chlorothalonil decreased by more than 50%; for EBDC, the decrease was 26%.

Mean kg a.i. of dichlobenil has remained stable although the percentage of treated hectares declined. When pronamide became available for dodder control in 1997, many late spring applications of dichlobenil (traditionally used at low rates that targeted dodder) were diverted to fewer early spring applications (at high rates that targeted broadleaved weed control) [Sandler 2007]. Hectares receiving diazinon and carbaryl (1996 compared to 2003) increased 10% and 31%, respectively, but growers used lower effective rates as mean kg a.i. applied declined 49% and 70%, respectively.

Chemigation remains the delivery mechanism of choice for insecticides and fungicides in Massachusetts. More than 90% of the hectares treated with chlorothalonil, EBDC and copper fungicides were applied through the sprinkler system (J. DeVerna, pers. comm.). Nine percent of the copper fungicides were applied by helicopter. More than 92% of the hectares treated with diazinon, carbaryl, and thiamethoxam were applied by chemigation. The remainder of the acreage treated with these insecticides was applied by helicopter. The method for herbicide application was varied. Chemigation was overwhelmingly used for pronamide (95%), but ground rig applicators were used for 95% of the dichlobenil applications; only 3% of the dichlobenil was applied by helicopter. Clopyralid was always applied as a ground application (spot application with a hand-held sprayer).

Cranberry growers are not reliant solely upon chemical pesticides. Other pest management options are biological control [Mahr 1999], pheromones, cultural management, and nutrient management. Many options require the application of a material, even if it is biological product, such as beneficial nematodes, stomach poisons for caterpillars, or fungi for dodder control. The value of these options will be impacted not only by the products' efficacy but by the precision of the delivery system (e.g., chemigation, boom applicator) and cost. Research has identified insect pheromones and has led to their use in trapping, monitoring, and mating disruption. In addition, research on the use of flooding, sanding, and planting density has provided insights into additional pest management options.

RESEARCH AND DEVELOPMENT OF PEST MANAGEMENT PRACTICES

Registration and Use of Pesticides

The Massachusetts cranberry industry and research scientists have good relationships with several chemical manufacturers as well as federal and state agencies that regulate and register new pesticides. These relationships are critical for the maintenance of currently registered compounds and well as future registrations. The cranberry industry has been very successful over the past decade in securing emergency and crisis exemptions (called Section 18 permits) from EPA. Section 18 permits enable growers to manage pests, such as cranberry weevil, dodder, and *Phytophthora cinnamomi*, with pesticides that have not yet completed the full EPA registration process. The outbreak of organophosphate-resistant weevils in early 2000's would have caused severe economic loss for many growers if not for the granting of a crisis exemption for the use of an insecticide that was pending registration [Averill and Sylvia 2002]. UMass Cranberry Station scientists have also obtained special local needs (SLN or 24c) labeling by conducting field trials to demonstrate efficacy, and subsequently working with state officials and registrants to incorporate the needed label changes.

New compounds are evaluated for food residue risk and crop injury through the federal specialty (minor) crops program, known as the IR-4 Project, whose headquarters are located in Princeton, NJ. For over forty years, the IR-4 Project has been the major resource for supplying pest management tools for specialty crops by developing research data to support registration clearances [IR-4 Project 2007]. Scientists at the UMass Cranberry Station work closely with scientists from IR-4, industry representatives, and university colleagues to annually determine product priorities. Field data are gathered from multiple cranberry growing regions and sent to IR-4 personnel, who collate the results and prepare a report for submission to EPA. The entire process is crucial for the registration of new materials for cranberry production in all growing regions of North America.

Biological Products

***Bacillus Thuringiensis* (B.T.) Products**: Several products containing the bacterium, *Bacillus thuringiensis* (B.t.), have been registered to control lepidopteran pests of cranberries (Fig. 2). These products are effective for control of the small larval (caterpillar) stages of cutworms, spanworms, and gypsy moths. These insect pests feed primarily on the leaves and buds of cranberry vines. B.t. products are very low in mammalian toxicity, specific to caterpillars and are not harmful to bees, wildlife, or beneficial insects. Growers can apply these products by air or chemigation.

Research on the first B.t.-based product introduced to the cranberry market was initiated by scientists at Ocean Spray Cranberries, Inc. (OSC) in 1986 (L. Dapsis, pers. comm.). The registration for DiPel on cranberries came in 1989. Since 1995, other B.t. products, such as MVP, Mattch, and Agree have become available for use in commercial cranberry production. Effective applications of these products require the grower to apply the chemical under a strict set of conditions. For example, the larvae should be small, the product must be uniformly applied, and a 24-hour rain-free period should follow application. Bog size, product choice, and method of application may also affect efficacy [Sandler and Mason 1997]. B.t-based products act as stomach poisons. Thus, the caterpillars must ingest a certain amount of chemical and repeat applications may be necessary. In the 1990’s, the cost of one or two applications was competitive with other insecticides.

According to the survey by Blake et al. (2007), B.t. products were not frequently used by Massachusetts growers at the close of the 20th century. In fact, less than 10% of the respondents said they frequently used Bt products while over 50% said they never used them. This response fits fairly well with that reported for North American cranberry growers by Weber (1996). Only one-third of the respondents reported that they had tried B.t., and almost half of those growers had fair or negative experiences. Data in Table 4 confirm these trends.

