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Cranberry Production Guide

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CRANBERRY PRODUCTION
A Guide for Massachusetts

University of Massachusetts Cranberry Station
College of Natural Resources and the Environment
East Wareham, MA

CRANBERRY PRODUCTION: A GUIDE FOR MASSACHUSETTS

Editors
Hilary A. Sandler and Carolyn J. DeMoranville

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Portions from the previous publication (SP-127) listed below have been updated slightly by the editors, but the initial authors' names continue to be associated with their original work:

Wildlife Utilization by S. Ellsworth and D. Schall of ENSR, Inc. Northborough, MA.
Wetlands Functions by G. Hollands, ENSR, Inc., Northborough, MA.

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Preface

The cranberry industry is important economically and aesthetically to the Commonwealth of Massachusetts. Although cranberry growers currently cultivate ca. 14,000 acres, they own more than 60,000 acres of land in the state. In the most recent survey, the cranberry industry accounted for 5,500 jobs and $2 million in payroll (Cape Cod Cranberry Growers' Association, pers. comm.). Earnings from the 2007 harvest were valued at ca. $64.6 million for 1.51 million barrels (one barrel =100 pounds of fruit) produced from 13,700 acres. Growers harvested an average of 109 barrels per acre during the 2007 growing season. The Massachusetts industry accounted for 23% of the total domestic production (6.4 million barrels) in 2007. Wisconsin is the largest producer of cranberries in the United States (usually >50%). Massachusetts and Wisconsin combine to produce over three-fourths of all U.S. cranberries.

In recent years, potential, new, and experienced growers have expressed interest in obtaining additional information relating to the modern practices associated with cranberry cultivation and production. In addition, there seemed to be a need for a comprehensive resource containing an array of technical information and historical perspectives that have formed the foundation of many of our management recommendations.

This document (CP-08) contains relevant sections of two former publications: Modern Cranberry Cultivation (a.k.a. SP-126 and SP-127 published in 1987 and 1997, respectively) and Massachusetts Cranberry Production: An Information Guide published in 1993. Selected sections from these publications have been revised, enlarged, and reorganized to reflect current industry knowledge and to incorporate recent research.

The intent of this publication is to provide the wide range of Massachusetts growers with a comprehensive, but workable, reference of cranberry production practices. It is our hope that the information contained in this manual will provide each reader with succinct and relevant information that will guide their daily decision-making in the field.

Anyone interested in the details of cranberry growing will benefit from the information presented in this publication. An extensive bibliography of historic and current research information is available at the back of the publication. For specific management recommendations, especially for pest control, please consult the Cranberry Chart Book. The Chart Book is updated yearly and is available as printed copies from the Cranberry Station by request and on the Cranberry Station web site in downloadable PDFs.

Other interested parties, including conservation commissioners, agriculture commissioners, public officials, and real estate agents, who may only be interested in a brief description of cranberry management practices (in lieu of trying to skim some of the more lengthy articles for general information), may wish to obtain a copy of the Executive Summary of this manual. Copies of the Executive Summary are available through the University of Massachusetts Cranberry Station or the Cape Cod Cranberry Growers' Association.

Introduction

The large American cranberry (*Vaccinium macrocarpon*) is a native American wetland fruit. Its vines thrive on the special combination of soils and hydrology found in the wetlands environment. Natural bogs evolved from glacial deposits that left kettle holes lined with impermeable materials. These kettle bogs became filled with water and decaying matter, creating the ideal environment for cranberries.

It takes more than a bog to grow cranberries. They also rely on a surrounding network of support acres - the fields, forests, streams, and ponds that make up the cranberry wetlands system.

Cranberry growers typically own 3-5 acres of uplands or surrounding lands for every acre of producing cranberry bog that they manage. This means Massachusetts cranberry growers are the stewards for more than 60,000 acres of open space. This open space is an important ingredient to the regional character that is so appealing to many residents of Southeastern Massachusetts. The vast cranberry system offers refuge for many plant and animal species. Like all wetlands, the cranberry wetlands system filters groundwater, recharges aquifers, and controls floods by retaining storm water runoff (Johnson 1985).

Many cranberry beds, particularly those located in Plymouth County, are built in areas that had been mined for bog iron. Bog iron, although a low grade ore, helped to establish the first iron industry in the country. When the steel industry in the Great Lakes region started to produce greater amounts and higher quality iron less expensively, iron manufacturing in Massachusetts declined. Subsequently, abandoned and apparently useless bogs became readily available for conversion to producing cranberry bogs (Thomas 1990).

Whereas cranberry production on Cape Cod has been mostly restricted to development of peat bogs, the abandoned iron ore bogs on the mainland were reclaimed by the rapid expansion of cranberry production. Both types of bog reclamations contributed to the development of a unique industry.

Production Statistics. Most of the world's cranberries are produced in the United States on approximately 39,000 acres. The traditional yield unit is the barrel, which is equivalent to 100 pounds. In 2007, the U.S. produced 6.395 million barrels of cranberries (Farrimond 2005) The predominant U.S. production areas are Wisconsin, Massachusetts, New Jersey, Oregon, and Washington. Limited commercial acreage can also be found in Rhode Island, Maine, New York, New Hampshire and Michigan (D. Farrimond, pers.comm.). These states typically combine to produce less than 1% of the U.S. production. Cranberries are also commercially cultivated in other countries including Canada (British Columbia, Quebec, and the Atlantic Provinces combine for about 10,000 acres) and Chile (1,000 acres). Fruit produced outside of the U.S. accounted for 19% of the world's production in 2006).

The cranberry industry is very important economically to Massachusetts, particularly in the southeastern region of the state. In 2007, sales of cranberries were valued at $70.9 million (National Agricultural Statistics Service 2008b), accounting for 16% of the cash farm receipts in Massachusetts (National Agricultural Statistics Service 2008a). Cranberry production is the third largest agricultural commodity in Massachusetts, following greenhouse 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 (Cape Cod Cranberry Growers' Association, pers. comm.).

Until the mid 1990's, cranberry growers from the combined area of southeastern Massachusetts, the Cape Cod peninsula, Martha's Vineyard, and Nantucket, led the industry worldwide in total production and total harvested acres. Since then, Wisconsin has taken the lead in terms of acreage and production, and Wisconsin produces most of the nation's cranberries (Table 1). Currently, Massachusetts and Wisconsin account for more than 75% of the U.S. cranberries in a typical year.

Table 1. 2007 Crop statistics for U.S. production.

State	Acres	Production (1,000 bbl)	Yield (bbl/A)
WI	17,600	3,710	211
MA	13,700	1,488	109
NJ	3,100	531	171
OR	2,700	490	182
WA	1,700	176	104

Source: New England Agricultural Statistics, Jan. 25, 2008.

Five towns, all within Plymouth County, account for approximately two-thirds of cranberry acreage in Massachusetts: Carver (3,400 A), Wareham (1,600 A), Middleboro (1,400 A), Plymouth (1,200 A), and Rochester (1,100 A) (Cape Cod Cranberry Growers' Association, pers. comm.).

Payment for crops. Cranberry growers usually enter into a multi-year contract with a company (handler) that will agree to buy their fruit. Growers are paid for their crop in terms of number of barrels. The price per barrel can be paid out to the grower in a variety of ways, depending on the contract. They can receive additional payments if their fruit has good red color (anthocyanin content) and excellent quality. Growers' crop payments may be reduced if their fruit is delivered with too much rotted fruit. Production efficiency is related to the number of barrels produced per acre. Harvest success is usually gauged upon the year-to-year comparison of the number of barrels produced from each particular farm.

Fig. 1. Traditional cranberry barrel. Yields are currently expressed as 'barrels', which are equivalent to 100 pounds. Photo courtesy H. Sandler.

Botany and Basic Farm Features

Hilary A. Sandler

BOTANICAL DESCRIPTION

Nomenclature. Cranberry belongs to the Ericaceae or heath family, to which plants in the genera *Rhododendron* and *Kalmia* (laurels) also belong. Members of this family prefer acidic soils (pH 4-5) that are moist, well drained and high in organic matter (3-15%). Cranberry is usually placed in the genus, *Vaccinium*, which has 22 species including lowbush blueberry (*V. angustifolium*), bog bilberry (*V. uliginosum*), and lignonberry (*V. vitis-idaea*) (Gleason and Cronquist 1991). Some botanists place cranberry in the genus, *Oxycoccus*, leading to some confusion in the literature with regards to nomenclature. For the purposes of this manual, we will refer to cultivated cranberry by the genus, *Vaccinium*.

The American or large-fruited cranberry, *V. macrocarpon*, is the most commonly cultivated cranberry. Its native range extends from Maine and the Atlantic Provinces to northern Illinois, and south to Tennessee (at high elevations). *V. vitis-idaea* is known by many names including partridge berry, mountain cranberry, and lignonberry and is widely distributed (mainly circumboreal). The small or European cranberry *V. oxycoccus*, has smaller leaves, flowers, and fruit and is not cultivated in North America (Eck 1990; Gleason and Cronquist 1991).

Vine and Leaves. The cultivated cranberry is a low-growing, trailing, woody, broadleaf, non-deciduous vine (Fig. 1). When the vines successfully colonize an area, they form a thick, continuous mat over the entire surface of a cultivated bed. Stolons, often referred to as runners, will range from one to six feet long. The leaves are leathery, subsessile, and elliptical-oblong (5-15 mm), and rounded at the tip (Gleason and Cronquist 1991). They are reddish-brown during the dormant season (October through April) and dark green during the growing season.

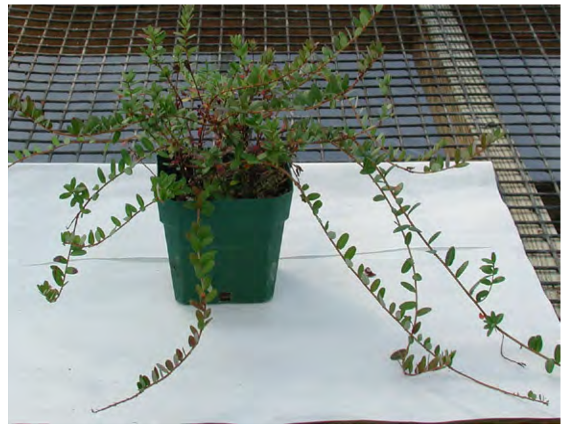

Fig. 1. Cranberry uprights and runners, approximately 2 years old. Photo courtesy K. Demoranville.

Uprights and Buds. Short vertical branches two to eight inches high, called uprights, originate from the axillary buds on the runners (Fig. 2) and grow for several years (Shawa et al. 1984; Eck 1990). The uprights are distinguished from runners by the whorled arrangement of their leaves and their vertical growth habit. Cranberry uprights can produce two types of buds: flowering (fruit) and vegetative. Flowering buds, also known as mixed buds, are easily recognized by their large size and plump appearance. The rosettes of leaves enclosing a fruit bud are saucer-shaped. In contrast, the vegetative bud is more pointed, and the leaves are more upright and tend to envelop the bud. The scales (or leaves) tend to look loose. The vegetative bud is often smaller than the fruit bud.

Roots. The cranberry root system is made up of very fine, fibrous roots that develop within the upper three to six inches of soil. Cranberry roots do not have root hairs. Cranberry vines are aided in the absorption of nutrients by a symbiotic relationship with mycorrhizal fungi

(Addoms and Mounce 1931). These fungi are known as ericoid mycorrhizae and primarily assist in the absorption of organic forms of nitrogen by the plant.

Fig. 2. Diagram of the principle parts of the cranberry plant including vegetative uprights, uprights with flowers and fruits, and the woody runner to which the uprights are attached (Beckwith 1932).

Flowers. Flowering buds are formed terminally on the uprights and become easily visible during the summer or early fall. Each fruit bud may contain two to seven flowers as well as leaves and a growing point. The plants come out of dormancy in April (depending on weather conditions and nutritional status) and begin to develop new leaves in late May. The flowering period begins during the middle of June and lasts from three to six weeks. The first berries are visible in late June or early July. The curve of the slender flower stem with the ready-to-open blossom is said to resemble the neck and head of a crane, hence suggesting the name, 'craneberry', which is now shortened to cranberry.

The cranberry flower is self-fertile, that is, the pollen from a given flower can fertilize the egg from the same flower. Agitation or wind can lead to successful pollination, but usually at very low rates (Filmer and Doehlert 1959). Cross-pollination (pollen from one flower fertilizes the egg in a different flower) produces bigger fruit with increased seed count (Marucci and Filmer 1964). Thus, most growers use honeybees and/or bumblebees to increase the chances of cross-fertilization and the production of large fruit.

Fruit. Berries are almost always produced on the uprights, although in some varieties under certain conditions, fruit may be produced on runners. Berries (and flowers) mature from the 'bottom up', so the largest fruits will be found towards the bottom of the upright and the smallest fruits will be towards the top (Fig. 3). The first fruit that form tends to be the largest because it preferentially draws the plant's carbohydrates to itself (Baumann and Eaton 1986; Birrenkott and Stang 1990). Berries reach maturity about 80 days after full bloom. Harvesting typically begins around mid-September and continues through early November.

Fig. 3. Cranberry uprights with flowers, pinheads, and fruit. Photo courtesy J. Mason.

Yield Components. Two components are considered particularly important for determining yield: number of fruit per upright and number of flowering uprights per unit area (Eaton and Kyte 1978; Eaton and MacPherson 1978). Percent fruit set varies among cranberry varieties but typically falls in the range of 25-45%. If a farm has 200 flowering uprights per square foot and produces 1.5 berries per upright, the resulting crop would be approximately 300 bbl/A (DeMoranville 2008).

BASIC FARM FEATURES

Cranberry beds in Massachusetts range from less than one acre to more than one hundred acres in size. They tend to be very irregular in shape since they typically follow the contours of kettle hole formations or abandoned iron ore bogs (Deubert and Caruso 1989). The bog area is typically the lowest part of the landscape. It is comprised of perimeter and interior drainage ditches and dikes that can readily contain water (Fig. 4). Due to the periodic need for flooding, beds 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.

Fig. 4. Aerial view of cranberry farms in southeastern Massachusetts. Photo courtesy J. LaFleur.

Water Control Structures. Growers need to manipulate water during the course of the season for a variety of reasons. These structures help to flood the beds, impound water, manipulate the water table, and provide drainage. The primary water control structures are flumes, dikes, and pumps (DeMoranville and Sandler 2000b).

Flumes are water control structures normally made from steel, aluminum or concrete (Fig. 5). They are installed in a dike to convey water, control the direction of flow or maintain a certain water elevation. Flumes may be fitted with filters containing activated charcoal to help filter discharge water under certain situations.

Fig 5. Flume with riprap. Outlet canal in back. Photo courtesy CCCGA.

Tailwater (relating to excess surface water) recovery systems and holding ponds are used to hold, recycle, and conserve water within the cranberry bog system. Systems are typically designed so gravity can be used to move water either on or off the bog. On flow-through beds (those containing a permanently flowing stream or constant water discharge), a bypass canal may be constructed to re-direct water during normal agricultural practices.

Dikes are embankments constructed of earth or other suitable materials to protect land against overflow or to regulate or contain water. They subdivide large bogs into smaller sections to facilitate water and pest management. Dikes are usually wide enough to permit the use of trucks and other machinery. Dikes are used to temporarily impound water for harvest, leaf litter removal, pest control, and protection against winter injury. Dikes can also be used to impound water for the preservation of water quality, limiting the discharge of sediments, and separating waters following a pesticide application. Dikes allow the control of water levels to maintain the depth from rooting zone to water table for optimum cranberry growth and productivity. Dikes can also surround tailwater or other irrigation ponds to facilitate water storage.

Pumps are usually located next to the water resources and typically housed in a small shed. The shed protects the pump from weather, helps to minimize noise, and limits vandalism.

Sprinkler Systems. Sprinkler systems are used for irrigation, evaporative cooling, frost protection, and chemigation (application of chemicals through the irrigation system). Irrigation systems typically consist of buried lateral pipes (PVC or metal) with risers attached at various spacings. Growers typically employ impact-style sprinkler heads (e.g., Rain Bird equipment). In the past few years, growers have begun to convert to the use of pop-up heads, similar to those used in lawns and golf courses. Almost all growers have adopted the use of sprinklers. S prinkler systems conserve water and perform the desired tasks much faster than flooding (the historical practice).

Cranberry Soil. Cranberry bog soil is unique because it consists of alternating layers of sand and organic matter (Fig. 6). D ead leaves (also referred to as trash or duff) accumulate over the course of time and sand is placed on top of the organic material every two to five years to encourage upright production and maintain productivity. The amount of sand that may be applied during this essential cultural practice varies from one-half to two inches.

In contrast to regular agricultural soils, cranberry bog soil needs no tilling, remains undisturbed over time, and little mixing of sand and organic matter takes place. T hus, alternating layers of sand and organic matter accumulate producing a ‘layer-cake effect’. One can often estimate the age of a cranberry bog by counting the layers of sand and organic matter in the soil profile.

Fig. 6. Soil core showing the alternating layers of sand and organic matter typical of a commercial cranberry farm. Photo courtesy H. Sandler.

Flags. People often notice the use of flags on commercial cranberry farms. Flags are used to mark the center line, which helps growers efficiently harvest fruit when the vines are under water. Flags can be used by researchers to mark the edges of plots for their experiments. Growers may also use flags to mark certain areas that have pest management or other production concerns.

Weather Stations. Some growers install weather stations on their farms to allow data collection of temperature, wind speed, relative humidity, and soil temperatures. T he information is usually downloaded to a computer or laptop or may be accessed by hand-held devices.

Descriptions of Cranberry Bogs in Massachusetts

Carolyn DeMoranville

PEAT-BASED BOGS

Bogs may form in any location where water collects and organic matter accumulates. In Massachusetts, bogs formed following the end of the last Ice Age as the glacier that reached as far south as Long Island and Nantucket Island melted and receded. As the glacier receded, outwash plains of glacial till were left behind. Sometimes blocks of ice that had broken from the glacier were left on or buried in the outwash. As large blocks melted, ponds were created. As smaller blocks melted, pits called kettle holes were formed (Fig. 1). Fine-grained sediments in these holes stabilized the water table and aquatic plants began to grow in from the edges, eventually filling the kettle holes. Over time, plants died, decaying plants accumulated, organic sediment layers formed, and a kettle-hole bog was created. Such bogs may consist of an entirely filled kettle hole or a partially filled kettle hole. The later would have the appearance of a bog adjacent to a pond (Johnson 1985).

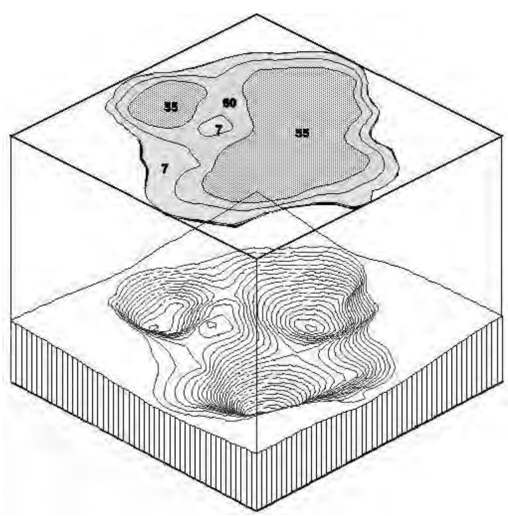

Fig. 1. Reproduction of a ground penetrating radar image of UMass State Bog showing kettle hole formations. Three soil types are depicted. Image courtesy Plymouth County Soil Survey, http://www.nesoil.com/gpr/bogs.htm.

When rapid melting of the glacier occurred, outwash channels were cut into the outwash plain. Later, as flow through the channels slowed, vegetation began to grow along the banks. Over time, the plants filled in the channel creating a wetland. These wetlands were of two morphologies, those with streams running through them that ended in an adjacent pond and those where the stream continued on to another wetland and eventually to a pond or the sea. Many Massachusetts bogs are of this type, although this may be difficult to recognize due to the construction of adjacent reservoirs built by cranberry growers and the construction of bypass canals to remove the stream flow from within the bog (Deubert and Norton 1987). So-called 'flow-through' bogs are of this type with the stream remaining within the bog.