Beneficial Nematodes: Biological control of black vine weevil, strawberry root weevil, and cranberry girdler is possible with use of beneficial nematodes. Nematodes are microscopic worms that parasitize and kill the larval (immature) stages of the above-mentioned cranberry pests. Beneficial nematodes target specific soil-inhabiting insects and should not be confused with the plant-parasitic nematodes, which are consider plant pathogens. Beneficial nematodes do not harm the cranberry plant. The immature stages of the pests feed on the cranberry roots and runners, severely restricting the uptake of water and nutrients.

A biological insecticide using the nematode, *Steinernema carpocapsae*, as the active ingredient was registered for use in cranberry farms in the mid-1980s. Projects researching the efficacy of the first beneficial nematode product, Biosafe-N (originally manufactured by the now-defunct company, BioSys), began in 1985. The cranberry industry was the first food crop in North America to employ beneficial nematodes as a biological control agent on a commercial basis. The product is nontoxic to plants, animals, and most beneficial insects and does not contaminate groundwater supplies. Use recommendations for managing soil insects were developed for cranberry and other small fruit crops [Polavarapu 1999; Booth 2000].

Growers in Massachusetts and in other cranberry regions have been using nematodes for black vine weevil and strawberry root weevil control since 1988. Good control was observed in Massachusetts (S. Roberts, pers. comm.) and Washington [Booth et al. 2002]. Although one application was usually sufficient, in some cases two applications were needed. Virulence was documented with *H. megidis* and *S. feltiae* on cranberry girdler larvae under natural conditions [Simard 2001] and in laboratory trials [Simard et al. 2002]. When available in the 1980-1990’s, the cost of the nematode product ranged from $310-615 per ha. Commercial availability of beneficial nematodes in the Northeast has been sporadic over the years and has reduced growers’ ability to fully incorporate this strategy into standard IPM programs in Massachusetts.

Research has focused on the development of different application techniques as well as looking at the efficacy of various species of nematodes. Nematodes can remain infective even when passed through various application equipment like irrigation sprinklers [Hayes et al. 1999]. Trials from 1986 showed that *Heterorhabditis heliothidis* and *Neoaplectana carpocapsae* (= *Steinernema feltiae*) had efficacy against black vine weevil [Shanks and Agudelo-Silva 1990]. The efficiency by which a nematode finds its host is affected by temperature [Long et al. 2000]. When nematodes were applied to cranberry farms when the temperatures were cool, some strains of *Steinernema* were less efficient at controlling girdler larvae and immature stages of the weevils than other species that are adapted to cool temperatures [Booth 2000].

Pathogens: *Alternaria destrucens* has been identified as a pathogen of dodder [Bewick 1987]. The commercial availability of this mycoherbicide has been hampered by many production problems over the past 20 years. However in 2006, a manufacturer in Pennsylvania (Sylvan BioProducts) registered the product, Smolder, for dodder control on cranberries in Massachusetts. Two formulations were registered: a preemergence granular and a postemergence wettable powder. In conjunction with scientists from Wisconsin, USDA, and Sylvan, field trials were initiated in 2006 at the UMass Cranberry Station and are continuing in 2007. Early results indicated that timing and application procedures need to be more clearly defined to maximize the performance of Smolder [Bewick and Cascino 2007]. *Colletrotrichum gloeosporioides* has also been identified as a pathogen of dodder [Mika and Caruso 1999], but no attempts have been made to commercialize this fungus.

Booth et al. demonstrated that a dried mycelial formulation of *Metarhizium anisopliae* has good potential as a biopesticide for black vine weevil and cranberry girdler [Booth et al. 2000]. This was a preliminary trial on a small scale. Determination of efficacy on large scale trials and concerns about the consistent supply of a commercial product have never been resolved. Several isolates of *Aureobasidum pullulans* were shown to have activity against cranberry black rot (*Apostrasseria lunata* and *Strasseria oxycocci*) [Stretch 1989]. Stretch suggested that integrating the pathogen into existing patterns of fruit handling could be possible if it was introduced in the wash cycle before the berries were placed into storage prior to sale. Another fungus, *Beauvaria bassiana*, has been identified as a pathogen of cranberry girdler [Hall 1954; Kamm 1973]. It must be noted that the conventional application of fungicides for fruit rot control may interfere with the long-term establishment and efficiency of most fungi (pathogens) for biocontrol.

Predators and Parasitoids: Published research on the potential use of parasites and parasitoids in cranberry production has focused on those infecting blackheaded fireworm (BHF) and cranberry fruitworm (CFW). Indigenous *Trichogramma* sp. nr. *sibericum* (now *T. sibericum*) and, to a lesser extent, *T. minutum*, parasitize BHF eggs [Li et al. 1994]. Other species (a tachinid fly and several parasitic wasps) have been reared from BHF larvae [Fitzpatrick et al. 1994]. It has been noted that spiders will prey on BHF moths in field cages [Fitzpatrick and Troubridge 1993] and on certain larvae of known cranberry pests [Bardwell and Averill 1996]. *T. minutum* has shown preferences for egg masses of spotted fireworm (*Choristoneura parallela*) based on plant host, egg number, and egg mass density [Stuart and Polavarapu 2000]. The authors noted that their results indicated the presence of complex interactions that may affect the development and implementation of successful biological control programs.

Franklin reported that *T. pretiosum* is a native egg parasite of CFW in Massachusetts [Franklin 1951]. Uncultivated or wild cranberry bogs provide habitat for these parasitoids, with documented level of parasitism ranging from 22% to 39% [Simser 1994]. It has been difficult to achieve adequate or sustained parasitism in the field and thus, the use of *Trichogramma* has not been pursued to any great extent. Simser tried two levels of inundative releases on commercial farms, but still recorded lower rates of CFW parasitism in the release area than in uncultivated (no additional release) bogs. A survey on blueberry found eight parasitoid species and one fungal pathogen of CFW [Murray et al. 1996]. The collected parasitoids included three ichneumonids, two braconids, two tachinids, and a bombyliid; the soil-borne fungus was *Percilomyces* near *farinosus*.

Research from New Jersey has shown that the discontinuation of the use of broad-spectrum insecticides will likely promote management of *Sparganothis* fruitworm [Marucci and Moulter 1992]. The scientists were studying abandoned bogs that had very high populations of *Sparganothis*. The sites received no pesticides and no supplemental water or fertilizer inputs. Within a few years after abandonment, the *Sparganothis* fruitworm population dropped to very low levels. The increase in natural enemy populations (in response to the withdrawal of pesticides) and reduced fecundity of the fruitworm could explain the population shift. Marucci and Moulter found high rates of parasitism and many species were listed as parasites of *Sparganothis*. *Trichogramma* spp. and a tachinid fly, *Erynnia tortricis*, were highlighted as important natural enemies.

Other Products: An agricultural decontaminant foam, alkyl dimethyl benzyl ammonium chloride (ADBAC), was tested as a growth deterrent for the field and storage rot pathogen, *Physalospora vaccinii* [Tubajika 2006]. At least 100 ppm ADBAC was needed to affect mycelial growth and complete inhibition was achieved at 1,000 ppm. The authors contend this product would fit well into an integrated program for fungal control. Biological fungicides containing *Pseudomonas syringae*, when applied in combination with carnauba wax, effectively reduced fruit decay in cranberry [Chen et al. 1999], but more research is needed to determine the range of pathogens affected. Several nontoxic household cleaners (e.g., vinegar, soap) have been evaluated for postemergence control of dodder [Morrison et al. 2005]. Cryolite bait has been used by many growers in the Pacific Northwest for control of black vine weevil and strawberry root weevil [Weber 1997]. Its use has been limited in Massachusetts and its production was discontinued in 2004 [Averill and Sylvia 2007].

Pheromones, Traps and Mating Disruption

Research on the identification of sex pheromones for several cranberry pests has been published. One of the earliest reports was for the pheromone of *Sparganothis* fruitworm [Roelofs and Comeau 1970; Polavarapu et al. 2001], followed by the identification of the sex attractants for cranberry girdler [McDonough and Kamm 1979] and BHF [McDonough et al. 1987; Slessor et al. 1987]. The chemistry of the sex pheromone of CFW was identified [McDonough et al. 1994]. Scientists initially hoped that the pheromone could be used for disrupting the mating behavior of this economically important pest [Senft 1995] but the line of research has not been pursued (A. Averill, pers. comm.). Researchers from Cornell University have been responsible for conducting most of the research related to the sex pheromone of cranberry white grub [Zhang et al. 1997; Robbins et al. 2006]. The sex pheromone of the cranberry blossomworm was recently identified through a collaboration of scientists from the USDA in Beltsville, MD and Rutgers University [Zhang and Polavarapu 2003].

Several of these chemical identifications led to the incorporation and adoption of pheromone traps into standard IPM programs as monitoring tools [Brodel 1985]. The effectiveness of pheromone traps for monitoring populations of cranberry girdler [Corliss 1990; Kamm et al. 1990], BHF [Shanks et al. 1990; Cockfield et al. 1994], and *Sparganothis* [Cockfield et al. 1994] has been evaluated by many cranberry scientists across North America. Traps are regularly used by more than half of the Massachusetts growers [Blake et al. 2007]. Trap catches are monitored to determine the beginning of the moth flight or peak flight, after which sprays can then be timed [Kamm and McDonough 1982; Averill and Sylvia 2007].

Applied research on mating disruption is another outcome stemming from the identification of sex pheromones. Following promising initial studies [Fitzpatrick et al. 1995; Baker et al. 1997; Fadamiro et al. 1998], it was demonstrated that the mating of BHF adult moths can be disrupted and reduced with the use of two commercial pheromone-release systems, although the numbers of eggs were not reduced in field plots treated with polyvinyl chloride (PVC) dispensers [Fitzpatrick et al. 2004]. Although useful as a research tool, distribution of PVC dispensers in the field was too labor-intensive for large farms. A sprayable formulation of BHF pheromone (3M Canada Company) was tested and registered for use in the U.S. and Canada (Fitzpatrick, unpublished data). However, due to the availability of chemicals that give good control of BHF and other cranberry pests, use of mating disruption for BHF has not been incorporated into Massachusetts IPM programs.