Over many years, plants grew in these wetlands and kettle holes then died and decayed. Organic acids were released during decomposition and so the pH in the bog decreased. Oxygen was limited in the sediment layers and so decomposition slowed as the sediment layer thickened. The deepest, most decomposed organic layers became sedimentary peat or muck, while the upper layers remained less decomposed fibrous peat.

What are now peat-based cranberry bogs in Massachusetts (Fig. 2) originated in these peatlands. Under these peat deposits lies an impervious layer that originated at the end of the last Ice Age. This impervious layer, or hardpan, makes it possible to flood these bogs for extended periods. This layer also serves to separate these bogs from the natural water table. Some cranberry bogs in Plymouth County are built on abandoned iron bogs, where the hardpan is a layer of iron oxide materials.

Deubert conducted a series of test borings to determine the depth to hardpan in cranberry bogs (Deubert and Caruso 1989). He pushed half-inch metal tubes, eight feet in length, through the soil in small peat-based cranberry beds in the Sandy Neck Dunes in an attempt to find the depth of peat in the various parts of the beds. In areas of poor productivity, the hardpan was either near the surface (less than 2 feet) or missing, while in the productive areas, the depth to hardpan averaged 7 feet. In this setting, the impermeable layer consisted of a yellowish-brown clay.

Fig. 2. Typical cranberry farm in Massachusetts. Photo courtesy H. Sandler.

Beginning in the 1990s, Doolittle, Fletcher and Turenne implemented the use of ground-penetrating radar (GPR) to estimate the depth of peat under many Massachusetts cranberry bogs. This device allows the study of bogs much deeper than the 8-foot depth limit of Deubert's study. The GPR method showed that bogs that developed in kettle holes or in outwash channels tend to have shallow layers of peat along the perimeter with substantial depth of peat near the bog centers (Doolittle et al. 1990). The GPR also showed the presence of the impermeable layer under these bogs.

Studies of natural bogs have shown that water saturates the lower layers of the peat. Wetting and drying cycles appear to be limited to the upper layers where living vegetation occurs. This would seem to indicate that vertical movement of water and dissolved chemicals is minimized in peat bogs, including peat-based cranberry bogs. However, there is considerable evidence that water can move horizontally in the upper layers of a cranberry bog. Growers take advantage of this property when they move moisture into the upper layers of their bogs by raising the water level in the drainage ditches. Conversely, drainage and root-zone aeration are achieved by lowering the water level in the ditches. By combining ditch level manipulation with sprinkler irrigation, cranberry growers maintain the water table within the bog (above the impervious layer) at the ideal level of 6 to 18 inches below the surface, allowing water to reach the roots but maintaining good aeration in the root zone (Fig. 3).

Peat-based cranberry bogs differ from natural bogs in that the upper layers of natural vegetation have been removed, the soil has been modified by the addition of a sand layer, and cranberry plants have been introduced. Not only are the cranberry plants separated from the natural groundwater table by an impervious layer, they are often also separated from the stagnant water in the underlying peat. Thus, cranberry bog soils are subject to desiccation as would be any other agricultural soil. This explains the need for extensive irrigation (0.5-2 acre-inch per week) during drought periods. While manipulation of ditch levels can move water into the upper soil layers, research has shown that during dry periods, the water table in the bed centers (furthest from the ditches) can drop below the ideal 18 inches and plants in the bed centers can suffer drought injury as a result (Fig. 3).

As one might expect, there are exceptions. Some cranberry bogs are situated in depressions such that water from surrounding uplands drains into them. Others have upwelling springs within the bog. Such ‘wet bogs’ must be drained periodically so that air can reach the roots for proper growth.

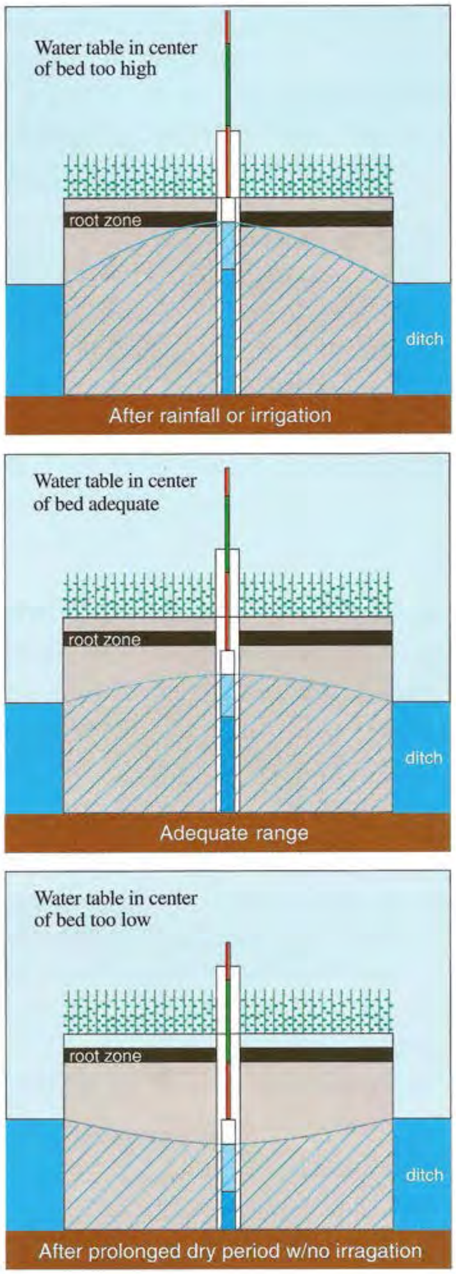

Fig. 3. Change in water table level in three scenarios. (Top) The level of the water table is too high; no irrigation needed and consider lowering ditch water levels. (Center) Float is in middle zone and no irrigation is needed. (Bottom) Middle zone of float is no longer visible, irrigation is needed to replenish water table. (Lampinen 2000).

MINERAL SOIL BOGS

Regulatory restrictions on development of new cranberry bogs in wetlands has resulted in a limitation on the sites where new bogs may be constructed. While renovation of existing wetland cranberry bogs is permitted, new acreage is restricted to non-traditional settings, typically uplands. As in the wetland bogs, an ample supply of good quality fresh water, adequate drainage of the bogs, and the ability to hold a flood to cover the cranberry vines are essential to successful cranberry production on mineral soils.

When bogs are constructed on mineral soils, the site is engineered to provide suitable hydrology and soil characteristics to mimic those in traditional wetland settings. Adapting the existing site hydrology to one that supports cranberry production may require manipulation of the water table, soil permeability, soil texture, and soil organic carbon content. The objective is to create a cranberry bog that can be managed using many of the same techniques used on peat-based bogs. In order to accomplish this objective, a slowly permeable subsoil layer (water confining layer) is placed so that a ‘perched’ water table is created at some distance above the true water table. An organic layer is placed above the confining layer with the sand planting medium on top. Such a construction design is shown in Fig. 4.

Water confining layer. A continuous, confining layer of sufficient density and thickness to restrict water permeability is constructed below the root zone of the cranberry bog, extending beneath the drainage ditches and into the interior of the dikes (Fig. 4.). This layer is necessary to flood for winter protection and harvest, to hold soil moisture reserves in the summer, and to minimize leaching. Examples of this layer include compacted fine soils such as clay or relatively impermeable sub-soil such as dense basal glacial till, glacio-fluvial clays, or ironstone (‘bog ore’) hardpans that may occur naturally on site.

Organic confining layer. This layer is placed above the confining layer and is 12 or more inches thick with at least 5% organic carbon (8.5% organic matter). Its purpose is to confine fertilizers and pesticides within the bog and to facilitate water relations in the perched water table. The best choices for this layer are peat or muck (20% organic carbon). The next best choice is to amend low-organic soil with organic materials containing humus (peat, muck, organic ditch dredgings, renovation sediments, yard compost, decomposed wood waste). Organic debris, including material scalped from the bog surface during renovation, can be composted and re-used as organic liners on new bogs.

Planting medium. The root zone should consist of about 6 inches of coarse sand (>70% in the 0.5-2 mm particle size range) to insure adequate drainage and aeration.

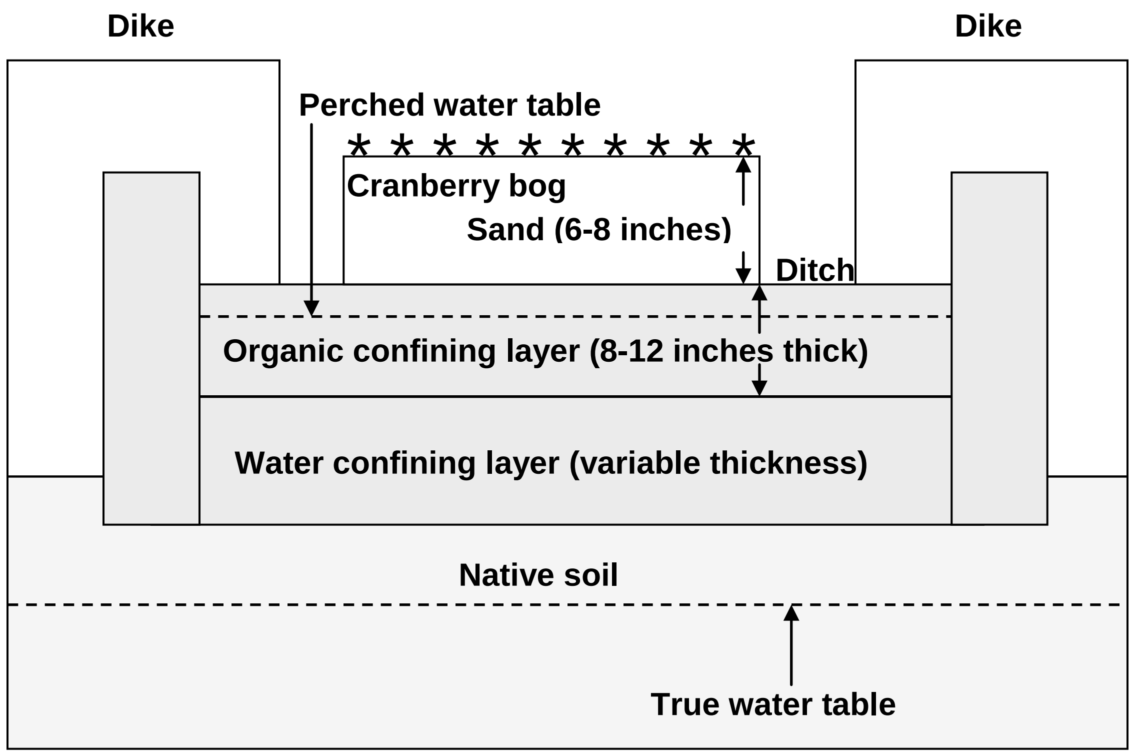

Fig. 4. Cross-section of a cranberry bog constructed in mineral soil, not to scale. Organic and water confining layers create a perched water table. Diagram courtesy C. DeMoranville (DeMoranville 2006).

Properties of Bog Soil

Carolyn DeMoranville

Cranberry bog soil, in commercial production, is a man-made substrate consisting primarily of sand. In the root zone of well-established Massachusetts cranberry bogs, organic matter makes up less than 3.5% of the soil; silt and clay combined may account for as much as another 3%; the remaining particles are sand. In these mature bogs, the soil is stratified or layered, with layers of almost pure sand alternating with organic layers composed of partially decomposed leaf litter and non-functional roots (Deubert and Caruso 1989). This layering arises due to the common cultural practice of applying sand to the bogs periodically to improve vigor and control pests. Newly established or renovated cranberry bogs have very little organic matter in the soil - they are virtually all sand in the root zone.

Cranberry bogs have been established in wetland and upland (or mineral) soils. In wetland soils, the underlying material of the bog is peat, and often an iron-containing hardpan. In mineral soil bogs, the underlying layer is formed of compacted clay, compacted silt material such as glacial till, or compacted topsoil. In all cases the underlying layer serves to hold water in the bog for flooding practices. The underlying layer also serves to separate the bog from ground water. Well-designed mineral soil bogs have a second sub-layer above the water-confining layer. This layer is composed of organic material for the purpose of retaining any pesticides and nutrients that move down through the upper sand layer.

The stratification in the root zone of the cranberry bog has an impact on the movement of water in the bog soil (Fig. 1). In tilled soils, organic matter is distributed throughout the soil profile and water tends to move almost entirely in a vertical direction. In stratified cranberry soils, water tends to move readily in a horizontal direction within the sand layers. This is of importance for maintaining soil moisture by manipulating the water level in the drainage ditches of the bog.

Fig. 1. Soil core profile the alternating layers of sand and organic matter found in many cranberry farms. Photo courtesy J. Davenport.

As mentioned previously, Massachusetts cranberry bog soil is approximately 95% sand, defined as consisting of particles varying in size from 0.05 to 2.0 mm in diameter. A comparison of 36 bog soils to the yield on those bogs showed a positive correlation between the percent coarse sand (0.5-2.0 mm) and crop production. Most likely this is due to improved drainage and decreased compaction in bogs with higher (70% or more) levels of coarse sand. When sand is added to cranberry bogs, coarse grained materials are the preferred choice.

In comparison to most agricultural soils, ideal cranberry soils are extremely acid (low pH). In an extensive study of cranberry bog soil pH in 1960 (Chandler and Demoranville 1961a), the average pH was 4.4 (range 3.3 to 5.5). When those sites were re-examined in 1990 (DeMoranville 1990) the average soil pH was

4.6 (range 3.9 to 5.9). In both surveys, more than 85% of the sites had soil pH between 4 and 5. The base saturation of cranberry bog soil reflects that acid nature - 70% or more of the base saturation is hydrogen ions (acid equivalents).

Soil pH tends to be lower in well-established bogs. In a study of cranberry bog soil chemistry (Davenport and DeMoranville 1993), pH in surficial soil from layered (established) bogs had average pH of 4.5, while sandy bogs averaged 5.0 and bogs with 10-20% organic matter content (from New Jersey and Washington) averaged 4.0.

The naturally low soil pH in Massachusetts cranberry bogs is maintained in part by the application of ammonium fertilizers and in part due to low alkalinity in local irrigation water sources. As cranberry plants take up the ammonium nitrogen from applied fertilizer, hydrogen ions are released into the soil in exchange. This process acidifies the soil. In a study of the water supplies of cranberry farms throughout North America, Massachusetts waters were the least alkaline (Hanson et al. 2000). As a result, the application of irrigation water does not affect the naturally low pH of the bogs.

Soils have the ability to hold positively charged elements (cations) due to the presence of negative charges on the surface of soil particles. This property is reported as cation exchange capacity or CEC. The negative charges that make up CEC are present on clay and on organic particles in the soil. In cranberry soil, virtually all of the CEC is due to organic matter. For this reason, mineral soil bogs and other sandy bogs (e.g., recently renovated bogs) have little ability to hold cations such as potassium, magnesium, and calcium. Even well-established bogs with an average of 3.5% organic matter have limited CEC.

As the only active soil constituent, organic matter has a considerable effect on the chemistry and physics of the cranberry bog soil. Decomposed organic material absorbs large quantities of water and slows the flow of water through the soil. In addition to providing sites for holding nutrient elements, the organic matter also traps residues of organic chemicals applied to the bog and supports the growth of soil microorganisms.

The low organic matter concentration in cranberry bog soils in Massachusetts has advantages and disadvantages when it comes to providing the proper nutritional support for the cranberry plants. Because CEC is low, fertilizer cations are poorly held leading to the need for frequent applications of low rates of fertilizer. However, organic matter also provides nitrogen through its breakdown by soil microorganisms (mineralization). When cranberry soils have high organic matter in the root zone (for example, the highly decomposed peat soils in Washington), too much nitrogen is often released, leading to excess vegetative growth of the cranberry plants and poor crops. In low organic matter soils, the grower can supplement the limited amount of nitrogen released by adding nitrogen fertilizer.

Activities on a Cranberry Farm

Hilary A. Sandler

Recent census data indicated that people are moving from urban areas to more rural areas. This is certainly true for the southeastern region of Massachusetts. More people are living in proximity to working cranberry farms and, consequently, have many questions concerning the regular activities relating to cranberry production. This chapter describes many of the management activities that occur on commercial cranberry farms throughout any given year. The activities are presented by season to establish a general chronology, but the reader should bear in mind that some practices may overlap from one season to another.

SPRING

Removal of the Winter Flood. The winter flood is usually drained from the vine canopy anytime from mid-February through mid-March. The vines will slowly break dormancy and begin to grow by mid-April.

Late Water Floods. If growers opt to use this flooding practice, the water will be pumped onto the farm by mid-April and will stay on for at least 30 days (perhaps longer, depending on location). Late water floods (Fig. 1) provide pest management benefits without the use of chemicals.

Frost Protection. Sprinkler systems are used to protect emerging buds from frost damage. Protecting buds from injury may require growers to run their sprinklers systems from early morning until just past sunrise. Protecting buds from frost injury usually starts in mid-April. Frost alerts traditionally happen into mid-June but may still occur as late as early July.

Weed Management. Preemergence herbicides are applied from late March through mid-June. Herbicides are typically applied by ground rig applicators but newer compounds can be injected through the irrigation system (chemigation). Short (24-48 hr) floods may be held in mid-May for pest management (black-headed fireworm and dodder control).

Fertilizers. Fertilizers can be applied when the soil temperatures warm to at least 50°F, so growers may be applying fertilizer any time from mid-May through late August. Depending on the vines and yield, applications may be made in the fall. Fertilizer may be applied through the irrigation system, by hand-held rotary spreaders, ground rigs, or by helicopter.

Planting New Vines. The best window to plant vines is during the month of May. However, other factors may push the planting date later into the season and perhaps even into the fall. Newly planted vines require frequent irrigation (ca. twice per day for several weeks) until new roots are established.

Fig. 1. Section of a cranberry bog with a late water flood. Photo courtesy B. Lampinen.

SUMMER

Irrigation. Cranberries require supplemental water when nature does not provide enough rainfall. Sprinkler systems will be running in the early morning or late at night to minimize loss due to evaporation. On very hot days, growers may opt to run the sprinklers during mid-day to cool the fruit and vines.

Bee Hives. Bees are used to assist in cross-pollination of cranberry flowers. Honeybee hives and bumblebee hives may be present on the farm during June through mid-July.

Fig. 2. Bee hives on a pallet ready for pollination activities. Photo courtesy J. Mason.

Scouting. Sweep netting is used to monitor insect populations from May through August. Flowers are counted in June to help time fungicide applications. Pheromone traps are set out by early June and monitored throughout the summer. Berries are inspected July through August for cranberry fruitworm eggs.

Pesticide Applications. Most pesticide applications are made from May through August. The chemicals are used to prevent serious damage to the crop by various insects and fungal pathogens. Most chemical applications are made through the irrigation system (chemigation).

FALL

Frost Protection. As in the spring, growers may need to protect the fruit from frost injury. Since fall temperatures can drop early in the evening, sprinkler systems may be started well before midnight in many cases.

Fig. 3. Scouting for insects with a sweep net. Photo courtesy J. Mason.

Harvest. Depending on weather conditions, harvest begins in September and lasts into early November. Fruit may be dry harvested and sold for fresh market (higher dollar value) or harvested in water and sold as processed fruit. During water harvest, the berries float and are corralled using floating booms. The berries are removed from the flood via a conveyor or vacuum hose. More than 90% of the cranberries in Massachusetts are wet harvested. Due to fruit rot pressure, all wet-harvested berries from Massachusetts must be sold as processed fruit.

Ditch Cleaning. Ditches are needed for moving water through the farm system. Growers will clean their ditches by hand or with machines at various times throughout the season. Mud piles can be removed with a small ATV or by helicopter.

WINTER

Sanding. The preferred method of sand application is on the ice of a flooded bog during the winter months (ice sanding). This prevents vine injury caused by sanding equipment operating on the bog (dry sanding). When the ice melts, the sand sinks slowly to the surface of the bog.

Fig. 4. Corralled cranberries in shallow harvest flood in Massachusetts. Photo courtesy J. Friedrich.

Winter Flood. The cranberry plant is dormant during the winter. The vines become reddish in color after harvest and remain that way until late March-early April. Growers maintain a flood on their cranberry farms during the winter months to prevent winterkill. Winterkill, or winter injury, occurs when the following conditions happen: 1) the root zone is frozen; 2) sub-freezing temperatures prevail day and night; and/or 3) winds of moderate velocity are present. On an unflooded bog, the plant would not be able to absorb water through the roots, and transpiration losses increase. The plants would dry out as if they were in drought conditions.

Monitoring for Oxygen Deficiency. Growers monitor their floods during the winter months to assess oxygen levels. During the winter, vines need oxygen to survive even though they are dormant. Oxygen is made available through photosynthesis, a reaction that is driven by sunlight. Oxygen levels can be especially critical if the ice on the bog becomes cloudy, or if significant snowfall on top of the ice limits sunshine penetration. When the critical level is reached, water is removed from beneath the ice to allow air to reach the plants.

Equipment Maintenance and Construction. Since cranberries are such a small industry, many equipment companies do not cater to the mechanical needs of cranberry growers. Growers must retrofit and/or manufacture many of the machines and much of the equipment that they use on the farm. Many growers use the winter months to maintain or construct equipment.

OTHER ACTIVITIES

Sign Posting. Growers are required by state and federal law to post signs around their property prior to the application of certain pesticides. Sign posting requirements change periodically. Contact the Cape Cod Cranberry Growers' Association's website for current requirements (www.cranberries.org).

Pumps. Cranberry growers run pumps to operate their irrigation system at various times throughout the year. Most pumps are housed in small sheds near the water resource. The sheds protect the pump from weather and vandalism and help to minimize noise.

Trucks. Large trucks may drive through cranberry properties at various times during the year, but are especially common during harvest and sanding operations.

Regulations of Pesticide Use and Applicator Licenses. All pesticides must be tested and registered for use by the U.S. Environmental Protection Agency and the Commonwealth of Massachusetts. Commercial users of pesticides must be licensed or certified by the Massachusetts Pesticide Bureau. Licensed applicators must attend educational programs to maintain their certifications or licenses. All certified and licensed applicators must report their pesticide usage annually to the Massachusetts Pesticide Bureau.

Cultural Practices in Cranberry Production: Sanding and Pruning

Carolyn DeMoranville and Hilary A. Sandler

Sanding is a commonly used cultural practice in cranberry production in Massachusetts (Cross and Demoranville 1969). Growers apply thin (1/2 to 2 inch) layers of sand on the surface of producing cranberry beds at 2- to 5-year intervals to promote growth, improve productivity, suppress disease and weeds, and reduce insect populations. Sanding is particularly well suited to the cranberry system. The layers of sand anchor runners and cover bare wood at the base of uprights (vertical stems), promoting rooting and the production of new uprights. Mechanical pruning can be used to improve the architecture of the canopy and remove runners. Severe pruning and mowing of the vines may be used to generate cuttings for the planting of additional acres. Although mechanical pruning can be difficult due to the trailing nature of the cranberry growth habit and the potential to remove upright tips bearing flower buds, it is becoming more popular due to the high cost of obtaining and transporting sand (Fig. 1).

Growers can improve the canopy environment with either sanding or pruning. Although both practices will give physical improvements such as increased potential for photosynthesis, better aeration, and improved vine health, each practice offers unique benefits and consequences when compared to the other. These specific differences are highlighted in the following discussion.

SANDING

Historically, sanding was probably the first practice used in cultivating wild cranberry plants. Henry Hall of Dennis, MA has been credited with being the first to observe the beneficial effects of sand on cranberry vines in 1816. He noted that sand blown from nearby dunes that partially covered the vines was associated with increased growth, vigor, and yield of cranberries. He then spread sand on wild cranberry vines, thus beginning the first cranberry cultivation.

Sanding covers the leaf litter (leaf trash) on the surface of the cranberry bog. This has several benefits, including stimulation of organic matter decomposition (nitrogen release and relief of root congestion), suppression of fruit rot fungus inoculum, and limitation of the habitat of cranberry girdler larvae that feed at the base of exposed stems (Tomlinson 1937; Cross and Demoranville 1978). Uniform applications of sand can also suppress dodder germination (Sandler et al. 1997). Sanding improves soil drainage and may physically strengthen peat soils so that mechanical operations on the farm are easier.

Fig. 1. Applying sand directly on the vines in spring. Photo courtesy H. Sandler.

The sand layer reduces moisture in the upper layer of the soil leading to more rapid warming in the spring and increased release of nitrogen from organic matter in the soil, increasing the potential for growth and productivity without additional fertilizer input. Development of the plants may also be accelerated. Sand absorbs and releases more heat than the organic layer that it covers so that frost danger is less on sanded beds (temperatures remain 2-3°F higher on freshly sanded beds if the sand is moist) (Cross and Demoranville 1969).

Many of the pest management benefits of sanding are dependent upon the deposition of uniform layers of sand. Recent research (Hunsberger et al. 2006) has shown that when sanding depth was measured in the spring after the sand had settled into the vine canopy, uniform layering was rarely achieved. The nonuniform application of sand to the production surface could explain the variable results seen when growers apply sand for pest management reasons.

Application of Sand. Sand can be applied directly onto dry vines by ground rigs that ride on the vines (dry sanding, Fig. 1) or on rails (rail sanding), applied during winter on top of frozen flood waters (ice sanding, Fig. 2), sprayed onto the vines via sand-water slurry (hydrosanding) or delivered via a floating barge in shallow flood waters (barge sanding) during the spring or fall. Yield impacts are variable depending on method of application, cranberry variety, and thickness of the sand layer (Strik and Poole 1995; Davenport and Schiffhauer 2000).

When choosing a method, growers should weigh several factors, including the following. Ice may not be available when a farm needs sanding. Barge sanding may not anchor runners well. Hydrosanding may cause mechanical damage, especially if the vines are not dormant at the time of sanding. Sanding on the vines (dry sanding) is the least desirable choice as damage to the bog and crop reduction in the year of sanding may result even if the sanding is done when the vines are dormant. Rail sanding may lessen the impact of dry sanding. Sanding is considered important enough that many growers believe that even damaging methods are preferable to no sanding.

Fig. 2. Ice sanding on frozen flood waters with a sand buggy. Photo courtesy H. Sandler.

Particle Size. Sand with few fine particles (fine sand, silt, and clay) gives the best result when sanding a bog. These fine particles are also the most likely to remain suspended in water and move off of the target area during barge sanding or hydrosanding. Coarse sand with particle sizes between 0.5 and 2 mm promotes proper drainage and increases root growth. However, gravel should be avoided and the screening of sand prior to application is recommended. An ideal bog sand has >70% of particles in the coarse range and less than 3% silt or clay.

How Much Sand to Use? The amount of sand to be applied depends on how recently the bog has been sanded and the sanding method chosen. If the farm has been sanded recently, a layer 0.5-0.75 inches thick is recommended if ice sanding or dry sanding but more should be used if the last sanding was 4 or more years ago. The exception is barge sanding. When barge sanding, at least 1 inch should be applied. To apply 1 inch of sand to one acre, 134 cubic yards of sand is required. In 2007, a cubic yard of sand could be purchased for approximately $12.

Applying layers greater than 1-inch thick can cause significant yield loss as seen in recent studies by Lampinen and DeMoranville (Lampinen and DeMoranville 2003). Applying a 2-inch layer is considered extreme. The repeated application of sand layers on deep peat beds can cause compression of the peat and uneven settling of the bog. Applying extra sand to low areas on deep-peat beds only raises the soil surface temporarily and may actually be associated with sinking of the soil later.

Some Positive Benefits of Sanding:

1. Improved plant growth due to increased breakdown of soil organic matter, stimulation of root growth, and improved aeration in the root zone. Covering the bare wood at the base of upright stems stimulates basal shooting and new uprights are formed. This stimulation is similar to the physiological response to mechanical pruning.

2. Sanding is important in the management of cranberry girdler. The girdler insect larvae live in the trash (leaf litter) on the bog floor. Sanding buries this trash layer and insect pupae. However, sanding must be done in the fall or winter to be effective against this insect.

3. Sanding can suppress germination of the seeds of the parasitic weed, dodder (Sandler et al. 1997). To be effective, the sand layer must be uniform and at least 1-inch thick.

4. It has been often observed that sanded beds are less likely to suffer spring frost damage compared to unsanded beds. Compared to vines with a thick trash layer, temperatures on a newly sanded farm will be at least 2^{o}F higher in the spring if the sand is wet.

New Plantings. Sanding is of particular importance in the management of new plantings. Cranberries are traditionally planted as unrooted cuttings and then heavily fertilized to promote the production of runners (trailing stems) from axillary buds on the stems. As these runners cover the soil surface, thin layers (0.5 inch) of sand are applied to anchor the runners, promoting rooting at the nodes and leading to the production of upright stems that will then bear the crop. At minimum, new plantings should be sanded after the second season and may need to be sanded after the first season as well, depending on how much growth has occurred.

Possible Negative Aspects of Sanding:

1. Heavy sanding on deep peat-based beds can lead to uneven settling of the subsoil (compression), leaving the bed out of grade or even leading to 'sink holes'.

2. Sanding directly on the vines almost always leads to reduced crop in the year of sanding and if sand is one inch or thicker, the yield suppression may continue in the year following sanding.

3. Sanding on the ice increases the chances for leaf drop in the following spring. Water must be removed from beneath the ice as soon as possible after sanding.

4. Herbicides must be used with caution on sanded beds. Casoron applied prior to sanding or immediately after sanding will damage the cranberry plants. High rates of iron sulfate may also damage recently sanded beds. Devrinol may be used after sanding but must be watered in immediately. Otherwise, light reflected from the sand may accelerate herbicide degradation and limit efficacy.

PRUNING

Cranberries are pruned to remove excess runners and old, long upright shoots and to facilitate the use of dry harvesting equipment. In fact, some modern dry harvesters, notably the Furford Harvester, combine pruning action with harvesting. When runners are present and upright stands become dense, light penetration to the individual plants is limited. This light limitation leads to declines in yield either due to decreased flower bud initiation or limitations on pollinators reaching the flowers to set fruit or both. A dense canopy also provides a moist micro-climate for the growth and spread of fruit rot disease fungi (Caruso and Ramsdell 1995).

Fig. 3. Pruning vines in the spring. Photo courtesy S. Jordan.

Pruning is becoming more important to Massachusetts growers as local sand (available on-site) resources decrease and the cost of sand increases. Research is being conducted by UMass Cranberry Station staff to investigate the incorporation of low-cost practices, such as pruning, to improve the canopy environment and fruit quality, and reduce pesticide use. Research conducted by I. Demoranville in Massachusetts during the 1960's demonstrated equivalent yields with either very light (approx. 0.5 ton/A) pruning every year or sanding every three years. In a replicated experiment conducted from 2006-2007, pruning had less impact on yield compared to sanding, increased light penetration into the plant canopy and was associated with increased fruit color (anthocyanin) (Suhayda et al. 2007).

Historical Pruning Research. Most studies of cranberry pruning were conducted in New Jersey, where excessive growth is often a problem due to the deep muck base beneath the bogs. From 1915-1917, Franklin Chambers (Chambers 1918) conducted pruning experiments on Whitesbog (New Jersey) in which he set up a grid of 12 plots, 6 of which were pruned in December of 1915. Half of the pruned and unpruned plots had heavy vines, the rest had very heavy vine cover. Of the 6 pruned plots, one was pruned to the standard of that time, removing most runners and many uprights (approx. 3.75 ton/A); two plots were pruned less severely (most runners and few uprights removed - approx. 2.75 ton/A); two plots were pruned lightly leaving many runners (approx. 2 ton/A) and; the last plot was pruned severely, removing all runners and most of the uprights (over 10,000 lb/A).

In the year after pruning, the average crop in the pruned plots was 10% *less* than in the check plots. However, in the second year after pruning, crop in the pruned plots was 45% *higher* on average than that in the controls. In fact, even the severely pruned plot had higher yield than the average of the controls, although lower than that in the other pruning treatments. Crop increase due to pruning was most dramatic where the vines were initially very heavy (62% increase in year 2). Highest yields were in the plots where 2-4 ton/A of vines were removed.

Fig. 4. Grower-manufactured pruner with knives attached to a rotating head in front combined with a hydraulic rake attachment in the rear. Photo courtesy H. Sandler.

In 1954, Charles Doehlert conducted another test of pruning at Whitesbog in New Jersey in which he compared removing runners only (this was done with a hand-clipper to insure no removal of uprights) to pruning out 1-inch strips 8 inches or

4 inches apart or 2-inch strips 8 inches apart (Doehlert 1955). Pruning was done in the spring and that fall, he assessed upright density and flower buds for the following year. His research showed that severe pruning decreased upright density *and* flower bud production by approximately 10%.

In observations over many years in New Jersey, Phil Marucci noted that while there were at least as many flowers per unit area in dense vine stands, yield was greater where the vines were less dense (Marucci 1987). He also noted that in dense vines, the percent of flowering uprights bearing no fruit was as much as three times greater than in nearby areas where vines were less dense and shorter. He attributed this in part to the inability of pollinating bees to reach flowers buried in a dense canopy. He suggested that a bog should be pruned when, in a year with no frost and normal bee activity, greater than 10% of flowering uprights fail to set even one berry. In an experiment using a Furford Harvester as a pruning device (Fig. 5), Marucci found that after a single pass with the Furford (during harvest), 14% of flowering uprights bore no fruit the following year. However, when a second, strictly pruning, pass was made with the Furford after harvest, the percent of barren flowering uprights dropped to 8%.

Fig. 5. Dry harvesting with a Furford picking machine that prunes vines as well as picks fruit. Photo courtesy B. Wick.

Strik and Poole looked at date of pruning (2 months post-harvest vs. spring) and pruning severity (none, light, moderate, heavy) in Oregon (Strik and Poole 1991). They found that time of pruning had no effect on subsequent growth and production. Severe pruning (1.5-2.5 ton/A removed) was associated with reduced crops due to the removal of uprights bearing flower buds during the pruning. Pruning in two consecutive years intensified the effects. Even light pruning two years in a row led to reduced yield (no significant reduction after only one year of pruning). In one of two years, fruit set was improved by pruning, however, this did not make up for the fewer flowing uprights and flowers in the severely pruned treatments. Fruit from unpruned plots had the least anthocyanin (red pigment) of all treatments, supporting the observation that light penetration to the fruit is important in color development.

After applying pruning treatments for two years in a row, Strik and Poole left all treatments unpruned the third year. In that year, plots where light pruning had been done previously had the greatest yields compared to no pruning or severe pruning (Strik and Poole 1992). In the light pruning treatment, approximately 1 ton/A of prunings were removed. This treatment, in alternate years, was then recommended for Oregon cranberry production.

Timing and Methodology. Cranberry vines are pruned during or just after harvest or early in the spring. Cranberry pruning machines are usually a series of vertical knife blades set at an angle to the direction of movement and spaced at 1-foot intervals on a rotating frame. This device is mounted on a buggy or small tractor (Fig. 3 and 4). A water picker modified to carry the pruning head has been used in Oregon. Such pruners move through the bog, removing runners and some uprights. The severity of pruning relates to knife spacing and speed of operation.

Alternatives to these pruning machines are mechanical harvesters such as the Western Picker and Furford Harvester that prune during dry harvest (Fig. 5) or knife rakes (hand pruning; Fig. 6). These harvesters can be used for pruning after water harvest or for additional pruning of dry harvest beds by making a second pass across the bog.

Regardless of pruner used, severe pruning or mowing greatly reduces yield. In some instances, even light pruning can cause some reduction in yield. However, Strik and Poole (1992) showed that light pruning (up to 1 ton/A) in alternate years resulted in larger *cumulative* yield compared to no pruning or severe pruning, even if crop was reduced in the year of the light pruning. In our current research project, pruning at 0.25 ton/A increased yield in the year of pruning in replicated plots, and at grower sites, light pruning was most often associated with increased or unaffected cumulative yield in the two years following pruning (DeMoranville 2007).

Fig. 6. Farmer worker using a hand-held knife rake that can prune lightly or heavily. Photo courtesy H. Sandler.

Some Positive Benefits of Pruning:

1. Flowers are more accessible to bees, fruit set percent may improve. Flower longevity may also be extended in a more open canopy.

2. Light exposure in the canopy increases promoting fruit color and flower bud development.

3. Fruit rot disease pressure may be reduced.

4. Harvesting is more efficient when runners are minimal. This is especially true for dry harvesting.

5. Prunings may be used to plant new areas or fill in thin spots or may be sold for planting elsewhere.

Possible Negative Aspects of Pruning:

1. Mechanical damage may occur.

2. Removal of more than 1 ton/A of clippings may reduce crop in the following year. More severe pruning is associated with crop reduction of at least 10%. However, crop reduction may be compensated for by increased production in the second year.

Harvesting and Handling Cranberries

Carolyn DeMoranville

Nationally, cranberries are harvested from early September until early November. The exact harvest dates vary by region, weather conditions, and cultivar being harvested. In addition, some consideration must be given to whether the fruit will be sold in the fresh market, used in white juice products, or used for other processing. With the exception of white harvest, the fruit are harvested at full maturity with good color (anthocyanin content) but prior to the fruit becoming overripe. Timing of harvest is important for fresh-market fruit so that the berries are sufficiently red but retain good storage quality, while fruit for the processed market ideally has maximum color.

Fruit Development. During fruit development, acids in the cranberry reach a maximum level prior to the appearance of the red color. The predominant acids in cranberry fruit are (in descending order) citric, quinic, malic, and benzoic. These acids are the source of the tart and astringent flavors of cranberry. As the fruit color develops, the sugar content of the fruit increases. At full maturity, the cranberry fruit is 88% water, 4.2% sugar, and 2.4% acid. The remaining constituents of the mature fruit are pectins, other structural carbohydrates and minerals (Fellers and Esselen 1955)

Cranberry marketing companies produce 'no color added' products, so the color at harvest is of great importance in processed berries. Since, the primary pigments, anthocyanins, are antioxidants, color also has implications in the health benefits of cranberry products (Reed 2002; Neto 2007). However, the most studied health benefit associated with cranberry is related to proanthocyanidins in the berries.

Cranberries contain unique proanthocyanidins (PACs) that can prevent the adhesion of certain of bacteria, in particular *E. coli*, associated with urinary tract infections to the urinary tract wall (Howell et al. 2001). The anti-adhesion properties of cranberry may also inhibit the bacteria associated with gum disease (Weiss et al. 2002) and stomach ulcers (Burger et al. 2002) from forming biofilms associated with these disorders. Cranberry PACs are present early in fruit ripening prior to full color development.

Color development in cranberry fruit varies with climactic conditions and so differs from year to year and from region to region (Sapers et al. 1986). In addition, various cultivars develop color at different rates. All of these are considerations when a grower plans a harvest schedule. If the fruit is being harvested for the fresh market, ability to develop further color in storage is also of importance and may vary with cultivar and developmental stage at harvest. Of the four major cultivars grown in Massachusetts, Ben Lear and Early Black develop color earliest (by early to mid-September), Stevens develop full color from mid- to late-season (early to mid-October) and Howes are the latest (mid-October). Factors that may slow color development are warm temperatures, particularly at night, and poor penetration of light to the berries (thick canopy).

Harvesting of Cranberries. There are two basic methods of harvesting cranberries. The first, dry harvesting, dates back to the origins of cranberry cultivation. The second system, flood or water harvesting dates to the 1920's and was first mechanized in the mid-1950's (Dana 1990; Eck 1990).

DRY HARVESTING

The earliest harvesting was done on dry beds by workers who hand picked the fruit into wooden boxes and barrels. By the turn of the century, wooden rakes were being manufactured for hand-scooping cranberries. These hand scoops, consisting of wooden or metal tines or teeth set 0.5 inches apart in a wooden catch frame, became the industry standard by the 1930's. In modern cranberry production, hand scoops are only occasionally used to harvest bed edges or experiment plots.