Additional work on mating disruption has been published within the last six years for *Sparganothis* fruitworm [Polavarapu et al. 2001] and oriental beetle [Wenninger and Averill 2006]. Work from the New Jersey group established that mating disruption was promising for management of *Sparganothis* but more research was needed to determine the best application method and frequency of application to maximize disruption. Encouraged by initial results, the Massachusetts scientists noted that aspects of the biology of oriental beetle may bolster the effectiveness of mating disruption should the cost of the product make it more attractive for commercial implementation. Recent research also indicated that mass trapping with bucket traps baited with the pheromone for *Hoplia equina* may also provide additional management options for this soil pest [Weber et al. 2005].

Cultural Control Options

Even though cultural practices have been used in cranberry production for many decades, incorporation of these management techniques into modern cranberry production cannot be overemphasized. Integration of any appropriate cultural practices is an essential component to any modern management program. Examples of cultural practices used in cranberry production that impact pest management are discussed below.

Flooding: Cranberries evolved in a wetland setting and as such are able to withstand periodic flooding without sustaining injury. Growers use flooding for many management purposes including harvesting, frost protection, and winter protection [DeMoranville 1998]. Manipulation of water resources within the bog system has been a traditional method of pest control [Beckwith 1925; Beckwith 1940; Franklin 1951]. Holding a late water flood (i.e., reflooding the bog from mid-April to mid-May) can decrease the inoculum potential of the fruit rot fungi, cause a general reduction of annual weeds, suppress the spread of *Rubus* spp. as well as suppress populations of certain insects and mites [Averill et al. 1994; Averill et al. 1997].

Short spring floods can control BHF [Cockfield and Mahr 1992] and dodder [Sandler 2003; Sandler and Mason 2004]. These spring floods are typically held for 24-48 hr and can reduce the pesticide input into the system. Short (3 to 7 days) late summer floods can also be used for management of cranberry girdler [Beckwith 1925; Fitzpatrick in press], and longer floods (held for 3-4 weeks after harvest of the fruit) can reduce CFW emergence from hibernacula and suppress growth of dewberries [DeMoranville et al. 2005]. Seeded CFW hibernacula placed in flooded beds had 85% lower moth emergence compared to nonflooded beds. The impact of the floods on dewberries was less consistent; crown numbers and weed coverage were reduced in some situations but not in others. Flooding for pest management is not always successful in terms of reducing pest populations. In New Jersey, data collected from short flooding experiments for management of *Sparganothis* were not promising [Teixeira and Averill 2006]. The authors concluded that flooding will not replace the control seen with chemical control or mating disruption.

Flooding, even if successful in reducing pest populations, carries a certain degree of risk to the vines. Until the early 2000’s, flooding was primarily viewed through the lens of pest management only. Recent research has shown that flooding at different times of year for various lengths of time can impact the total nonstructural carbohydrate concentration (TNSC) of the vines [Botelho and Vanden Heuvel 2005]. Carbohydrate resources are important (even crucial) to proper fruit set [Birrenkott and Stang 1990; Hagidimitriou and Roper 1994]. Carbohydrate stress may be observed after prolonged periods of net respiration during flooding [Botelho and Vanden Heuvel 2005; Vanden Heuvel 2005]. Botelho and Vanden Heuvel (2006) found that TNSC was generally unaffected by late water floods, winter floods, and short-term spring floods. However, fall floods often resulted in decreased TNSC. Thus, the use of fall floods for pest management may carry the risk of yield reduction.

Potential increased risk and less than optimal results do not preclude the usefulness of flooding in some situations. However, the complex interactions of flood duration, water temperature, carbohydrate concentration, yield expectations, and pest pressures showcase the wide knowledge base needed to farm cranberries in the 21st century. Cranberry growers must understand the dynamics of the pest populations on their farms, consider the historical record of chemical and cultural practices, incorporate their experience and environmental concerns, and then make the best management decision for each farm on a year-by-year basis.

Sanding: Sanding, i.e., the application of a thin (1.25 to 5 cm) layer of sand on the production surface at 2 to 5 year intervals, is the most commonly used cultural practice in Massachusetts [DeMoranville et al. 1996]. Sand can be applied directly onto dry vines by ground rigs that ride on the vines (dry sanding) or on rails (rail sanding), applied during the winter on top of frozen flood waters (ice sanding) or delivered via a floating barge in shallow flood waters (barge sanding) during the spring or fall. Sanding buries long runners, which encourages rooting and upright production [Tomlinson 1937]. Sanding improves drainage and can physically strengthen peat soils so that mechanical operations are easier. After sanding, development of the plant may be accelerated, so frost hardiness may be lost earlier in the spring [Cross and Demoranville 1969]. On the other hand, sand absorbs and releases more heat than the organic layer such that frost danger is lower on sanded bogs.

Sanding has many benefits including stimulation of organic matter decomposition [Cross and Demoranville 1978] and suppression of fruit rot inoculum by burying infected leaves [Tomlinson 1937]. Uniform applications of sand on a regular interval may reduce infestations of cranberry girdler and green spanworm [Franklin 1913; Tomlinson 1937]. Research is on-going to determine the impact of sanding on CFW (A. Averill, pers. comm.). Uniform sand applications can also inhibit emergence of dodder seedlings [Sandler et al. 1997]. Sanding can have varying impacts on yields and seems to be related to cultivar, application method, and depth of the sand layer [Strik and Poole 1995; Davenport and Schiffhauer 2000]. The effect of sanding can also be influenced by irrigation method and nitrogen rate [Lampinen and DeMoranville 2002; Lampinen and DeMoranville 2003]. The poorest crop performance was seen in wet areas receiving high nitrogen rates and deep sand application.