Fig. 1. Furford dry harvester. Photo courtesy B. Wick.

Mechanized dry harvesters have been used since the 1920's, although they did not come into general use until the late 1940's. The first commercial picking machine was sold by W. B. Mathewson. As did all the dry harvesters to follow, this machine was based on mechanizing a cranberry scoop and relied on tines that stripped the fruit from the vines. In the Mathewson design, sets of tines were mounted on a revolving cylinder. In the late 1940's, the Western Picker was introduced in Oregon. This machine differed from previous harvesters in that the tines were fixed in position (passive detachment system) and a pruning blade was part of the design so that harvesting and pruning were accomplished simultaneously.

The Darlington Picker was introduced in the late 1950's. This machine was lightweight and used a rotating tine system. However, both the Western and Darlington Pickers had the disadvantage of picking only a 2-foot width with each pass, limiting harvest capacity to no more than one acre per day. In the 1960's, the Furford Harvester (Fig. 1) was developed on the West Coast and has moved into general use for dry harvesting in Massachusetts. Based on modifications to the fixed-head harvesters, the picking head width is increased on a Furford without increased loss of fruit during harvest. Furfords run faster and pick a wider path than other dry harvesters (Fig. 1). They also contain a pruning blade.

Due to climactic conditions on the East Coast, all berries to be sold on the fresh market must be dry harvested. However, dry harvesting has fallen from favor for process-market fruit due to the general inefficiency of the machines. It is common for dry harvesters to leave up to 20% of the fruit on the bog. The fruit that is harvested often sustains bruising during the dry harvest operation. Finally, dry harvesting is quite labor-intensive. Each Furford harvester covers only one to two acres per day; other models cover even less ground.

Fig. 2. Examples of self-propelled dry harvesters used to pick cranberry fruit. Photo courtesy www.FAO.com.

The fruit is collected in boxes or bags (Fig. 2 and 3) that must be removed from the bog and transferred into bulk containers. These containers are taken on trucks to a receiving station for sorting and storage. In addition to concerns regarding bruising of fruit by mechanical pickers, care must be taken not to bruise fruit when dumping it into bulk containers. In many dry harvest operations in Massachusetts, the bulk containers or bins are brought out onto the bog and filled from harvest bags collected from the pickers. Periodically during the day, the bulk containers are moved to waiting flat-bed trucks by attaching straps to a rig carried by a helicopter. The bins are then airlifted to the truck.

If pruner/pickers are used, the grower may rough-screen the crop prior to delivery to remove excess prunings. Fruit is then delivered to packing houses where it is stored in common storage until cleaning and separating operations are carried out prior to pack-out. Fruit containing chaff (leaf litter and stems), delivered in bulk bins, is rough screened into smaller (1/3 barrel) boxes prior to storage. Cranberries may be held for two to three months in common storage if fall temperatures are not too warm. Under refrigeration, they may store well for several months. Bruising, physiological breakdown, and storage rots (due to fungal pathogens introduced in the field) can all limit storage longevity.

Fig. 3. Example of a tractor-driven dry harvester used to pick cranberry fruit. Photo courtesy D. Bragg, www.dbe.ca.

WATER HARVESTING

Water harvesting overcomes two of the problems associated with dry harvesting: uncollected fruit and high labor costs associated with the slower dry harvest process. Water harvesting takes advantage of the buoyancy of cranberries -- the fruit float in the flood water and are accessible to the harvester (Fig. 4-6). A single water harvester covers many more acres than a dry harvester in a day, so the crop is brought in more quickly and labor costs are reduced. Water harvest has the additional advantage of not being weather-sensitive. Water harvest can be done even on rainy days, which is not possible with dry-harvesting equipment.

Early water harvesting in Wisconsin was done using hand rakes with long handles. A shallow (~ 6 inch) flood was put on the bog and the raked fruit was easily removed. Few berries were left behind as they were floating above the surface of the soil. Vine injury was also minimized. In the 1940's and 1950's, the process was mechanized by mounting a rake with either fixed or retracting tines on the front of a self-propelled machine that also had a conveyor to move the fruit into waiting float-boats. Fruit harvested by these methods was dried and sold on the fresh market. This was possible in Wisconsin due to ease of drying in a less humid climate and conditions that did not promote fungal growth in the harvested fruit.

Fig. 4. Wet harvester (water reel) used to harvest cranberries in shallow floods. Photo courtesy F. Caruso.

In the early 1950's, the current industry standard water harvester was introduced. This machine is known as the water reel or beater and consists of horizontal bars mounted on a shaft that rotates as the machine moves forward. The horizontal bars are held one or two inches above the surface of the bog so that they hit against the upright shoots, causing the fruit pedicels to break and releasing the buoyant fruit to float to the surface. This type of rough handling further precludes the possibility of drying these fruit and selling them fresh.

Wet-raked fruit are deposited into containers as part of the raking operation. However, fruit removed by the water reel is left floating in a shallow layer (five to six inches) of water. In order to remove this fruit from the bog, the water level is increased until the fruit float free of the tips of the vines. The fruit is then gathered to one edge of the vine using corralling booms and taking advantage of the prevailing wind. Once the fruit is corralled at the bog edge, it is lifted into trucks using conveyors or hydraulic pumps. As the fruit is sent to the truck in the conveyor system, trash (leaves and stems) is removed by passing the harvested mass over a coarse grating. The berries and small debris pass thought the grating onto an inclined belt, down which the berries roll, while the debris clings to the belt and is carried away, often to a second, smaller truck.

Fig. 5. Wet harvester design called the Ruby Slipper, which is rear-mounted. Note the yellow paddles instead of the metal reel seen above. Photo courtesy B. Wick.

Alternately, a low-pressure berry pump lifts the fruit mass through a large-bore hose onto an inclined grate. A second pump feeds water to cleaning nozzles. The washing spray pushes debris through the grate into a trash truck, where the trash is de-watered (the water is diverted back onto the bog). The fruit roll down the surface of the grate into the waiting delivery trailer.

Water-harvested berries are delivered in trailer trucks holding up to 500 barrels to receiving stations where they are washed and placed into bulk containers for freezing. The frozen berries are used for subsequent processing. Fruit that has been bruised by water reels and sits in warm harvest flood water has reduced storage life and is poorly suited for fresh fruit.

Storage quality, however, is of some importance to modern cranberry processing operations. Fruit is sent to commercial freezers in bulk containers so large that the center berries may not freeze for up to one month. During that time they are subject to the same post-harvest problems encountered with fresh fruit.

Fig. 6. Water reel harvesting berries in a shallow flood. Photo courtesy F. Caruso.

NOTE: For further information on the health benefits of cranberries, including links to research on that subject, see the web page of the Cranberry Institute. http://www.cranberryinstitute.org.

Renovating Cranberry Farms

Hilary A. Sandler

Traditionally, cranberry vines have been planted into a prepared area with a life expectancy measured in decades. However, with the development of new varieties and increased pressure on a shrinking profit margin, growers are re-thinking this conventional approach regarding their expectation for the longevity of a vine's productivity. At present, traditional renovation (replanting) is a costly procedure; however research efforts by UMass and individual growers are focusing on innovative techniques that are much more economical, such as mowing and rototilling.

Why Renovate? Over the course of time, conditions may arise on the bog that become severe enough to necessitate renovation of the bog. Examples would include significant weed infestations, invasion by nonproductive (mongrel) vines, and significant differences in grade (which makes flooding difficult). Recently, interest in renovating in order to replant with new vigorous hybrid varieties has become a reason motivating growers to take the next step.

Traditional Approach. The establishment of a new planting or renovation and its associated activities are among the most expensive operations performed by cranberry growers. The actual cost of a complete renovation project, depending on access to local materials, equipment, and labor, can range from $10,000 per acre to $25,000 per acre (L. Reno, pers. comm.). Typical activities include removal of existing vines by bulldozer (Fig. 1), laser leveling of the bog surface, addition of a deep sand layer approximately 4 to 8 inches, fumigation, repairing or replacing irrigation systems, purchasing and planting of new vines, and the application of fertilizers and herbicides (DeMoranville et al. 1996b; DeMoranville et al. 2001). Renovated areas may be fumigated (e.g., with Basamid or metham (Vapam) prior to planting. Vines are typically planted at densities between 1 to 2 ton per acre, depending on cost and availability. Napropamide (Devrinol) is the recommended preemergence herbicide for new plantings (DeMoranville et al. 2001). The substantial financial and time investment associated with the renovation of the bed and establishment of the new vines mandates that the grower maximize vine colonization and minimize the effects of weed competition.

Fig. 1. (Top) Scraping and removing established vines. (Bottom) Applying a thick uniform layer of sand prior to planting. Photos courtesy H. Sandler.

Choices must be made regarding planting density, nutrient management, and pest management when establishing the new vines. A recent study (using the cultivar Stevens) suggested that the most cost-effective production scheme for establishing a new bog is to plant vines at a low density (~ 1 ton per A), use moderate rates of nitrogen (~50 lb N per A), and apply a yearly application of Devrinol for weed control (Sandler et al. 2004a). This combination efficiently produced optimal vine coverage, reduced weed biomass by 85% compared to untreated plots, and gave the best weed control per dollar spent. This study gives a good guideline for renovating or establishing a new cranberry farm, but ultimately growers must rely on their own experience and resources when making renovation and planting decisions.

Fig. 2. (Top) Scattering unrooted cuttings. (Bottom) Disking in unrooted cuttings. Photos courtesy D. Cannon.

Planting Material. Vines can be planted as long (12-18 inches) unrooted cuttings or as small rooted plugs. Unrooted cuttings are uniformly scattered on the ground and then disked into the ground (Fig. 2). This has been the conventional approach and is quite effective for propagating established varieties. Use of unrooted cuttings allows growers to mow or prune established plantings, collect the vines, transport them to the new area and scatter the cuttings. Vines are available for purchase (ca. $1,000-2,500 per ton, depending on variety) but use of one's own vines saves money.

In comparison, the new hybrid varieties from Rutgers University breeding program are being propagated and sold as rooted plugs (Fig. 3 and 4). Plugs are more expensive but since the vines already have roots when they are placed in the ground, their survival and colonization rates are high. In addition, the use of plugs greatly reduces the introduction of weeds with the vine material and thus, greatly reduces the labor and material inputs needed to manage weeds in the first few years. Plugs are planted at 1-foot intervals (ca. 45,000-50,000 plugs per acre at a cost of $0.25 per plug).

Fig. 3. Propagating rooted cuttings in the greenhouse. Photo courtesy C. DeMoranville.

Site Preparation and Establishment. Many choices and decisions are involved in the preparation of the cranberry farm for renovation and planting and no single list fits every situation. Growers must decide how to deal with the existing plant material, both vines and weeds. If weed pressure is the main reason for renovation, growers may consider the use of chemicals to minimize the chance for re-infestation. Most farmers use laser leveling to ensure the evenness of the grade of the planting surface. Sand must be obtained and transported to the site and distributed onto the surface. Conventionally, growers apply a thick layer of sand (ca. 6 inches), but recently growers are exploring the use of thinner sand layers or no sand. Labor is needed to scatter the vines or plant the plugs. Most growers take the opportunity during renovation to reconfigure and/or upgrade the bog irrigation system and address any drainage issues.

Fig. 4. Planting rooted plugs with a modified strawberry planter. Photo courtesy H. Sandler.

Fertilizers are used to stimulate initial growth of the vines. At planting, phosphorus fertilizer is added to encourage good rooting. In the first year, vines are fertilized frequently with nitrogen to promote runner growth. Runner growth is needed to enable vines to colonize the surface. Preemergence herbicides can be used once root growth has started (usually 3 weeks). Irrigation in the first month is critical; it is not unusual for plants to need irrigation at least twice per day until the roots are established.

Benefits to Renovation

Opportunity to upgrade irrigation system and bog drainage.

Re-grade farm to increase water use efficiency.

Increase production.

Square edges to improve overall farm efficiency.

Reduce weed pressure.

Considerations when Renovating

Buy vines from a known reputable source.

Plant at a reasonable density with proper fertilization to ensure good colonization.

Maintain proper irrigation of newly planted vines.

Scout vines for signs of pest damage.

Manage weeds in the very beginning as much as possible.

Stabilize ditches to minimize erosion until vines have established.

Apply a light coating of sand (0.25-0.5 inch) in the first (and/or perhaps the second) winter.

Influence of Weather on Cranberry Production

Carolyn DeMoranville and Frank Caruso

This section describes some of the climactic factors that play a role in cranberry crop development and fruit quality. The main focus here will be on the effects of temperature, sunshine (intensity and daylength), and rainfall on crop production and quality. Information on cold tolerance and winter hardiness is discussed elsewhere.

H.J. Franklin and C.E. Cross studied these factors and published their findings and observations in the 1940's (Franklin et al. 1943; Franklin and Stevens 1946; Franklin and Cross 1948). While we can expect many of the weather impacts on cranberry production to remain unchanged, changes in cultural practices could be expected to affect some aspects of the interaction between weather and cranberry production. During the 1980s, I. Demoranville studied the Franklin and Cross weather relationships and recorded observations of changes brought about by changing cultural practices (Cross 1987; DeMoranville et al. 1997). Degaetano and Shulman examined the size of New Jersey cranberry crops from 1906 into the 1980's in relation to temperature, rainfall, sunlight hours, and several other weather factors (Degaetano and Shulman 1987). They found that some relationships differed depending on which half of the period they studied. Their findings regarding the second half of the study period are included here.

FRUIT DEVELOPMENT, SIZE, AND YIELD

Sunshine. *Year prior to the crop*: Based on a review of crop records, Franklin proposed that total sunshine in the year prior to the crop was positively correlated with high yields. This was due to the positive effect of abundant sunshine in the months of May, August, September, and November. Many effects of sunshine might be explained by an increase in photosynthetic activity, particularly at key developmental stages. Cross (1987) explained the relationship between yield and previous year sunshine by noting that sunshine in May promoted strong production of vegetative uprights that later in the season would set fruit buds for the following year's crop. Sunshine in the other three important months would promote the initiation and growth of these buds. August and September would be of particular importance since fruit development for the current crop would be competing for photosynthetic resources with following-year bud development.

An examination of Massachusetts crop records shows that of the 12 highest crops in history, three were associated with less than average total sunshine during the previous year. Obviously, sunshine alone does not guarantee a large crop in the following year. However, abundant sunshine and strong buds for the following season are positive factors. This may be especially important if late water is to be held the following spring since this practice can be associated with depletion of photosynthetic reserves (carbohydrates).

Franklin and Cross maintained that sunshine, especially late in the year prior to the crop and during the winter of the crop year, was critical for the sizing of the fruit the following year. This again could relate to the production of strong flower buds. One of the factors that determine berry size is the production of seeds, each of which after pollination, is formed from a fertilized ovule in the flower base (ovary). Strong flower buds might be expected to have numerous viable ovules in each flower, increasing the potential for the development of sufficient numbers of seeds to result in large berries.

When sunshine for May, August, September, and November in the year prior to the crop was reviewed for the crop years from 1984 to 1995, the positive correlation between sunshine and large berries was confirmed. In five of those years, Early Black berries were undersized and sunshine was below normal; while in five other years, the Early Black fruit were average size or larger and sunshine was above normal.

Year of the crop: One of Franklin's observations was that a large crop never followed a February in which the hours of sunshine were 150 hours or less. If we examine the data in Table 1 for the years of his study, it is easy to understand why he made that statement. Sunshine deficit in February was associated with crop reduction that fall in 10 out of 12 instances.

Table 1. Cranberry crops following February sunshine of 150 hours or less (adapted from Franklin and Cross, 1948).

February Year	**Sunshine Hours**	**Production (bbls) Same yr**	**5-yr Ave.**
1922	114	337,000	368,000
1938	114	325,000	402,000
1927	118	385,000	402,000
1926	126	438,000	393,000
1935	132	332,000	424,000
1939	135	490,000	472,000
1932	137	415,000	426,000
1907	141	310,000	325,000
1911	141	298,000	381,000
1920	143	309,000	394,000
1916	144	364,000	373,000
1900	146	200,000	241,000

To see if the relationship holds for the recent past, we can look at the years from 1960 to 2000 (Table 2). We find that in all of these modern cases, crops were above average despite sunshine of less than 150 hours. This is a prime example of how a change in cultural practices has changed a weather relationship to cranberry cropping. Certainly, winter management of cranberries in Massachusetts has changed since Franklin's day -- rather than leaving the flood in place from December until spring, modern growers remove flood water from beneath winter ice and often change the flood water mid-winter. These practices were designed to avoid oxygen deficiency injury, previously thought to be induced by lack of light penetration through the winter flood. However, recent research by Vanden Heuvel and Roper (2006) indicated that winter sunlight was not important in preventing injury to the plants (shown by covering the vines with black cloth) and that oxygen deficiency may not be as important as previously believed.

Table 2. Cranberry crops following February sunshine of 150 hours or less, 1960 - 2000.

February Year	**Sunshine Hours**	**Production (bbls) Same yr**	**5-yr Ave.**
1989	99	1,815,000	1,535,000
1999	97*	1,875,000	1,848,200
1969	119	755,000	679,000
1973	131	901,000	853,000
1997	140	2,100,000	1,806,000
1982	142	1,278,000	1,098,000
1984	145	1,663,000	1,227,000
1998	145	1,875,000	1,849,200

*Record low

In New Jersey, sunlight hours in May and June of the crop year were positively correlated with yield. It was believed that this was due to increased photosynthesis that led to good supply of carbohydrates for fruit development and good pollination conditions (cranberry bloom in New Jersey occurs by mid-June).

Temperature. The geographic range for commercial cranberry growing has long been considered to be limited to areas with moderate summer temperatures (i.e., no warmer than those of New Jersey). However, cool summer temperatures could lead to an extended bloom period and slow fruit development, which along with daylength constraints, may determine the northern limit for cranberry production. As of 1985, commercial cranberry growing areas of North America were defined by the isotherm for a July daily average maximum temperature of 85°F (Pilcher 1985).

Year prior to the crop: Warm temperatures in May and June were associated with high yield the following year in New Jersey, most likely due to a stimulation in the growth of vegetative uprights that were likely to set flower buds for the following season. This complements the finding of Franklin for the need for adequate sunshine in the spring prior to the crop to promote strong vegetative uprights.

In New Jersey, warm temperatures in October and November were correlated with greater crops the following year. Degaetano and Shulman (1987) theorized that stronger buds developed during warm falls. However, warm falls followed by quickly declining temperatures in early winter may have a negative impact due to cold injury in poorly acclimated buds (not fully winter hardy). The 2002 and 2007 Massachusetts crops can be used as illustrations. In both years, the temperatures were just above the 30-year average in the previous October but 4ºF above average in November and 6ºF above average in December. The following crops were among the five poorest in Massachusetts for the past 20 years.

Cold temperature in early winter may also be a negative factor for cranberry production even when fall temperatures are near normal. Poor crop years (3 of the 7 worst in the last 20 years) in Massachusetts were associated with prior December temperatures that were four or more degrees below normal. The 1990 crop is a good illustration, when December 1989 averaged more than 10 degrees below normal and the 1990 crop was 500,000 barrels less than the 1989 crop, making it one of the five poorest crops for the past 20 years.

Year of the crop: Many of Franklin's and Degaetano and Shulman's observations regarding temperature effects in the crop year relate to frost damage (negative effect of low temperatures in April and May) and heat stress damage (negative effects of high temperatures in May through August). In modern times, most of these effects are overcome by proper irrigation management.

Cross (1987) noted that high temperatures and high humidity in late May and June were associated with the production of very lush and tender new foliage. When such growth was subjected to bright sun, high temperatures, and moderate to strong winds, new growth and flowers were subject to blast (burning of the tissue). In 1997, some growers in Massachusetts reported blast of new growth and flowers after two days in June had temperatures over 90°F (following two weeks in the 50-62°F range). This damage is similar to scald damage to fruit later in the summer and can be especially severe if the bog soil is dry. Under these conditions, the plants lose moisture through transpiration faster than they can replace it through uptake by the roots. High temperatures in these months were also a negative factor in New Jersey (Degaetano and Shulman 1987).