Sanding may not always have positive pest management outcomes. Sand as the surface layer may shorten herbicide longevity [Sandler and DeMoranville 1999]. Weed seeds of problematic plants can actually be introduced by the application of sand to the vines, increasing weed problems [Mason et al. 2006]. Pest control (e.g. cranberry girdler, dodder) often depends on the deposition of uniform layers of sand. Growers will strive to apply a certain target depth, but recent research reported that the majority of measurements of sand depths actually deposited to the bog floor were much lower than the target depth [Hunsberger et al. 2006]. In fact, deposition patterns were very irregular and would reduce the expectation of pest suppression that requires a uniform layer of sand, such as dodder. To achieve consistent pest management benefits from sanding, improved technology is needed to deposit uniform layers of sand to the production surface.

Pruning: Pruning has indirect effects on pest populations but provides overall benefits to vine vigor and is an important cultural practice. Periodic pruning of vines improves aeration in the vine canopy and makes the environment unfavorable for fruit rot infection [Caruso and Ramsdell 1995]. Pruning also minimizes the amount of vine growth allocated to vegetative runners and generally improves yield [Strik and Poole 1991; Strik and Poole 1992]. Pruning is presently being viewed as an inexpensive method to generate vine material for new plantings. Recent studies analyzing the economics of propagating cranberry vines intended for new plantings or commercial sale have indicated more biomass (pruned vines) was associated with increasing rates of nitrogen (at high pruning intensities), but the increase in monies gained from vine sales could not replace the income lost by the reduced fruit yield (Sandler, unpublished data). Subsequent research could include evaluating the impact of pruning and nitrogen rate on weed populations.

Pruning is becoming more important to Massachusetts growers as local sand (available on-site) resources decrease and the cost of sand increases. A Sustainable Agricultural Research and Education (SARE) grant has been awarded to the staff of the UMass Cranberry Station to evaluate the impact of lengthening the interval between sanding events by substituting more frequent pruning events. The project is an excellent example of the multidisciplinary approach needed to develop new practices that will promote sustainability. The primary goal of the research is to develop, demonstrate, and implement grower-identified practices than improve water and canopy management, reduce costs and improve pest management (C. DeMoranville, pers. comm.). Studies are currently investigating the incorporation of low-cost practices that have potential to increase fruit quality and contribute to pesticide reduction, such as pruning, irrigation scheduling, drainage management, bed sanitation, and integrated nutrient management.

Other Cultural Practices: Sanitation (removal of leaf trash after harvest) is very important for minimizing fruit rot inoculum [Caruso and Ramsdell 1995]. Proper use of water is important to successful disease management and overall vine health. Improving drainage can help mitigate *Phytophthora* root rot [Caruso and Wilcox 1990]. Minimizing the length of time that leaves remain wet will reduce the infection potential of fruit rot fungi. Proper maintenance and calibration of the sprinkler system and other equipment are important procedures that are practiced by cranberry growers. Adequate pressure and clean nozzles are critical to ensure that proper amounts of chemicals are delivered to the target area.

Renovation of older plantings to new (hybrid) varieties, along with installation of improved irrigation systems, is being more readily embraced by current cranberry growers than in the past. The age of the planting can influence the pest complex that must be managed [DeMoranville et al. 2001]. Newly planted bogs typically need less fungicide and insect inputs; but should be intensively managed for weed pests. Choice of vine density, nitrogen rate and weed management strategy interact to provide thorough colonization of newly planted vines [Sandler 2004]. The most cost-effective production scheme for establishing new beds that minimizes weed infestation is to plant vines at a low density, use moderate amounts of nitrogen, and apply an annual application of a preemergence herbicide [Sandler et al. 2004]. As vines age, additional pests may become established. Scouting should be performed routinely, and the process of integrating cultural, biological, and chemical controls becomes part of the regular pest management program.

Nutrient Management

Nutrient management is important when considering pest management in terms of the overall health of the plant. Sustainable nutrient practices have positive impacts on the environment as well as the plant. Use of organic fertilizers, slow-release fertilizers, and small split applications reduce leaching loss. Ammoniated forms of nitrogen are readily and preferably taken up by cranberry vines [Addoms and Mounce 1932; Greidanus et al. 1972; Dirr 1974] and protect the groundwater. Calcium-boron supplements improve pollination and increase yield potential [DeMoranville and Deubert 1987].

Inorganic fertilizers with various proportions of the major elements of nitrogen, phosphorus and potassium (NPK) are the most commonly used fertilizer products in cranberry since they provide quick vine response. However, growers are incorporating slow-release products and foliar fertilizers into their regular programs. Best management practices (BMP) for nutrient management recommend that growers use moderate application of nitrogen fertilizers [DeMoranville et al. 1996]. From a pest management perspective, this practice helps in two ways. Using appropriate amounts of nitrogen limits overgrowth of vines that can encourage infection from fruit rot organisms [Davenport 1996]. Secondly, lush vine growth can provide a suitable habitat for tipworm and flea beetle infestations [Averill and Sylvia 1998]. Growers can reduce pest problems through judicious use of fertilizer.

Research on the organic product, fish hydrolysate (or fish fertilizer), was initiated at the UMass Cranberry Station in 1987 [DeMoranville 1992]. Results indicated that fish hydrolysate may be a suitable alternative to inorganic soluble fertilizers. Growers first tried fish fertilizer, made using recycled products from the state's fishing industry, as a nutrient source in 1989. Fish fertilizer is an efficient material; it remains in the root zone longer than inorganic soluble fertilizers. Use of this slow-release, organic material is particularly well suited to areas that have a high leaching potential. Since 1987, studies on the use of fish fertilizer have included: investigation of the impact of fish fertilizer with routine cranberry practices; proper timing of the organic fertilizer on cranberry bogs; and use of lower doses to capitalize on the efficiency of the fertilizer [DeMoranville 1992].

Phosphorus [Roper et al. 2004] and nitrogen [Davenport and Vorsa 1999] are important elements of interest in Massachusetts due to increased concern for protection of water quality, both on state and federal levels [DeMoranville 2006]. The development of BMP for nutrient management was identified in the 1990s as a way to help address some of these concerns. Outcomes from the research initiative included that once established and consistently producing good fruit yields, cranberry vines need low rates of phosphorus to complete their life cycle and maintain a healthy vine canopy [Davenport et al. 1997; DeMoranville and Davenport 1997]. Another study that focused on the discharge of nitrogen and phosphorus from cranberry bogs concluded that discharge was primarily associated with flooding [Howes and Teal 1995]. Data from DeMoranville (2006) showed that describing the flow and discharge of nutrients through the cranberry system can be complex and thus, the need to field test potential nutrient management BMP recommendations is an area for future research.

CHANGING DEMOGRAPHICS AND THE FUTURE OF CRANBERRRY PRODUCTION

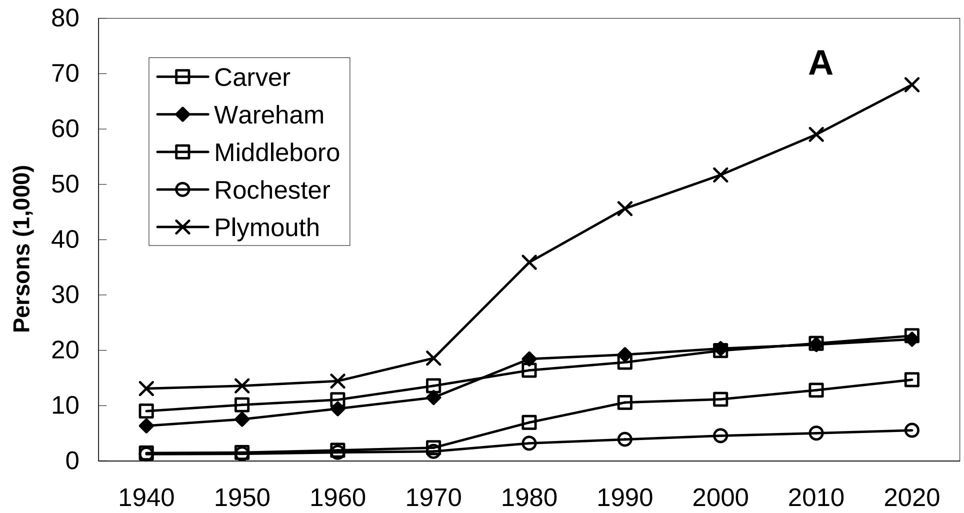
Population Growth: The five towns with the greatest cranberry acreage in Massachusetts are found within Plymouth County: Carver (1,375 producing ha), Wareham (650 ha), Middleboro (565 ha), Plymouth (485 ha), and Rochester (445 ha) (Fig. 3).

According to the most recent census, Plymouth has the largest land area of the five towns (250 km^2) and the second highest population density (207 persons per km^2) [Plymouth County 2007]. Middleboro is the next largest town of the group with a land area of 176 km^2 and a population density of 113 persons per km^2. The towns of Carver, Wareham, and Rochester are approximately the same size in land area (93 km^2) but vary in population density. Wareham has the highest density of the five towns with 219 people per km^2; Carver is half as densely populated at 113 people per km^2 and Rochester is half again less dense at 49 people per km^2 [UMass Donahue Institute 2005].

Figure 3. Distribution of cranberry farms in the towns of southeastern Massachusetts ca. 2000. Each mark represents one farm, regardless of size. Map courtesy of the Cape Cod Cranberry Growers' Association.

Populations in the five main cranberry towns are projected to increase. Carver and Plymouth are projected to have a 30% increase in per capita density (people per km^2) from the year 2000 to 2020 (Fig 4A). Within the same time frame, Rochester, Middleboro, and Wareham are projected to see increases of 21%, 14%, and 8%, respectively. Although land in cranberry represents a small percentage of the total land in these towns, increases in population density in the towns overall translates into more population pressure on the limited farm acreage. The greatest percentage is held in Carver where 15% of the land area of the town is in cranberry production (see State Map). Land holdings drop off quickly as cranberry accounts for 7%, 5%, 3%, and 2% of the land in the towns of Wareham, Rochester, Middleboro, and Plymouth, respectively.