Franklin concluded that high temperatures in July were damaging to the crop. He wrote, "The harmful effect of high temperatures in July is probably due to the burning (blasting) of flowers and small berries that occurs rather commonly on the bogs in hot weather" (Franklin and Stevens 1946). Degaetano and Shulman (1987) found that hot summers were a negative factor in New Jersey as well, due to blast and scald injury. Massachusetts records show that between 1925 and 1970 there were 10 years when July temperatures averaged from 1 to 4.6°F above normal; all crops in those years were average to small. However, during the period between 1971 and 1997, there were 10 years with July temperatures averaging 1°F or more above normal and all but one of the crops in those years were large. The exception was 1975 when the crop was severely reduced by scald in August. This shows the value of sprinkler systems for cooling the bog and preventing blast and scald.

In 1992 and 1993, the development of cranberry fruit (increase in weight during the season) was studied in five states (DeMoranville et al. 1996a). The rate of fruit sizing differed from state to state. In Wisconsin, where the growing season is short, the fruit developed at a more rapid rate than in the Pacific Northwest where the season is milder but longer. After studying temperature and sunshine data, the research team concluded that the number of days in July and August with moderate temperatures was the key to rapid fruit development. The ideal temperature range consisted of minimum daily temperature above 60°F and maximum daily temperature below 86°F. That single weather factor accounted for more than 80% in the variability from region to region; the most rapid growth rate occurring when temperature was in this range. Equations were developed for the rate of fruit weight gain (R) and for the number of days to accumulate 0.5 gram of weight per berry (D). These equations were developed using data for the cultivars, Stevens, Pilgrim, and Crowley:

$$D = -86.6 + 2.1\ A_{60} + 6.2\ JAT - 2.1\ AMT$$

$$R = -0.0156 + 0.0013\ AMT - 0.0005\ J_{86}D$$

where JAT is July average temperature, AMT is August average maximum temperature, $A_{60}D$ is the number of days in August with minimum temperature less than 60°F, and $J_{86}D$ is the number of days in July with maximum temperature greater than 86°F.

The equations show that the important limiting factors were high temperatures in July (confirming Franklin's observations) and low temperatures in August. In the years of the study, high temperatures were limiting in New Jersey while low temperatures were limiting in Oregon and Washington. In one of two seasons, low temperatures were limiting in Wisconsin. Massachusetts had the fewest periods of temperature extremes in both seasons, resulting in the shortest number of days (21 and 14 days in 1992 and 1993, respectively) required for fruit to accumulate 0.5 gram fresh weight (starting from six weeks after 30% out-of-bloom).

Rainfall. *Year prior to the crop:* Franklin and Cross theorized that ample rainfall in October of the year prior to the crop was important to the yield of the subsequent crop (Franklin and Cross 1948). Wet conditions post-harvest were helpful in 'healing' the injury to the vines from dry harvest operations. With the advent of water harvest, the need for ample rain in October is lessened with respect to vine recovery. However, plentiful precipitation in October and November is of great value in building water supplies for the winter flood. Rainfall during this time is also critical for the cranberry vines, as growers dismantle their sprinkler systems prior to harvest and the beds are not irrigated thereafter. If a drought occurs during this time (a rare occurrence), the plants can enter dormancy in a weakened state. This may result in less fruit production the following year.

Year of the crop: Franklin noted that, "monthly rainfall of two to four inches throughout the growing season (May-August) is evidently conducive to large production" (Franklin and Stevens 1946). Also he noted that, "definite drought in any month of the growing season is harmful." From 1925 to 1970, there were 10 years with two months with rainfall under two inches during the growing season. All of the crops in those 10 years were average or small. From 1970 through 2007, there have been nine growing seasons that fit the rainfall parameters mentioned above; all of those crops were also average to below average. This indicates that even with sprinkler irrigation, drought conditions are detrimental to production.

Franklin also pointed out the negative impact on cropping of excessive moisture from rainfall and/or high water table. Part of the negative impact of excessive precipitation may be due to low sunshine. However, work by Lampinen and DeMoranville (unpublished data) showed that on a bog with excessive soil moisture, fruit retention was reduced compared to that in an adjacent bed with less saturation (Fig. 1). This indicates that saturated soil, rather than lack of sunshine, may be the predominant negative factor when rainfall is excessive and drainage is inadequate.

Abundant precipitation in July and August appears to be important in berry sizing. However, with adequate irrigation in recent years, this factor should be of little importance, but this has not always been the case. Lack of moisture for an extended time (approximately two to three weeks) during the period from mid July through early September (as seen in 1995, 2005, and 2007), may cause an interruption in the growth of berries that affects their size at harvest. Irrigation helps, but is apparently not always sufficient substitute for rain when it comes to fruit development. Research by Lampinen (unpublished data) showed that weekly demand of the cranberry plant for water varies from 0.5 to 2 inches per week with maximum demand occurring in July.

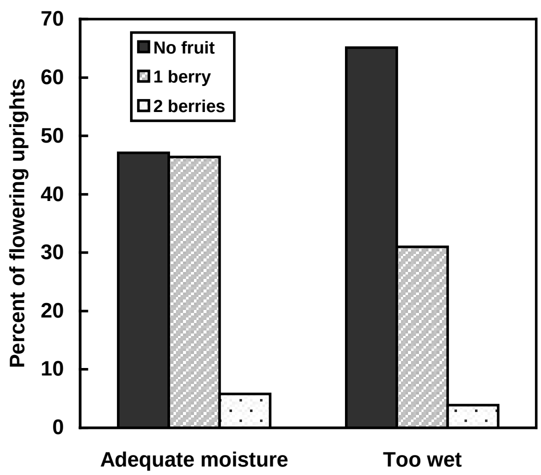

Fig. 1. Fruit retention on flowering uprights from a bog receiving adequate irrigation or excessive watering. Note that with excess water, significantly more uprights retained no fruit. Differences in all three categories were significantly different between adequate and wet areas. Data from Lampinen and DeMoranville (unpublished data).

OTHER FACTORS AFFECTING BERRY SIZE AND YIELD

Seed Number. Berry size within a variety is proportional to average number of seeds per berry, although the statistical relationship is weak. On average, large berries will have more viable seeds than small berries. Large berries average about triple the number of seeds of small berries and average-sized berries have about double the number of seeds of small berries (I.E. Demoranville, personal observation). It has been noted that the development of fully sized fruit was dependent on the production of a threshold number of seeds – once that number was reached, adding more seeds had little additional impact on fruit size (Cane and Schiffhauer 2003). Both observations highlight the importance of good pollination and fertilization of the ovules in the flower. Adequate numbers of flower visits by bees and sufficient quantities of viable pollen are critical. Both frost and winter injury can lead to reduction in pollen viability and possibly that of the ovules.

Soil Moisture. A plentiful, but not excessive, amount of moisture in the soil is important in the sizing of berries. Approximately 88% of the fresh weight of a cranberry fruit is water (Fellers and Esselen 1955). Rainfall and sub-irrigation (via drainage ditches) are most helpful, but sprinkler irrigation is necessary to maintain uniform moisture when rainfall is deficient. Conditions of either drought or excessive water can interrupt the growth cycle of the fruit: uniform moisture without soil saturation is the key. Further, excessive soil saturation has been associated with poor fruit retention (Fig. 1).

Hail. Hail injury is most serious during the flowering period in June and July, when blossoms and flower buds are either severed or battered so severely that fruit set is affected, leading to yield reduction. In August, developing fruit may be bruised, punctured, or detached from the plant during a hail event. Such berries may form hard, brown scars that could be a problem for fresh market but would not affect their use for processing. Some of the injured berries may be predisposed to infection by the fungi that cause fruit rot. Whether infection occurs or not is dependent on the conditions that occur immediately after the hail injury, e.g., high humidity, which would retain a film of moisture on the surface of the berry where the injury occurred.

Cranberry plants usually recover well from any leaf damage. Only rarely is flower bud production for the following year affected. Summer hail storms in Massachusetts occur most often in the afternoon and evening, rarely at night and in the morning. Hail is always associated with violent thunderstorms, which nearly always approach from the north-northwest to west-southwest quadrant.

Plant Nutrition. If 88% of a cranberry fruit is water, the remaining 12% is mineral nutrients and carbohydrates (the products of photosynthesis--sugars, acids, and starch). Early-season nutrition is key to the plant's ability to produce adequate growth for photosynthesis and fruit filling. Approximately 90% of the dry matter in the berries is carbohydrate. Availability of essential nutrients during fruit development is also important. However, excessive use of nitrogen fertilizer can result in fewer, poor-quality fruit.

Timing of Harvest. Cranberry fruit continue to increase in weight, although at a slower rate, in September compared to that in July and August. Fruits continue to increase in weight until late September for early varieties and mid-October or longer for late varieties. Early harvest may result in loss of 10% or more of potential yield. A recent evaluation of field samples in Massachusetts showed that Ben Lear and Early Black cranberries increased in weight by ~20% during September and by an additional 5% in early October (DeMoranville and Sandler, unpublished data).

Winter Desiccation. Loss of water in leaf and bud tissues may occur under certain conditions during the winter. This transpirational loss may become severe when the root zone is frozen. Desiccation may result in leaf loss in the spring. Since cranberries accumulate nonstructural carbohydrates (the fuel for metabolism and growth) in the spring (Hagidimitriou and Roper 1994), the loss of leaf tissue may have a significant impact on subsequent production of new growth and fruit. Winter floods are held to minimize this type of damage. Fall application of antitranspirants may reduce the loss of leaf tissue on beds that cannot hold a winter flood (Sandler 1998b). It is not known whether antitranspirants will also minimize leaf loss on flooded beds that are periodically exposed to the weather during the dormant season.

FRUIT QUALITY

Ripening and Color Development. In cranberries, ripening can be followed by monitoring the changes in the ratio between soluble solids (sugars; °Brix) and acids. Acidity increases at a rapid rate through August (Sapers, et al., 1986). As the fruit ripen, acid content levels off while sugars increase so that the ratio increases (Sapers, et al., 1986; Fellers and Esselen, 1955). Color (anthocyanin content) develops in cranberry fruit in tandem with the ripening process. However, fruit judged to be ripe based on internal chemistry may be poorly colored (Sapers et al. 1986). This indicates that in addition to ripening, environmental factors play a role in controlling color development.

Temperature: Franklin (Franklin and Stevens 1946) noted that cool weather in August promoted the early ripening (coloring) of cranberry fruit. Indeed, it appears that warm weather in August and September can delay the color development of cranberries in Massachusetts. This effect appears to be intensified if the spring was cold. Early in the fall, cranberry fruit developed more color if temperatures were low compared to that at higher temperatures (Hall and Stark 1972). As the fruit gained color (later in the fall), continued increase in color was less responsive to differentials in temperature. Interestingly, low temperatures also accelerated red color development in cranberry leaves (fall dormant coloration).

Cranberry development was compared to the accumulation of growing degree days (GDD) at three locations in Wisconsin (Hawker and Stang 1985). They found that vegetative growth and flowering occurred at the same number of GDD at all locations. However, fruit maturity as determined by anthocyanin production did not correlate well with GDD, occurring any time after 1,500 or 1,650 GDD, depending on location within the state. Involvement of other environmental cues, specifically daylength, was proposed.

Other factors: The use of certain fungicides, notably those in the mancozeb and maneb (and previously registered Zineb) types, can retard color development in cranberry fruit. Excessive use of nitrogen fertilizer can also have a negative effect, most likely due to shading of the fruit by excessive upright growth. This confirms the importance of light in the production of anthocyanins in the fruit. Indeed, berries deep in the canopy color poorly, if at all.

Scald. Scald is a physiological disorder of cranberry fruit characterized by a circular pattern of softening and discoloration. It was long believed that scald was caused by high temperatures, a sort of cooking of the fruit. This is only partially true, soil and air moisture also play a role in the development of scald. Scald is not caused by damage from water droplets left on the fruit following irrigation during daylight hours. A major scald event in New Jersey in August 1990 was studied and some of the factors that lead to this disorder were determined (Croft 1992; Croft 1993). Yield losses of 10% or more were associated with this period of scalding conditions. Weather and bog records for the days of the scald occurrence showed low relative humidity (20%), excessive temperature in the vines (100°F) with shelter temperature of only about 80°F, strong solar radiation (very bright skies), extremely low soil moisture in the upper layer, and a large amount of heat release from the soil to the atmosphere each afternoon.

Cranberry plants cool themselves through a process called transpiration, in which water carried up though the roots into the leaves is released through pores (stomata) in the leaf surface. As the escaping water evaporates at the leaf surface, energy is used and the leaf cools (evaporative cooling). Cranberry plants have little ability to control water flow out of the stomata. When the air is dry and the surface of the plant is very hot, water is rapidly lost, sometimes faster than it can be replaced from the roots. If the soil is dry, the water loss can become critical. Cranberry fruit do not transpire, but may be cooled by water circulation within the fruit. However, when water is limiting and transpiration from the leaves is rapid, water may be drawn from the fruit. As the fruit overheat, scald develops.

If moisture is available in the soil, transpiration and water circulation should be adequate to cool the plants and fruit. Occasionally, conditions occur where water loss is too rapid for the plants to replace transpiration losses even in moist soil. Such conditions may lead to scald. If the soil is dry, these conditions will develop more rapidly. Because scald can develop even when irrigation or rainfall has been adequate, a forecast for scalding conditions was important. Based on observations made in 1990, a scald forecast was developed for New Jersey.

Scald Forecast Checklist for New Jersey
adapted from Croft (1992)

Meteorological predictors:

•Dew points of 55°F or less during midday hours.

•High temperatures of 80°F or more (sheltered).

•Clear or scattered sky conditions.

•Recent development of high pressure dropping down from the north.

Contributing factors:

•Low moisture in the bog soil.

•Wind speed of more than 10 knots.

•No rainfall in the past 48 hours.

When scald is forecast, sprinkler irrigation in the midday to early afternoon hours is recommended to supplement transpiration with external evaporative cooling. The sprinklers should run for at least an hour to thoroughly wet the vines and fruit. Sprinkling should continue long enough for the vines to remain damp until the sheltered temperature drops below 85°F. It is not necessary to continue irrigation until sunset.

Fruit Rot Disease. Franklin and Cross (1948) found a strong relationship between various weather factors and the quality of Massachusetts cranberries. The general reliability of the relationship was responsible for the issuing of keeping quality forecasts starting in 1949 and continuing to the present. A preliminary forecast is issued in early April to aid in decision making regarding the use of late water. Points are awarded based on sunshine, temperature, and rainfall (Tables 3 and 4). A final forecast is issued in early June prior to fungicide applications for fruit rot disease.

Sunshine: Below average total sunshine the year before the crop year has a favorable affect on crop quality. Below average sunshine in February of the crop year is beneficial; however, March sunshine *above* average is favorable.

Temperature: Franklin set threshold temperatures for the months of March, April, May and June and showed that if temperatures were below these thresholds, then the quality of cranberries would be favorably affected. Franklin's threshold temperatures are about two degrees below normal for March and April; nearly normal for May and June.

Rainfall: Less than average rainfall in March, April and May is favorable for keeping quality.

From 1948 through 2007, the keeping quality forecasts issued by the UMass Cranberry Station had an 87.9% success rate, with quality no worse than predicted. In only 13 years (12%) was the quality poorer than predicted, while in 21 years (20%) the quality was better than forecasted.

In addition to the normal forecast factors, there appears to be a strong relationship between sunshine during the months of June, July, and August and the keeping quality forecast. During the years when the keeping quality was not as good as predicted, less than normal sunshine occurred in all three months. Summers with above normal sunshine for the three months were associated with quality as good or better than predicted. The month that appeared to exert the greatest influence was July, if the departure from normal was greater than ten percent.

Table 3. Factors affecting how points are awarded for the keeping quality forecast (Franklin and Cross, 1948: Table 1; Franklin and Stevens, 1946: Tables 11 and 12).

1. If the total of sunshine hours from previous year is less than the 50-year average of 2,274 hours. **4 points**

2. If the total of sunshine hours for February for the present year is less than the 50-year average for that month (143 hr). **1 point**

3. If the total of sunshine hours for March for the present year is more than the 50-year average for that month (179 hr). **2 points**

4. If the total precipitation for March for the present year is less than the average of East Wareham and Middleboro mean of 4.39 inches. **1 point**

5. If the average temperature for March of the present year at Middleboro is below the March threshold of 34°F. **2 points**

6. If the average temperature for April for the present year at Middleboro is below the April threshold of 44°F. **2 points**

7. If the total precipitation for April for the present year is less than the average of East Wareham and Middleboro (6.70 inches). **1 point**

8. If the average temperature for May for the present year at Middleboro is below the May threshold of 52°F. **2 points**

9. If the total precipitation for May for the present year is less than the average of East Wareham and Middleboro (3.20 inches). **1 point**

MAXIMUM POINTS 16

Table 4. Possible point totals from items 1-5 (Table 3). These totals are applied to the preliminary keeping quality report only.

0 = Very poor
1 = Poor
2 = Poor to fair
3 = Fair
4 = Fair to good
5 = Good
6 = Very good
7 = Very good to excellent
8 = Excellent
(9 or 10 points never awarded)

FLOWER BUD INITIATION AND DEVELOPMENT

Cranberry flower buds are initiated in the year before the crop is harvested. The signal to initiate flower buds comes from the leaves. By removing the mature leaves at different times, one can determine when the signal for the floral induction event is sent. That date was determined to be July 8 in Wisconsin (Roberts and Struckmeyer 1943) and July 4 in British Columbia (Eaton 1978). Daylength seems to play a controlling role in this process but a certain minimum temperature may also be required (Pilcher, 1985). By August, the initial stages of the flower bud could be observed and visible changes in the buds continued until some time in October in Wisconsin. Bud development almost certainly continues later into the year in milder growing areas. Eventually the flower buds become dormant until the following spring. The signal to enter dormancy is most likely a combination of low temperatures and short days.

Chilling. During the dormant period, chilling units accumulate. In the most simple models, chilling units are recorded as the number of hours below a critical base temperature. Research in many crops indicates that chilling units cease to accumulate at very low temperatures, most likely when temperatures drop below 32°F. In common with other perennial fruit crops, the cranberry plants must accumulate a critical number of chilling units in order to break dormancy in the spring and initiate flowering for the new season. The time during that chilling units accumulate is referred to as a rest period. Once the critical number of chilling units is accumulated, the chilling requirement is satisfied and the plants will break dormancy as soon as external environmental conditions, primarily temperature and lengthening days, are favorable.

Chandler and Demoranville (Chandler and Demoranville 1964) proposed that 2,500 hours below 45°F were required as a rest period for cranberries prior to bud break and normal flowering. At greater than 1,500 hours (but less than 2,500), some abnormal flowering was observed. However, their plants were chilled in the dark. When chilling conditions were applied to cranberries under an 8- or 9-hour daylength (similar to field conditions), approximately 1,000 hours of chilling below 45°F was sufficient for subsequent flowering (Eady and Eaton 1969; Pilcher 1985). However, longer chilling periods hastened the flowering response.

It appears that chilling units alone do not account for optimum flowering response. A daily period above 45°F combined with daily hours below 45°F and a 9-hour daylength allowed a flowering response after 1,000 hours of chilling, whereas at constant temperatures below 45°F, 2,500 hours of chilling were required to get the same response (Eady and Eaton 1972; Rigby and Dana 1972). In addition, rapid transition to flowering after chilling required long days. If daylength was limited to 8 hours after the completion of chilling, flowering was abnormal (Rigby and Dana 1972).

A chilling model was developed based on these research results (Hawker and Stang 1985). The model was based on accumulation of daily chilling units when the minimum daily temperatures were between 51°F and 30°F. The start and end dates for accumulation were based on daylength as well as minimum temperature. Chill unit accumulation began when daylength was 14.5 hours (Wisconsin) or when minimum daily temperature fell to 51°F (lower latitudes) and continued until daylength was again 14.5 hours or minimum daily temperature rose to 30°F.

Strik and DeMoranville compared chilling requirement of Stevens cranberry in Oregon and Massachusetts using the simplified model of counting hours between 32ºF and 45ºF. Using this approach, the chilling requirement in Oregon was ~600 hours while in Massachusetts the requirement was only met after ~1800 hours. In addition, using this method, Stevens (from beds less than 5 years old) in Massachusetts had adequate chilling after only 1100 hours. The interregional differences offer evidence that the simple model may not be adequate to describe the cranberry chilling requirement. However, the variation between the requirement of plants from juvenile vs. mature Stevens beds remains unexplained.

Post-chilling. At the end of the period during which chilling units accumulate, events leading to bud break and flowering may begin. Once dormancy has broken in response to increased temperature and daylength, completion of the developmental cycle (vegetative growth, flowering, and fruiting) depends on the accumulation of heat units or growing degree days (GDD). Investigators in Wisconsin and Washington (Hall and Stark 1972; Hawker and Stang 1985) showed that flower and fruit development were dependent on the accumulation of GDD, with both occurring in a predictable manner based on models for heat unit accumulation. The Washington model emphasized the importance of moderate temperatures between 45°F and 85°F (Pilcher, 1985). Research in Massachusetts has identified 40ºF as the appropriate base temperature for compiling GDD for cranberry (DeMoranville, 1992). Vanden Heuvel and DeMoranville (unpublished data) found that plants began vegetative growth (leaf expansion) at about 500 GDD and initial fruit development began at approximately 1500 GDD.

Water Use in Cranberry Production

Carolyn DeMoranville

Water is the single most important resource for growing cranberries. Growers rely on a plentiful supply of clean water for the production of their crop. Cranberry growers manage water on their beds to ensure sufficient moisture and adequate drainage for optimum plant growth. Water management practices on cranberry beds differ from those used for other forms of agriculture because of the variety of ways that water is used in cranberry culture. Water is used for disease and insect control, frost and heat protection, sanding, harvesting, and protection from winter desiccation and cold injury. Because of the periodic need for sizable amounts of water, impoundment of water adjacent to the beds is a normal farming practice in cranberry production. In addition to storage ponds and sumps, components of a typical water management system for a cranberry bog include irrigation systems, wells, flood gates and flumes, lift pumps, and drainage ditches and pipes.

Growers may construct bypass canals to reroute water that normally flows through the bog. This practice is designed to protect water quality during fertilizer or pesticide applications. Such canals may be part of a tailwater recovery system as well, enhancing water conservation.

Cranberry growers often re-use water, recapturing it through the use of tailwater recovery systems that move water from the bog back to a storage reservoir. In some instances, water is also recycled among growers, particularly at harvest. Therefore, water uses on cranberry beds are not always consumptive. Newly established beds, however, do require more irrigation to satisfy the needs of growing vines. Because cranberry culture typically is carried out in moist areas such as wetlands and marshes, irrigation needs are limited and comparatively small.

Bruce Lampinen studied evapotranspiration potential in a Massachusetts cranberry bog during the growing season (May through September). He found that on average, the water demand of the cranberry plants was one inch per week. However, on a weekly basis, demand varied from 0.5 inch (early and late season) and as much as 2 inches per week during the hottest days in mid-summer. Additional water is needed in July and August for the sizing of developing fruit. When rainfall is not sufficient to meet these demands, supplemental irrigation water is applied using sprinklers (see the Irrigation chapter).

Table 1 shows estimates of the seasonal water (in acre-feet) needed for cranberry production in peat-based and mineral soil cranberry beds based on a limited study at 4 sites. As a general rule, growers plan for up to 10 acre-feet of water storage capacity to meet all production, harvesting, and flooding needs even in drought years. The actual required capacity will vary depending on the rate of recharge of the water supply, the extent of water recapture and reuse, and the efficiency of the bog system. With the implementation of appropriate BMPs, water needs may be reduced substantially.

Table 1. Estimated water use in cranberry production in acre-feet. Data from a study of 4 bog systems from 2002-2004. Beds in the study were fairly level.

Management Practice	Peat-based beds	Mineral soil beds
Winter flood	1.6	1.5
2nd flood (as needed)	0.9	0.8
Frost protection*	0.7	1.1
Chemigation	0.1	0.1
Irrigation	0.5	0.9
Water harvest	1.6	1.6
Total	**5.4**	**6.0**

*Mineral soil beds tend to be planted with cultivars requiring more frost protection in the spring.

Avg. annual rainfall (1971-2000) -- 3.9 feet

Water Management Act. The Water Management Act (WMA), M.G.L. Chapter 21G, was enacted in 1985 for the purpose of managing water resources in Massachusetts. The act required consumptive use of water beyond a threshold amount (100,000 gal/day or 9 million gallons within a three-month period) to be registered with the Massachusetts Department of Environmental Protection (DEP). Despite the only nominal flux in water use attributed to cranberry growing, the DEP regulated the cranberry industry as 'virtually non-consumptive' in order that cranberry growers would be provided the protections of the WMA in regards to rights to use water.

For cranberry growers, rights to water are determined by the following four factors.

1) <u>Registration</u> of historic use (baseline) in 1988 based on previous 5-year water use. Registrations are renewed every 10 years.

2) The <u>threshold volume</u> of water - for cranberries, this is calculated on an acreage basis so that the threshold for cranberries is 4.66 acres based on water use of 10 acre-feet per year. This threshold is increased 9.33 acres for water-conserving 'new style' bogs that meet certain criteria including level surface, tailwater recovery, water control and irrigation designed to NRCS specifications, and a farm plan in place. If a grower's acreage within a watershed area remains within these thresholds, no registration or permit is required.

3) Addition of acres to a registration or permit based on <u>conservation credits</u> awarded for the implementation of practices that conserve water.

4) Growers may apply for <u>permits</u> for acres that are not covered under the three items above or for new acres.

Growers report their permitted and registered water use annually and pay an annual fee to maintain the registration or permit.

Water Control Structures. Commercial cranberry management requires the ability to manipulate water during the course of the season. Water control structures are essential to a successful cranberry operation. Among these structures are spillways and conduits used to temporarily divert water flow, dikes and flumes, and structures fitting the more traditional definition of a dam used to permanently detain water, creating the reservoirs required in the bog system.

Activities that rely on diking systems and water control structures include flooding the beds, impounding water, manipulation of the water table in the bed, and drainage functions. Dikes are also used to separate the cranberry beds into manageable units for flood harvest.

<u>Dikes</u>: Dikes are embankments constructed of earth or other suitable materials. In cranberry management, perimeter and interior dikes are used to temporarily impound water for harvest, trash (leaf litter) removal, pest control, and winter protection. Dikes are also used to impound water for the preservation of water quality, limiting the discharge of sediments and segregating waters following the application of pesticides. Dikes allow the control of water levels to maintain the depth from rooting zone to water table for optimum cranberry growth and productivity. Dikes surrounding tailwater or other irrigation ponds facilitate water storage.

Dikes are constructed to a height 1 foot above the normal flood elevation of the bog. Dikes are stabilized by seeding to grass or other plants, by mulching, or by placing soil stabilization fabric (e.g., geotextile, netting, or burlap). Vegetated embankments are maintained by mowing as needed to prevent the spread of seeds onto the beds and to facilitate removal of berries during flood harvest.

<u>Flumes</u>. Flumes are water control structures (usually constructed of steel, aluminum, or concrete) that are installed in a dike to convey water, control the direction of flow, or maintain a required water surface elevation.

In cranberry systems, the primary purpose of the flume is to control discharge, distribution, delivery, or direction of water flow in open channels (ditches, canals) or on the cranberry beds. They are also used for water quality control, holding back sediment and impounding water following pesticide applications.

Flumes designed for controlling water movement onto cranberry beds have a structure elevation such that a foot-deep flood can be maintained on the bed. Flumes designs should allow the water table to be lowered to an adequate depth to favor proper rooting during the growing season.

<u>Drainage</u>. Proper soil drainage results in healthy vines that reduce the incidence of diseases such as root rot and the need for fungicide applications for its control. Proper drainage also improves fertilizer use efficiency resulting in lower fertilizer inputs. Waterlogged soils lead to a poorly aerated root zone and limit the plants' ability to acquire nutrients from the soil. In addition, saturated soil conditions can limit the ability of the cranberry plant to retain fruit.

The drainage system should have the capacity to carry water away from the bog and regulate the water table level as management needs dictate. Cranberry drainage systems may include ditches, subsurface tiles, pumping systems, ponds, sumps, and tailwater recovery.

Additional drainage is required if one or more of the following conditions is present: water accumulates on the surface of the bog for extended periods, erosion occurs, vines or fruit show damage from low aeration, Phytophthora root rot is present or is increasing, an anaerobic, swampy odor is present, soil test manganese levels exceeds 800 ppm, or yields are down.

<u>For additional information:</u>

DeMoranville, C. J. and Sandler, H. A. (2000). Water Resource Protection and Enhancement. Best management practices guide for Massachusetts cranberry production. http://www.umass.edu/cranberry/services/bmp/waterresource.shtml.

Cape Cod Cranberry Growers Association Grower Advisories:
Dam Monitoring and Maintenance
http://www.cranberries.org/pdf/advisories/dam_monitoring_maintenance_2007.pdf.

Water Management Act
http://www.cranberries.org/pdf/advisories/water_management_act.pdf.

Sprinkler System Design, Use, and Performance

Dan Barnett, Jack Heywood, and Peter Jeranyama

A sprinkler system is a collection of component devices which, powered by a pump, transports water from either groundwater or surface water (e.g., a small man-made reservoir, or a natural water body like a pond, stream or lake) that projects water into the air and deposits it onto the surface of the ground. It consists of metal or plastic pipes, which are either horizontal (mains, submains, and laterals) or vertical (risers), and rotating sprinkler heads, made mostly of metal, with nozzles mounted in them. The horizontal pipes are typically buried under the surface. There are also a number of other parts including fittings, valves, vents, filters, etc.

Purchasing and accepting a design of a sprinkler system are probably some of the most important decisions that a cranberry grower will make. Before designing a system, examine the water source to be sure that it is of acceptable quantity and quality. One should consider the wide range of present and future water needs when deciding on pump specifications, capabilities, and location, as well as the traits of all the components to be sure that they will function in a compatible and integrated manner. The design of the system should avoid excessive water velocities, and limit the pressure loss due to friction as water moves through the system.

John Norton, an agricultural engineer with the Cooperative Extension Service, wrote a paper summarizing the history of design and use of sprinkler systems on cranberry beds (Norton 1987). He included the results of low temperature research conducted at the Cranberry Station in the 1950's when there were relatively few sprinkler systems on commercial cranberry beds. Because of that work, sprinkler system use has expanded and can be found on nearly every bog today. As one grower has said, "It is probably our most important tool; we use it for almost everything." Three vital operations performed by sprinklers on cranberry beds are irrigation, frost protection, and chemigation (see next three chapters).

Irrigation applies supplemental water for plant growth and berry development. Frost protection applies water to prevent damage to buds and berries when they are sensitive to temperatures below freezing. Chemigation is the process of applying chemicals by injecting them into the sprinkler system. This application method is commonly used with many pesticides and some fertilizers used on the beds. Unlike systems designed for other crops that may only use one or two operations, cranberry sprinkler design must consider and balance the special needs of all three practices.

The Sprinkler System Standard used by the USDA Natural Resources Conservation Service (NRCS) instructs that design requirements be based on a Coefficient of Uniformity (CU). This measurement of the evenness of water application is expressed as a percentage. It was developed by J.E. Christiansen (Christiansen 1942) and is calculated by doing a catchcan test. This test involves setting out cans in a grid pattern between sprinklers and comparing the quantity of water caught in each can. The NRCS design specifications mandate the system to achieve a CU of at least 85% whenever any one of the following three criteria is met:

- Use on a high-value crop.
- Use on a shallow-rooted crop.
- Used to dispense chemicals.

Sprinkler systems used in cranberry production meet all three of these criteria.

Two situations could occur if a lower CU were used. First, the shallow-rooted cranberry plants could suffer moisture stress. Second, chemigation would be unsatisfactory because the system would be depositing either too much chemical in some places (a possible environmental, phytotoxic, or food residue problem) and/or too little in other places (resulting in poor pest control and inadequate fertilization). Furthermore, investing in a high performance system is economically justified because of the high dollar value of cranberries and the improvement in the quantity and quality of the crop.

In 2004, the Center for Irrigation Technology (CIT) at the California State University-Fresno, California Agricultural Technology Institute in cooperation with the Cape Cod Cranberry Growers' Association (CCCGA), conducted numerous tests to check the efficiency of various sprinkler head for potential use in cranberry systems. As a result of these tests, systems have been designed to incorporate new technology. These include the use of pop-ups heads that are designed to be less labor-intensive and more economical.

TRADITIONAL SYSTEMS

Head Spacing. Sprinkler heads on cranberry beds are arranged in a triangular staggered pattern to provide better coverage on the irregular shapes of the cranberry farm. When the spacing is described, the first, smaller number refers to the spacing <u>between laterals</u> on the main pipe, and the second, larger number refers to the distance <u>between heads</u> on a lateral. Several different spacings are used in modern cranberry production.

Although rare in Massachusetts now, 60' x 70' spacings used to be common in the industry. Decline in the use of systems with this design is just as well because their CU's are poor. Currently, 50' x 60' spacings are the most common design. This spacing is capable of achieving a CU of 85%, but only if close attention is paid to some critical details. Spacings of 40' x 50' are also used in some cases.

Wind. Cranberry sprinkler systems are designed to function in 0-5 mph wind conditions. Chemigation should only be done when the wind is calm. Most often, calm conditions prevail during times when frost protection is needed, permitting good coverage. Irrigation is also typically done in the calm early morning hours (unless the grower is trying to cool the bog during extremely hot weather).

Pressure. The best CU for common spacings occurs when the system is run at a minimum of 40 psi. If the pressure is lower, the CU goes down. Increasing the pressure to 55 psi does not significantly improve the CU. Therefore, the pump should be run at a high enough pressure to enable the <u>weakest head</u> in the system to operate at 40 psi. The pressure differential between the pump and the weakest head, and the pressure variation throughout the system as a whole, will be small (less than 15%) if the main and laterals are properly sized to reduce the pressure losses due to friction.

Risers. Risers are vertical pieces of pipe that connect the sprinkler head to the underground lateral (Fig. 1). These simple items have a critical effect on CU. It is absolutely necessary that they be long enough on a 50' x 60' system to make the nozzle 18 inches higher than the top of the vines in order to get a CU of 85%. They must be rigid and perfectly plumb, or the CU can drop by 10% or more. This is why the 50' x 60' spacing requires such a high level of attention. The only practical way to keep the riser plumb is to anchor it. Growers may pour cement around the riser to stabilize it while still allowing for its removal before picking operations begin. Others stake the riser with either wood or metal. An ingenious plastic stake that requires some skill to install and remove is also available.

Sprinkler Heads. The sprinkler heads used on cranberry beds are operated best with only one open outlet. Sprinkler heads with two outlets (front and rear) are available, but do not deliver acceptable performance on cranberry beds. A 0.75-inch size head is used on a 50' x 60' system. The body is made of brass with a spoon drive arm, also made of brass. One manufacturer offers an aluminum arm, claiming that it works better during frost protection. This same head can also be used on a 40' x 50' system, but a smaller nozzle must be used and some modifications may be necessary. Some types of 0.5-inch size heads are compatible with 40'x50' spacings. Most of these smaller heads are made of brass (plastic body heads are available but these cannot be used for frost protection). Some are made of stainless steel, and both come with either a spoon drive arm or a wedge drive arm (for faster turning). Whatever size and type is chosen, it must be able to turn at least once per minute to provide good frost protection. This requires the right match of nozzle size with drive arm, spring tension, and washers in order to operate correctly.

Fig. 1. Impact sprinkler head on metal riser. Photo courtesy H. Sandler.

One way to prevent spraying sensitive areas during chemigation is to use screens with full-circle (FC) heads. Another way is to use part-circle (PC) heads. A PC head set at 180° waters its area twice for each complete rotation of a FC head. Therefore, ideally, these PC heads should have an output equal to half of an FC head. This is not always possible because FC heads can run with smaller nozzles than PC heads. The best, lowest output PC head is a half-inch size with a 7/64-inch nozzle. If clogging is a concern, then a 1/8-inch nozzle could be used. This head should be used with both 50'x60' and 40'x50' systems. The CU for an area with PC heads drops about 10% on a 50'x60', and about 5% on a 40'x50'. Once again, the closer spacing is superior.

Nozzles. The proper size nozzle for a 50'x60' system is 5/32-inch, rated at 4.5 gallon per minute (gpm) when run at 40 psi. This produces a precipitation rate of 0.144 acre-inch per hour. A 40'x50' system uses a 1/8-inch nozzle rated at 2.96 gpm operated at 40 psi. The precipitation rate in this case is 0.142 acre-inch per hour. The output of the two spacings is almost the same because the smaller size nozzles on the 40'x50' system compensate for the fact that it has more heads per acre.

New nozzle styles are available that are superior to the common round hole, straightbore (SB) nozzle. They are given different names by each manufacturer. For example, Rainbird calls theirs, LPN nozzles. They are made of plastic and have a square hole. Weather-Tec calls theirs a 'multi pressure' nozzle; it is made of brass with a stainless steel insert. It has three points that flare slightly at the tip of the nozzle, orientated as if they were on a clock face at the 12, 4, and 8 o' clock position. All of these nozzles can be referred to as high uniformity (HU) nozzles because they improve the CU by 10%. They do not deliver as tight a water stream as regular round hole nozzles. Some of the water breaks away at the corners or flares as it leaves the end of the nozzle, and falls in areas not well watered by the standard SB nozzle. HU and SB nozzles come in approximately the same size and may be used in both full- and part-circle heads.

Straightbore nozzles with vanes (special plastic inserts that narrow the water stream) were found to produce CU's that were no better than plain straightbore nozzles even when they were run with 10-15 psi more pressure (Center for Irrigation Technology 2004).

NEW AND INNOVATIVE SYSTEMS

Head Spacing. New systems can be triangular or rectangular with numerous spacing configurations. Coefficient of uniformity can approach 91% with the right combination of head, spacing and pressure.

For example, a system with Hunter I-20 high pop (hp) heads and a number 3.5 nozzle at 40 psi on a 50' x 35' triangular spacing delivers a CU of 91%.

A 50’ x 60’ system head swap (Hunter I-20 hp for Impact head) will deliver an approved 87% CU with a number 4 nozzle at 50 psi (weakest head).

Wind. It is similar to traditional systems.

Pressure. The best CU is achieved with the new systems operating at 40 to 50 psi depending on the spacing chosen.

Risers. Same as traditional system, if needed.

Sprinkler Heads. As a result of tests performed by California Agricultural Technology Institute, Fresno, in 2004 (Center for Irrigation Technology 2004), the following heads can be used:

1. Hunter 12” high pop-up
2. Rainbird 14.5” impact on 12” to 18” risers, depending on spacing and pressure
3. Weather-TEC GSO ½” impact head on 12” to 18” risers, depending on spacing and pressure

See following tables for pressure, nozzle size, spacing type, spacing dimensions and CU for pop-up and impact heads. Pressure for all impact head data is 40 psi. For impact head tables, RB = Rainbird; WT = WeatherTec. Spacings listed for all data are industry conventions; reverse for cranberry. Popup head data results from SpacePro Program (CIT), 10/26/04. Impact head data results from SpacePro Program (CIT), 5/3/05.

Nozzles. Straightbore nozzles (manufactured by Hunter and Rainbird) and WTEC multipressure nozzles produce the required performance of CU ≥85% with a minimum precipitation rate of 0.095 inches per hour, while the average is ≤ 0.18 inches per hour.

One advantage of new systems with Hunter pop-ups is the flexibility of nozzle choice. Hunter pop-ups have five interchangeable nozzle sizes. Precipitation rates can be customized to bog wet/dry conditions, based on nozzle choice. In addition these new systems have improved uniformity, ability to turn individual heads on and off, and decreased vandalism.