Population censuses have documented the town of Plymouth as having the highest population of the five towns, growing from 13,100 persons in 1940 to 51,700 persons in 2000 (Fig. 4A). The number of people per hectare of producing cranberry in Plymouth increased from 27 to 106 for the same time period. Estimates show an increase of 32% during the period 2000-2020 such that it is projected that within the next 13 years, there will be 147 persons per hectare of producing cranberry in the town of Plymouth.



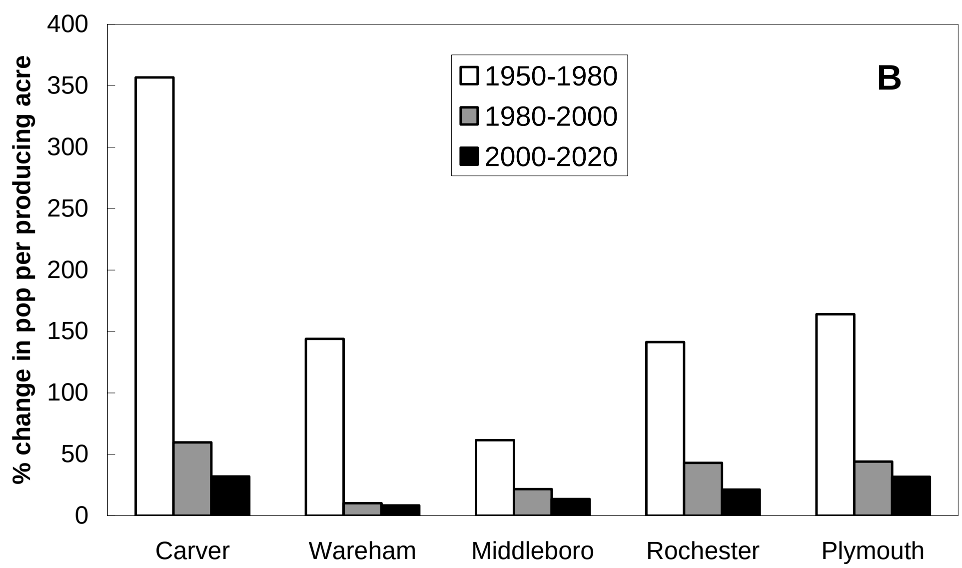


Figure 4. A) Number of persons in five towns in Plymouth County, MA, from 1940-2000 (actual) and for 2000-2020 (projected) in Massachusetts. Selected towns represent the top five towns in terms of number of hectares. B) Percentage change in population per producing hectare in five Massachusetts towns for three time periods, 1950-1980, 1980-2000 (actual) and 2000-2020 (projected).

The town of Carver has seen the greatest population growth per hectare of cranberry production in the past 65 years (Fig. 4B). In the thirty years from 1950 to 1980, the change in population per hectare of producing cranberry bog increased over 350% from 1.1 persons to just over 5 persons. The census during the years 1980-2000 showed an increase of 60%, up to 8.1 persons per ha; projections for the year 2020 estimate almost 11 people per ha. Carver had substantial increases population density per ha of cranberry in the 1970's and 1980's, with 190% and 52% increases, respectively.

After Plymouth, Middleboro is the town with the next highest density of people per cranberry hectare. In 1950, Middleboro had 18 people per hectare of cranberry; projections estimate the density will more than double by 2020, reaching 40 people per ha. Wareham is expected to reach a similar density by 2020. Rochester is projected to have the lowest density of the five towns (12.5 persons per ha) by 2020, but this is still an increase of 245% since 1950. Unlike the other towns, Middleboro saw its greatest percentage increase in population during the 1960's (23%); the other four towns had their greatest percentage increase in the 1970's (approximate increases for the towns of Carver: 190%; Plymouth: 90%; Rochester: 80%; and Wareham 60%). Middleboro has the smallest percentage increase in terms of the change in the number of people per ha of cranberry bog for the period of 1950-2000, but even still, the density almost doubled during the 50-year period.

The impact of rapid development of the region on future cranberry production is apparent as one drives through the towns with cranberry acreage. The most prominent trend is that new houses are being built within close proximity to the active production area with many of the new homes being constructed on the surrounding uplands of the cranberry farm. A recent report [Woods Hole Research Center 2007] noted that some very large residential developments are partially completed (e.g., a complex in the town of Plymouth that includes up to 2900 homes, 1255 ha, with 72 ha of business and commercial land) or are being planned (e.g. in the towns of Carver and Plymouth, 6000 homes utilizing 3900 ha, and 557,600 square meters of commercial space). Substantial development is occurring in the heartland of cranberry production.

One could argue that new neighbors are moving close to cranberry areas due to choices made by the growers themselves. Massachusetts cranberry growers typically own 3.75-6.25 ha of uplands for every hectare of cranberry bog. The economic downturn that occurred in the cranberry industry at the turn of the 21st century forced a portion of growers to make difficult pest management [Sandler 2002], business, and personal decisions just to remain economically viable. Some had to leave farming for other careers (either temporarily or permanently) and some opted to sell their non-farm property to developers to obtain necessary income. The sale of these proximal properties will have long-term impacts on the dynamics that develop between the farmer and the resident.