FINAL REMARKS

As growers continue to seek to increase production and efficiencies on their beds, sprinkler systems have to become more precise instruments. Their use for many different tasks puts a high demand on the system’s designer, components, and users.

An intelligent design that makes use of the latest data and technology, which is carefully installed and wisely operated, will go a long way toward helping the grower obtain an abundant, high quality harvest. It also helps to save energy costs and conserves water.

The following tables represent a collaboration of efforts:
Work was conducted by Center for Irrigation Technology at California State University, funded by Cape Cod Cranberry Growers Association, and analyzed by Dave Nelson, USDA, Natural Resource Conservation Service.

Hunter I-20 Pop-Up Heads

Overlap Uniformities from Profile Test

(white)	Better design layouts (CU > 87%; DU > 78%; SC < 1.2; Min in/hr > 0.095; Mean in/hr < 0.18)
(gray)	Layouts meeting minimum criteria (CU > 85%; DU > 76%; SC < 1.3; Min in/hr > 0.095; Average in/hr < 0.25)

Nozzle	Pressure	GPM	Spacing Type	Industry Spacing	CU	DU	SC(5%)	in/hr (min)	in/hr (ave)	in/hr (max)	Heads per acre	GPM per acre
#3	40	2.49	Rectangular	40.0 x 40.0	89%	85%	1.2	0.100	0.132	0.192	27	67.2
#3	50	2.72	Triangular	60.0 x 30.0	91%	87%	1.1	0.106	0.139	0.216	24	65.3
#3	50	2.72	Triangular	55.0 x 30.0	91%	88%	1.2	0.114	0.152	0.216	26	70.7
#3	50	2.72	Triangular	50.0 x 40.0	89%	82%	1.2	0.096	0.126	0.216	22	59.8
#3	50	2.72	Triangular	50.0 x 35.0	89%	82%	1.3	0.096	0.143	0.216	25	68.0
#3	50	2.72	Triangular	45.0 x 45.0	88%	83%	1.2	0.095	0.124	0.216	22	59.8
#3	50	2.72	Triangular	45.0 x 40.0	87%	80%	1.2	0.098	0.139	0.216	24	65.3
#3	50	2.72	Triangular	45.0 x 35.0	89%	81%	1.3	0.104	0.159	0.216	28	76.2
#3	50	2.72	Triangular	40.0 x 45.0	89%	81%	1.3	0.096	0.139	0.216	24	65.3
#3	50	2.72	Triangular	40.0 x 40.0	89%	82%	1.3	0.103	0.157	0.216	27	73.4
#3	50	2.72	Triangular	35.0 x 45.0	93%	87%	1.3	0.096	0.159	0.244	28	76.2
#3	50	2.72	Rectangular	50.0 x 40.0	88%	84%	1.2	0.096	0.126	0.216	22	59.8
#3	50	2.72	Rectangular	50.0 x 35.0	88%	82%	1.2	0.096	0.143	0.244	25	68.0
#3	50	2.72	Rectangular	45.0 x 45.0	91%	87%	1.1	0.096	0.124	0.216	22	59.8
#3	50	2.72	Rectangular	45.0 x 40.0	91%	86%	1.2	0.100	0.139	0.216	24	65.3
#3	50	2.72	Rectangular	45.0 x 35.0	91%	86%	1.2	0.112	0.159	0.244	28	76.2
#3	50	2.72	Rectangular	40.0 x 50.0	88%	84%	1.2	0.096	0.126	0.216	22	59.8
#3	50	2.72	Rectangular	40.0 x 45.0	91%	86%	1.2	0.100	0.139	0.216	24	65.3
#3	50	2.72	Rectangular	40.0 x 40.0	91%	88%	1.1	0.118	0.157	0.216	27	73.4
#3	50	2.72	Rectangular	35.0 x 50.0	88%	82%	1.2	0.096	0.143	0.244	25	68.0
#3	50	2.72	Rectangular	35.0 x 45.0	91%	86%	1.2	0.112	0.159	0.244	28	76.2
#3.5	40	3.03	Triangular	35.0 x 50.0	91%	87%	1.2	0.132	0.161	0.226	25	75.8
#3.5	40	3.03	Rectangular	35.0 x 45.0	90%	84%	1.2	0.132	0.179	0.225	28	84.8
#3.5	40	3.03	Triangular	30.0 x 60.0	86%	79%	1.2	0.114	0.157	0.242	24	72.7
#3.5	40	3.03	Triangular	30.0 x 55.0	88%	82%	1.2	0.126	0.171	0.242	26	78.8
#3.5	40	3.03	Rectangular	55.0 x 35.0	88%	83%	1.3	0.110	0.147	0.225	23	69.7
#3.5	40	3.03	Rectangular	55.0 x 30.0	86%	80%	1.3	0.110	0.171	0.242	26	78.8
#3.5	40	3.03	Rectangular	50.0 x 35.0	87%	83%	1.3	0.114	0.161	0.226	25	75.8
#3.5	40	3.03	Rectangular	45.0 x 35.0	87%	80%	1.3	0.124	0.179	0.228	28	84.8
#3.5	40	3.03	Rectangular	35.0 x 55.0	88%	83%	1.3	0.110	0.147	0.225	23	69.7
#3.5	40	3.03	Rectangular	35.0 x 50.0	87%	83%	1.3	0.114	0.161	0.226	25	75.8

Hunter I-20 Pop-Up Heads

Overlap Uniformities from Profile Test

(white box) Better design layouts (CU ≥ 87%; DU ≥ 78%; SC ≤ 1.2; Min in/hr ≥ 0.095; Mean in/hr ≤ 0.18)

(gray box) Layouts meeting minimum criteria (CU ≥ 85%; DU ≥ 76%; SC ≤ 1.3; Min in/hr ≥ 0.095; Average in/hr ≤ 0.25)

Nozzle	Pressure	GPM	Spacing Type	Industry Spacing	CU	DU	SC(5%)	in/hr (min)	in/hr (ave)	in/hr (max)	Heads per acre	GPM per acre
#3.5	40	3.03	Rectangular	35.0 x 45.0	87%	80%	1.3	0.124	0.179	0.228	28	84.8
#3.5	40	3.03	Rectangular	30.0 x 55.0	86%	80%	1.3	0.110	0.171	0.242	26	78.8
#4	40	3.76	Rectangular	50.0 x 40.0	86%	83%	1.3	0.106	0.172	0.263	22	82.7
#4	40	3.76	Rectangular	45.0 x 45.0	86%	86%	1.1	0.125	0.169	0.263	22	82.7
#4	40	3.76	Rectangular	40.0 x 50.0	86%	83%	1.2	0.106	0.172	0.263	22	82.7
#4	50	4.26	Triangular	65.0 x 40.0	86%	77%	1.3	0.101	0.154	0.215	17	72.4
#4	50	4.26	Triangular	60.0 x 50.0	87%	83%	1.2	0.101	0.133	0.215	15	63.9
#4	50	4.26	Triangular	60.0 x 45.0	85%	77%	1.3	0.108	0.148	0.215	16	68.2
#4	50	4.26	Triangular	55.0 x 50.0	85%	78%	1.3	0.108	0.146	0.215	16	68.2
#4	50	4.26	Triangular	50.0 x 55.0	85%	77%	1.3	0.096	0.146	0.215	16	68.2
#4	50	4.26	Rectangular	60.0 x 45.0	85%	79%	1.3	0.103	0.148	0.215	16	68.2
#4	50	4.26	Rectangular	55.0 x 50.0	87%	81%	1.2	0.107	0.146	0.215	16	68.2
#4	50	4.26	Rectangular	50.0 x 55.0	87%	81%	1.2	0.107	0.146	0.215	16	68.2
#4	50	4.26	Rectangular	50.0 x 50.0	89%	80%	1.3	0.108	0.160	0.23	17	72.4
#4	50	4.26	Rectangular	50.0 x 45.0	89%	81%	1.3	0.109	0.178	0.257	19	80.9
#4	50	4.26	Rectangular	45.0 x 60.0	85%	79%	1.3	0.103	0.148	0.215	16	68.2
#4	50	4.26	Rectangular	45.0 x 55.0	89%	81%	1.3	0.108	0.162	0.226	18	76.7
#4	50	4.26	Rectangular	45.0 x 50.0	89%	81%	1.3	0.109	0.178	0.257	19	80.9
#6	50	5.93	Triangular	65.0 x 50.0	88%	82%	1.3	0.100	0.170	0.228	13	77.1
#6	50	5.93	Triangular	60.0 x 55.0	89%	84%	1.3	0.100	0.167	0.228	13	77.1
#6	50	5.93	Rectangular	60.0 x 55.0	86%	81%	1.3	0.100	0.167	0.244	13	77.1
#6	50	5.93	Rectangular	55.0 x 60.0	86%	81%	1.3	0.100	0.167	0.244	13	77.1
#8	40	6.30	Rectangular	55.0 x 55.0	86%	82%	1.2	0.116	0.180	0.359	14	88.2
#8	50	6.90	Triangular	65.0 x 55.0	86%	77%	1.2	0.102	0.166	0.252	12	82.8
#8	50	6.90	Triangular	60.0 x 55.0	88%	82%	1.2	0.122	0.180	0.254	13	89.7
#8	50	6.90	Rectangular	65.0 x 55.0	87%	77%	1.3	0.097	0.166	0.239	12	82.8
#8	50	6.90	Rectangular	60.0 x 60.0	90%	82%	1.2	0.099	0.165	0.202	12	82.8
#8	50	6.90	Rectangular	60.0 x 55.0	90%	86%	1.1	0.125	0.180	0.294	13	89.7
#8	50	6.90	Rectangular	55.0 x 65.0	87%	77%	1.3	0.097	0.166	0.239	12	82.8
#8	50	6.90	Rectangular	55.0 x 60.0	90%	86%	1.1	0.125	0.180	0.294	13	89.7

Impact Heads

Overlap Uniformities from Profile Test

(white)	Better design layouts (CU ≥ 87%; DU ≥ 78%; SC ≤ 1.2; Min in/hr ≥ 0.095; Mean in/hr ≤ 0.18)
(gray)	Layouts meeting minimum criteria (CU ≥ 85%; DU ≥ 76%; SC ≤ 1.3; Min in/hr ≥ 0.095; Average in/hr ≤ 0.25)

Sprinkler	Nozzle	Riser Ht	GPM	Spacing Type	Industry Spacing	CU	DU	SC(5%)	in/hr (min)	in/hr (ave)	in/hr (max)	Heads per acre	GPM per acre
RB 14VH	#6.5 WT	12	2.97	Rectangular	30.0 x 30.0	95%	93%	1.1	0.207	0.232	0.268	48	142.6
RB 14VH	#6.5 WT	12	2.97	Rectangular	35.0 x 30.0	95%	91%	1.2	0.153	0.199	0.238	41	121.8
RB 14VH	#6.5 WT	12	2.97	Rectangular	40.0 x 30.0	93%	87%	1.2	0.137	0.174	0.198	36	106.9
RB 14VH	#6.5 WT	12	2.97	Rectangular	45.0 x 30.0	92%	88%	1.2	0.117	0.154	0.194	32	95.0
RB 14VH	#6.5 WT	12	2.97	Rectangular	50.0 x 30.0	90%	85%	1.2	0.099	0.139	0.194	29	86.1
RB 14VH	#6.5 WT	12	2.97	Rectangular	30.0 x 35.0	95%	91%	1.2	0.153	0.199	0.238	41	121.8
RB 14VH	#6.5 WT	12	2.97	Rectangular	35.0 x 35.0	93%	88%	1.2	0.120	0.170	0.208	36	106.9
RB 14VH	#6.5 WT	12	2.97	Rectangular	40.0 x 35.0	91%	85%	1.2	0.106	0.149	0.185	31	92.1
RB 14VH	#6.5 WT	12	2.97	Rectangular	45.0 x 35.0	92%	87%	1.2	0.102	0.132	0.164	28	83.2
RB 14VH	#6.5 WT	12	2.97	Rectangular	30.0 x 40.0	93%	87%	1.2	0.137	0.174	0.198	36	106.9
RB 14VH	#6.5 WT	12	2.97	Rectangular	35.0 x 40.0	91%	85%	1.3	0.106	0.149	0.185	31	92.1
RB 14VH	#6.5 WT	12	2.97	Rectangular	40.0 x 40.0	91%	87%	1.2	0.104	0.130	0.166	27	80.2
RB 14VH	#6.5 WT	12	2.97	Rectangular	30.0 x 45.0	92%	88%	1.2	0.117	0.154	0.194	32	95.0
RB 14VH	#6.5 WT	12	2.97	Rectangular	35.0 x 45.0	92%	87%	1.3	0.102	0.132	0.164	28	83.2
RB 14VH	#6.5 WT	12	2.97	Rectangular	30.0 x 50.0	90%	85%	1.2	0.099	0.139	0.194	29	86.1
RB 14VH	#6.5 WT	12	2.97	Triangular	30.0 x 30.0	92%	90%	1.1	0.197	0.232	0.309	48	142.6
RB 14VH	#6.5 WT	12	2.97	Triangular	35.0 x 30.0	95%	90%	1.2	0.159	0.199	0.258	41	121.8
RB 14VH	#6.5 WT	12	2.97	Triangular	40.0 x 30.0	95%	92%	1.1	0.153	0.174	0.195	36	106.9
RB 14VH	#6.5 WT	12	2.97	Triangular	45.0 x 30.0	93%	90%	1.1	0.128	0.154	0.178	32	95.0
RB 14VH	#6.5 WT	12	2.97	Triangular	50.0 x 30.0	91%	87%	1.2	0.108	0.139	0.174	29	86.1
RB 14VH	#6.5 WT	12	2.97	Triangular	55.0 x 30.0	91%	87%	1.2	0.103	0.126	0.161	26	77.2
RB 14VH	#6.5 WT	12	2.97	Triangular	60.0 x 30.0	92%	89%	1.1	0.097	0.116	0.148	24	71.3
RB 14VH	#6.5 WT	12	2.97	Triangular	30.0 x 35.0	92%	88%	1.2	0.166	0.199	0.233	41	121.8
RB 14VH	#6.5 WT	12	2.97	Triangular	35.0 x 35.0	94%	92%	1.1	0.148	0.170	0.191	36	106.9
RB 14VH	#6.5 WT	12	2.97	Triangular	40.0 x 35.0	95%	91%	1.2	0.117	0.149	0.164	31	92.1
RB 14VH	#6.5 WT	12	2.97	Triangular	30.0 x 40.0	92%	87%	1.2	0.141	0.174	0.212	36	106.9
RB 14VH	#6.5 WT	12	2.97	Triangular	35.0 x 40.0	94%	90%	1.2	0.120	0.149	0.169	31	92.1
RB 14VH	#6.5 WT	12	2.97	Triangular	30.0 x 45.0	93%	90%	1.1	0.131	0.154	0.194	32	95.0

Impact Heads

Overlap Uniformities from Profile Test

Better design layouts (CU ≥ 87%; DU ≥ 78%; SC ≤ 1.2; Min in/hr ≥ 0.095; Mean in/hr ≤ 0.18)

Layouts meeting minimum criteria (CU ≥ 85%; DU ≥ 76%; SC ≤ 1.3; Min in/hr ≥ 0.095; Average in/hr ≤ 0.25)

Sprinkler	Nozzle	Riser Ht	GPM	Spacing Type	Industry Spacing	CU	DU	SC(5%)	in/hr (min)	in/hr (ave)	in/hr (max)	Heads per acre	GPM per acre
RB 14VH	#6.5 WT	12	2.97	Triangular	35.0 x 45.0	95%	92%	1.1	0.113	0.132	0.164	28	83.2
RB 14VH	#6.5 WT	12	2.97	Triangular	30.0 x 50.0	92%	89%	1.1	0.110	0.139	0.194	29	86.1
WT G50W	#6.5 WT	12	3	Rectangular	45.0 x 30.0	89%	81%	1.3	0.150	0.202	0.289	32	96.0
WT G50W	#6.5 WT	12	3	Rectangular	50.0 x 30.0	88%	83%	1.2	0.133	0.182	0.289	29	87.0
WT G50W	#6.5 WT	12	3	Rectangular	55.0 x 30.0	87%	82%	1.3	0.113	0.165	0.289	26	78.0
WT G50W	#6.5 WT	12	3	Rectangular	35.0 x 35.0	91%	88%	1.2	0.179	0.222	0.332	36	108.0
WT G50W	#6.5 WT	12	3	Rectangular	40.0 x 35.0	89%	82%	1.3	0.134	0.195	0.269	31	93.0
WT G50W	#6.5 WT	12	3	Rectangular	45.0 x 35.0	88%	83%	1.2	0.124	0.173	0.257	28	84.0
WT G50W	#6.5 WT	12	3	Rectangular	50.0 x 35.0	89%	86%	1.2	0.118	0.156	0.257	25	75.0
WT G50W	#6.5 WT	12	3	Rectangular	55.0 x 35.0	89%	84%	1.2	0.105	0.141	0.257	23	69.0
WT G50W	#6.5 WT	12	3	Rectangular	35.0 x 40.0	89%	82%	1.3	0.134	0.195	0.269	31	93.0
WT G50W	#6.5 WT	12	3	Rectangular	40.0 x 40.0	88%	82%	1.3	0.127	0.170	0.223	27	81.0
WT G50W	#6.5 WT	12	3	Rectangular	45.0 x 40.0	88%	85%	1.2	0.111	0.151	0.214	24	72.0
WT G50W	#6.5 WT	12	3	Rectangular	30.0 x 45.0	89%	81%	1.3	0.150	0.202	0.289	32	96.0
WT G50W	#6.5 WT	12	3	Rectangular	35.0 x 45.0	88%	83%	1.2	0.124	0.173	0.257	28	84.0
WT G50W	#6.5 WT	12	3	Rectangular	40.0 x 45.0	88%	85%	1.2	0.111	0.151	0.214	24	72.0
WT G50W	#6.5 WT	12	3	Rectangular	45.0 x 45.0	90%	87%	1.1	0.095	0.135	0.195	22	66.0
WT G50W	#6.5 WT	12	3	Rectangular	30.0 x 50.0	88%	83%	1.2	0.133	0.182	0.289	29	87.0
WT G50W	#6.5 WT	12	3	Rectangular	35.0 x 50.0	89%	86%	1.2	0.118	0.156	0.257	25	75.0
WT G50W	#6.5 WT	12	3	Rectangular	30.0 x 55.0	87%	82%	1.2	0.113	0.165	0.289	26	78.0
WT G50W	#6.5 WT	12	3	Rectangular	35.0 x 55.0	89%	84%	1.2	0.105	0.141	0.257	23	69.0
WT G50W	#6.5 WT	12	3	Triangular	40.0 x 30.0	93%	88%	1.2	0.189	0.227	0.316	36	108.0
WT G50W	#6.5 WT	12	3	Triangular	45.0 x 30.0	92%	91%	1.1	0.173	0.202	0.264	32	96.0
WT G50W	#6.5 WT	12	3	Triangular	50.0 x 30.0	89%	83%	1.2	0.131	0.182	0.228	29	87.0
WT G50W	#6.5 WT	12	3	Triangular	55.0 x 30.0	88%	83%	1.2	0.127	0.165	0.221	26	78.0
WT G50W	#6.5 WT	12	3	Triangular	60.0 x 30.0	88%	85%	1.2	0.124	0.151	0.212	24	72.0
WT G50W	#6.5 WT	12	3	Triangular	65.0 x 30.0	89%	86%	1.2	0.106	0.140	0.2	22	66.0
WT G50W	#6.5 WT	12	3	Triangular	35.0 x 35.0	92%	89%	1.2	0.187	0.222	0.296	36	108.0

Impact Heads

Overlap Uniformities from Profile Test

(white)	Better design layouts (CU ≥ 87%; DU ≥ 78%; SC ≤ 1.2; Min in/hr ≥ 0.095; Mean in/hr ≤ 0.18)
(gray)	Layouts meeting minimum criteria (CU ≥ 85%; DU ≥ 76%; SC ≤ 1.3; Min in/hr ≥ 0.095; Average in/hr ≤ 0.25)