Those involved in any aspect of research, production, and handling of cranberries are well aware that future population growth in Southeastern Massachusetts will increase the interface of the general public with the pest management and crop production activities conducted by cranberry growers compared to that seen in the past. The pressure comes not only from the fact that proximal properties are being sold but also that many people are leaving the urban centers of Boston and Providence to find more affordable housing in neighboring bedroom communities. This has encouraged development throughout Plymouth county, not just in towns with cranberry production. It is not unreasonable to project that the owners of the homes on the uplands and surrounding properties of cranberry farms will likely want a greater say in the activities that occur on the farm. Future extension efforts will undoubtedly focus on the distribution of information about how cranberries are grown to people who are not familiar with living near agricultural businesses.

The Evolving Cranberry Grower: Additional elements that will affect the character of the Massachusetts cranberry industry include long-term farm planning and the demographics of the current cranberry grower. At the turn of the 21st century, cranberry growers were in the latter part of middle age (33% aged 50-59 years and 27% aged 60 or over), educated, (48% with college and 11% with graduate education), full-time (63%), and experienced (34% with 11-20 years and 12% with 20 or more years). Unlike other cranberry regions in North America, most Massachusetts growers own small farms. Forty-seven percent reported farming 4 ha or less, one-third farmed 4 to 16 ha, while 21% reported farming more than 16 ha [Blake et al. 2007].

Many production pest management decisions are made based on current knowledge and past experience. The successful transfer of farmland from older to younger growers is of great concern for cranberry growers and other agricultural businesses in the state. Massachusetts agriculture, including cranberry, is sustained by its family farms. More than 80% of Massachusetts farms are family-owned and over 93% fit the category of small farms according to the USDA definition of sales below $250,000 U.S (SEMAP fact sheet). However, the majority of the institutional knowledge of cranberry management is unlikely to transfer to the next generation. Only one-quarter of growers from a recent survey said their children will take over the farm. Notably, almost half of the respondents had no idea who would inherit their farm and almost one-fifth did not even answer the question [Ganim-Barnes 2006].

Additional questions gathered information about cranberry growers' long-term plans for their farms [Ganim-Barnes 2006]. Most wanted to keep their land in farming if possible but a substantial portion of the respondents were unsure about the fate of their farm. One-third reported they will sell their farms for cranberry farming and 20% will continue in family farming. Another third did not know what will happen to their farms or had no response; 10% said they intended to sell land for development at some point in the future. The overwhelming majority of growers had no intention of abandoning productive acres, but 5% reported they will abandon a portion of their farm property in the next two years. The survival of the small family cranberry farm will depend upon how growers transfer their property, as well as to whom, if anyone, they transfer their knowledge.

Ganim-Barnes (2006) also queried growers as to their feelings on several aspects of technical assistance and research. Eighty-one percent said pesticide research was very important, followed by 48% citing environmental research and 41% citing horticultural research as very important. Equipment development and alternative cropland use were deemed very important by 25% or less of the respondents. Clearly, pesticides are still considered critical to current success and future productivity. However, growers are mindful of the encroaching interface between their farms and the growing population and cited environmental research as another very important factor that should be supported by the industry. Future research efforts will constantly try to resolve pest management issues by bridging the growers' need for profitable and responsible food production with the public's desire for a pleasing environment to live and raise their families.

CONCLUSION

Integrated pest management implies more than the application of chemicals at the appropriate time against the correct target pest. Knowledge of the pest's life cycle, symptoms, as well as the conditions that predispose the cranberry to infection or infestation contributes to effective management of cranberry pest problems. Implementing cultural practices, such as flooding and sanding, broaden the baseline defense against crop loss due to pest pressures. Many biological control opportunities exist for cranberry pest management but logistical obstacles, such as problematic production and distribution of reliable commercial compounds, prevent widespread incorporation of these strategies.

Cranberry growers and researchers face many challenges at the beginning of the 21st century. As environmental concerns continue to limit the availability and application of conventional (registered) pesticides, the incorporation of new chemistries and reduced risk compounds, along with biological and cultural control measures, into routine pest management programs will become even more crucial. Sustained population growth in the southeastern region of Massachusetts will put increased pressure on the farming community. The future of the cranberry industry will be shaped by many factors including the physical transition of farms and the intellectual transfer of pest management knowledge and experience from the present generation to the next.

Cranberry research has had a long history in Massachusetts. University, federal, provincial, and private industry scientists made significant contributions that allowed the industry to establish and survive, and even flourish especially in the latter part of the 20th century. For the foreseeable future, a small group of cranberry scientists remain dedicated to generate critical data that support the development and implementation of new pest management knowledge. The next generation of cranberry growers must be active participants in the learning and research process. Limited economic resources will surely press on the industry and the scientific community alike. Cooperation and collaboration between these groups will assist in the generation of pertinent observations and the design of appropriate experiments to address important issues. Ultimately, the outcome will be applied pest management and horticultural techniques that allow the farmer to grow cranberries in a sustainable and profitable fashion, while helping to preserve the environmental integrity of the open space acreage that is critical to the quality of life in Southeastern Massachusetts.

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