Sprinkler	Nozzle	Riser Ht	GPM	Spacing Type	Industry Spacing	CU	DU	SC(5%)	in/hr (min)	in/hr (ave)	in/hr (max)	Heads per acre	GPM per acre
WT G50W	#6.5 WT	12	3	Triangular	40.0 x 35.0	96%	94%	1.1	0.176	0.195	0.217	31	93.0
WT G50W	#6.5 WT	12	3	Triangular	45.0 x 35.0	93%	89%	1.1	0.134	0.173	0.203	28	84.0
WT G50W	#6.5 WT	12	3	Triangular	50.0 x 35.0	89%	83%	1.2	0.108	0.156	0.196	25	75.0
WT G50W	#6.5 WT	12	3	Triangular	55.0 x 35.0	88%	84%	1.2	0.097	0.141	0.189	23	69.0
WT G50W	#6.5 WT	12	3	Triangular	30.0 x 40.0	88%	82%	1.3	0.158	0.227	0.289	36	108.0
WT G50W	#6.5 WT	12	3	Triangular	35.0 x 40.0	91%	86%	1.2	0.147	0.195	0.257	31	93.0
WT G50W	#6.5 WT	12	3	Triangular	40.0 x 40.0	93%	86%	1.2	0.116	0.170	0.194	27	81.0
WT G50W	#6.5 WT	12	3	Triangular	45.0 x 40.0	89%	81%	1.2	0.101	0.151	0.182	24	72.0
WT G50W	#6.5 WT	12	3	Triangular	30.0 x 45.0	88%	82%	1.3	0.150	0.202	0.289	32	96.0
WT G50W	#6.5 WT	12	3	Triangular	35.0 x 45.0	91%	86%	1.2	0.141	0.173	0.257	28	84.0
WT G50W	#6.5 WT	12	3	Triangular	30.0 x 50.0	89%	85%	1.2	0.144	0.182	0.289	29	87.0
WT G50W	#6.5 WT	12	3	Triangular	35.0 x 50.0	92%	89%	1.1	0.127	0.156	0.257	25	75.0
WT G50W	#6.5 WT	12	3	Triangular	30.0 x 55.0	89%	85%	1.2	0.127	0.165	0.289	26	78.0
RB 30WH	5/32 SB	12	4.51	Triangular	45.0 x 35.0	86%	80%	1.3	0.174	0.236	0.433	28	126.3
RB 30WH	5/32 SB	12	4.51	Triangular	50.0 x 35.0	85%	79%	1.3	0.130	0.212	0.383	25	112.8
RB 30WH	5/32 SB	12	4.51	Triangular	45.0 x 40.0	94%	91%	1.1	0.158	0.206	0.358	24	108.2
RB 30WH	#9 WT	18	4.92	Triangular	50.0 x 40.0	92%	86%	1.1	0.184	0.245	0.463	22	108.2
RB 30WH	#9 WT	18	4.92	Triangular	45.0 x 45.0	90%	82%	1.2	0.158	0.242	0.473	22	108.2
RB 14VH	1/8" SB	12	2.89	Rectangular	35.0 x 30.0	90%	85%	1.3	0.135	0.229	0.327	41	118.5
RB 14VH	1/8" SB	12	2.89	Rectangular	30.0 x 35.0	90%	85%	1.3	0.135	0.229	0.327	41	118.5
RB 14VH	1/8" SB	12	2.89	Triangular	40.0 x 30.0	88%	81%	1.3	0.149	0.200	0.266	36	104.0
RB 14VH	1/8" SB	12	2.89	Triangular	45.0 x 30.0	88%	84%	1.2	0.129	0.178	0.231	32	92.5
RB 14VH	1/8" SB	12	2.89	Triangular	35.0 x 35.0	88%	81%	1.3	0.150	0.196	0.261	36	104.0
RB 14VH	1/8" SB	12	2.89	Triangular	40.0 x 35.0	93%	90%	1.2	0.120	0.172	0.204	31	89.6
RB 30WH	#9 WT	12	4.92	Triangular	50.0 x 35.0	87%	81%	1.2	0.172	0.247	0.481	25	123.0
RB 30WH	#9 WT	12	4.92	Triangular	45.0 x 40.0	93%	88%	1.1	0.167	0.240	0.47	24	118.1
RB 30WH	#9 WT	12	4.92	Triangular	50.0 x 40.0	85%	77%	1.3	0.136	0.216	0.47	22	108.2
WT G50W	#6.5 WT	18	3	Rectangular	50.0 x 30.0	89%	84%	1.2	0.180	0.239	0.344	29	87.0

Impact Heads

Overlap Uniformities from Profile Test

(white)	Better design layouts (CU ≥ 87%; DU ≥ 78%; SC ≤ 1.2; Min in/hr ≥ 0.095; Mean in/hr ≤ 0.18)
(gray)	Layouts meeting minimum criteria (CU ≥ 85%; DU ≥ 76%; SC ≤ 1.3; Min in/hr ≥ 0.095; Average in/hr ≤ 0.25)

Sprinkler	Nozzle	Riser Ht	GPM	Spacing Type	Industry Spacing	CU	DU	SC(5%)	in/hr (min)	in/hr (ave)	in/hr (max)	Heads per acre	GPM per acre
WT G50W	#6.5 WT	18	3	Rectangular	55.0 x 30.0	88%	82%	1.3	0.147	0.218	0.344	26	78.0
WT G50W	#6.5 WT	18	3	Rectangular	45.0 x 35.0	89%	83%	1.2	0.157	0.228	0.311	28	84.0
WT G50W	#6.5 WT	18	3	Rectangular	50.0 x 35.0	89%	86%	1.3	0.152	0.205	0.311	25	75.0
WT G50W	#6.5 WT	18	3	Rectangular	55.0 x 35.0	89%	84%	1.3	0.141	0.187	0.311	23	69.0
WT G50W	#6.5 WT	18	3	Rectangular	40.0 x 40.0	89%	82%	1.3	0.168	0.224	0.286	27	81.0
WT G50W	#6.5 WT	18	3	Rectangular	45.0 x 40.0	88%	85%	1.2	0.149	0.199	0.271	24	72.0
WT G50W	#6.5 WT	18	3	Rectangular	50.0 x 40.0	90%	85%	1.2	0.117	0.180	0.255	22	66.0
WT G50W	#6.5 WT	18	3	Rectangular	55.0 x 40.0	89%	83%	1.3	0.112	0.163	0.232	20	60.0
WT G50W	#6.5 WT	18	3	Rectangular	35.0 x 45.0	89%	83%	1.2	0.157	0.228	0.311	28	84.0
WT G50W	#6.5 WT	18	3	Rectangular	40.0 x 45.0	88%	85%	1.2	0.149	0.199	0.271	24	72.0
WT G50W	#6.5 WT	18	3	Rectangular	45.0 x 45.0	90%	86%	1.1	0.127	0.177	0.257	22	66.0
WT G50W	#6.5 WT	18	3	Rectangular	50.0 x 45.0	91%	86%	1.2	0.113	0.160	0.238	19	57.0
WT G50W	#6.5 WT	18	3	Rectangular	55.0 x 45.0	89%	83%	1.2	0.102	0.145	0.209	18	54.0
WT G50W	#6.5 WT	18	3	Rectangular	30.0 x 50.0	89%	84%	1.2	0.180	0.239	0.344	29	87.0
WT G50W	#6.5 WT	18	3	Rectangular	35.0 x 50.0	89%	86%	1.3	0.152	0.205	0.311	25	75.0
WT G50W	#6.5 WT	18	3	Rectangular	40.0 x 50.0	90%	85%	1.2	0.117	0.180	0.255	22	66.0
WT G50W	#6.5 WT	18	3	Rectangular	45.0 x 50.0	91%	86%	1.2	0.113	0.160	0.238	19	57.0
WT G50W	#6.5 WT	18	3	Rectangular	50.0 x 50.0	91%	85%	1.2	0.111	0.144	0.209	17	51.0
WT G50W	#6.5 WT	18	3	Rectangular	30.0 x 55.0	88%	82%	1.2	0.147	0.218	0.344	26	78.0
WT G50W	#6.5 WT	18	3	Rectangular	35.0 x 55.0	89%	84%	1.3	0.141	0.187	0.311	23	69.0
WT G50W	#6.5 WT	18	3	Rectangular	40.0 x 55.0	89%	83%	1.3	0.112	0.163	0.232	20	60.0
WT G50W	#6.5 WT	18	3	Rectangular	45.0 x 55.0	89%	83%	1.2	0.102	0.145	0.209	18	54.0
WT G50W	#6.5 WT	18	3	Triangular	50.0 x 30.0	90%	84%	1.2	0.177	0.239	0.298	29	87.0
WT G50W	#6.5 WT	18	3	Triangular	55.0 x 30.0	88%	83%	1.2	0.168	0.218	0.283	26	78.0
WT G50W	#6.5 WT	18	3	Triangular	60.0 x 30.0	88%	85%	1.2	0.159	0.199	0.271	24	72.0
WT G50W	#6.5 WT	18	3	Triangular	65.0 x 30.0	89%	86%	1.1	0.142	0.184	0.261	22	66.0
WT G50W	#6.5 WT	18	3	Triangular	70.0 x 30.0	90%	85%	1.2	0.121	0.171	0.237	21	63.0
WT G50W	#6.5 WT	18	3	Triangular	45.0 x 35.0	94%	89%	1.1	0.179	0.228	0.271	28	84.0

Impact Heads

Overlap Uniformities from Profile Test

(white)	Better design layouts (CU ≥ 87%; DU ≥ 78%; SC ≤ 1.2; Min in/hr ≥ 0.095; Mean in/hr ≤ 0.18)
(gray)	Layouts meeting minimum criteria (CU ≥ 85%; DU ≥ 76%; SC ≤ 1.3; Min in/hr ≥ 0.095; Average in/hr ≤ 0.25)

Sprinkler	Nozzle	Riser Ht	GPM	Spacing Type	Industry Spacing	CU	DU	SC(5%)	in/hr (min)	in/hr (ave)	in/hr (max)	Heads per acre	GPM per acre
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WT G50W	#6.5 WT	18	3	Triangular	55.0 x 35.0	89%	84%	1.2	0.130	0.187	0.249	23	69.0
WT G50W	#6.5 WT	18	3	Triangular	60.0 x 35.0	90%	85%	1.2	0.121	0.171	0.237	21	63.0
WT G50W	#6.5 WT	18	3	Triangular	65.0 x 35.0	91%	86%	1.2	0.114	0.158	0.227	19	57.0
WT G50W	#6.5 WT	18	3	Triangular	70.0 x 35.0	91%	85%	1.2	0.114	0.147	0.209	18	54.0
WT G50W	#6.5 WT	18	3	Triangular	40.0 x 40.0	93%	87%	1.1	0.156	0.224	0.256	27	81.0
WT G50W	#6.5 WT	18	3	Triangular	45.0 x 40.0	90%	82%	1.2	0.133	0.199	0.234	24	72.0
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WT G50W	#6.5 WT	18	3	Triangular	45.0 x 45.0	88%	80%	1.3	0.113	0.177	0.218	22	66.0
WT G50W	#6.5 WT	18	3	Triangular	50.0 x 45.0	87%	79%	1.3	0.113	0.160	0.209	19	57.0
WT G50W	#6.5 WT	18	3	Triangular	55.0 x 45.0	87%	80%	1.2	0.107	0.145	0.209	18	54.0
WT G50W	#6.5 WT	18	3	Triangular	30.0 x 50.0	90%	86%	1.2	0.190	0.239	0.344	29	87.0
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WT G50W	#6.5 WT	18	3	Triangular	30.0 x 55.0	90%	86%	1.2	0.168	0.218	0.344	26	78.0
WT G50W	#6.5 WT	18	3	Triangular	35.0 x 55.0	91%	85%	1.3	0.106	0.187	0.311	23	69.0
WT G50W	#6.5 WT	18	3	Triangular	30.0 x 60.0	85%	79%	1.2	0.137	0.199	0.344	24	72.0

Pressure for all impact head data is 40 psi.
RB = Rainbird; WT = WeatherTec.
Spacings listed for all data are industry conventions; reverse for cranberry.
Popup head data results from SpacePro Program (CIT), 10/26/04. Impact head data results from SpacePro Program (CIT), 5/3/05

Work funded by Cape Cod Cranberry Growers' Association and analyzed by NRCS.

Application of Irrigation Water

Peter Jeranyama and Brian Wick

Water and irrigation management are crucial to cranberry cultivation (Eck 1990). Cranberries can use up to 0.20-0.25 acre-inch of water per day during the hottest, driest, windiest weather. This would amount to one inch in four to five days under the most severe conditions.

Water management is arguably one of the most critical issues affecting the cranberry industry for four major reasons: crop production, environmental concerns, costs, and regulatory scrutiny. There is an increasing demand for water from other competing interests, and irrigation costs are increasing due to rising energy costs. In addition to the horticultural reasons, there are regulatory and environmental pressures from the Massachusetts Department of Environmental Protection (DEP) concerning the volume of water used, the risk of run-off, and related issues.

This chapter discusses the basic water needs required by cranberry vines and the current tools available to the industry to assess soil moisture and available methods that provide water to the vines.

BASIC WATER NEEDS FOR CRANBERRIES

A common practice is for vines to receive an inch per week from either rain, capillary action from groundwater, irrigation, or some combination of these. If provided by irrigation, it should be in at least half-inch increments to ensure good infiltration into the soil. Bogs that are low in organic matter, or that have a thick sand layer like those that have been renovated, may need more frequent irrigation. Recommendations (DeMoranville et al. 1996b; Sandler et al. 2004b) are to irrigate in the early morning (when the plants are normally covered with dew), so as not to extend the time that the plants are naturally wet (helps to reduce fungal infection periods). This practice also minimizes loss from evaporation, run-off, and drift, which can amount to 30% of water that comes out of the nozzle.

An evaporative demand study conducted by the UMass Cranberry Station showed that for many weeks during the season, most Massachusetts cranberry beds were too wet (Lampinen, unpublished data). Therefore, most beds required less than the traditional one inch of water applied per week during some weeks. Some weeks in the mid-season had higher demand but by adding an inch per week early in the season (when demand was less than one inch), water applied got 'ahead' of the actual soil moisture need and the beds ended up being too wet.

Impacts on Plant Health. Water management is important for maintaining healthy cranberry plants. Excessively wet soils increase the likelihood of Phytophthora root rot, while excessively dry soils can promote fairy ring disease. Further, soil moisture can affect the ability of the plants to acquire nutrients from the soil. When cranberry beds are either too wet or too dry, it can lead to inadequate rooting and leaf chlorosis, a condition known as yellow-vine syndrome (YVS), which occurs in part due to nutrient imbalances.

IRRIGATION SCHEDULING

The cranberry industry does not currently have adequate scientific data to determine, with confidence, what levels of moisture are optimum under varied local conditions (weather and soil types) nor how to properly monitor soil moisture conditions for the various soil types. In general, the following bog types exist in Massachusetts: 1) new renovations and constructions (0-10 years old) with constructed subgrade below sand, 2) renovated beds that have a peat/hardpan natural underlayment beneath a thick sand layer, and 3) older beds, that have developed a layered soil in the root zone, alternating sand and layers with root mass (organic layers). The layering structure of older bogs presents particular challenges to getting uniform contact with monitoring devices. Due to the variation in type, all monitoring and scheduling methods may not work for all beds.

Plants maintain hydration and internal temperature through a process called transpiration in which water is moved from the soil, through the roots and shoots and out through pores (stomata) in the leaves. The plant can control the rate of transpiration through control of the opening of the leaf stomata (pores) to let the water out. As this process occurs, moisture is depleted from the soil.

Crop Water Stress Index (CWSI) is a measure of plant transpiration calculated from temperature and air dryness. In other crops, CSWI has been correlated to yield, leaf water potential, and soil water availability. Since there is evidence that cranberry has poor control over its transpiration process, leaf measurements alone may not sufficiently define CWSI for cranberry. There is a need to use a 'cafeteria' approach to monitoring technology, using some methods that include plant processes and others that include the soil-water matrix, to quantify cranberry water stress at different soil water conditions. This information can then be used as the basis for irrigation scheduling over a wide variety of cranberry beds.

Measurement of water status in other crops is based on two technologies: 1) measuring the amount of water in the soils and 2) measuring the energy status (water potential) of the water. In cranberry production, these two technologies have been represented by water level floats and tensiometers, respectively.

Two desirable characteristics of a sensor or an indicator of plant water deficit are: 1) an ability to detect whether or not a plant is, in fact, under a drought stress, and 2) an ability to determine the severity or degree of the water stress.

Water Level Floats. In cranberry, water level floats (Fig. 1) have been used to determine when to irrigate, but they only measure the level of the water table and do not include any plant processes or plant evaporative demand. The plants largely control the use of the soil water, depleting it and triggering the need for irrigation; this is a possible disadvantage to relying solely on this technology. Water level floats have the advantage that one can see the level of the water table without walking onto the bog. Instructions for constructing a water level float are available from the UMass Cranberry Station. In essence, the water level float is a PVC pipe attached to a marked stick (to indicate depth ranges) that floats within a perforated (larger diameter) PVC pipe that is sunk into the bog (Lampinen 2000).

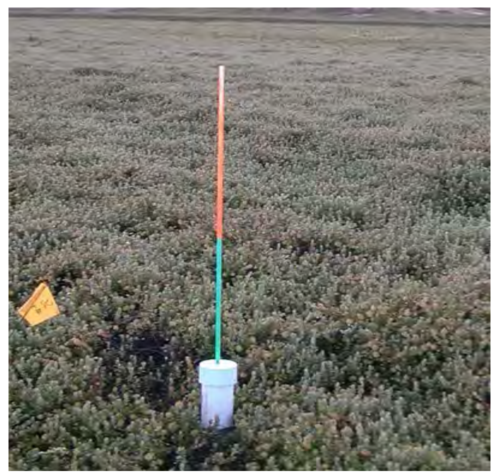


Fig. 1. Water level float installed on a commercial cranberry bog. Photo courtesy P. Jeranyama.

In a typical cranberry bog, water can wick up through the soil to the roots of the plants from a water table depth of up to 18 inches (Lampinen et al. 2000). By measuring the depth of the water table, the water level float allows the grower to quickly adjust that depth to maintain it between the 18-inch limit and 6 inches (the recommended depth to avoid waterlogging in the roots). Depth can be adjusted by using the sprinklers to provide surface irrigation or by moving water into the drainage system to provide water from beneath (subirrigation). Generally, a combination of the two is best.

Water demand by vines can be assessed by comparing the water level in the center of the bed to the water level in ditches to see if water is moving fast enough across the bed. By observing the water level float through several irrigation cycles, you can determine the number of hours required for an adequate irrigation. At minimum, one float should be placed in the bed center; additional floats can be installed at the highest and lowest areas of the bed.

Tensiometers. A tensiometer is a sealed, water-filled tube with a vacuum gauge on the upper end and a porous ceramic tip on the lower end. A tensiometer measures the soil water potential (energy status) in the soil. As the soil around the tensiometer dries out, water is drawn from the tube through the ceramic tip. This creates a vacuum in the tube that can be read on the vacuum gauge. When the soil water is increased, through rainfall or irrigation, water enters the tube through the porous tip, lowering the gauge reading. Growers can then schedule irrigation based on those readings.

Fig. 2. Typical tensiometer. Photo courtesy P. Jeranyama.

Measuring the energy status of water in the soil is valuable in providing a rigorous indication of the water availability to plants, with values that allow comparisons between a set of growing conditions. However, a general problem with estimation of soil moisture potential arises because of the heterogeneity within soils, with single point measurements rarely being representative. A combination of a wide distribution of soil moisture sensors may be required as the basis for irrigation scheduling.

A tensiometer reading in the 2 to 5 cbar range should be expected for a typical cranberry bog soil as long as the water table is between 8 and 18 inches. This range is adequate for cranberries (Table 1).

Some growers have not considered using tensiometers because they do not fully understand what they will be measuring. In other situations, growers have had limited success with tensiometers as they require much fine-tuning and manipulation in order to work effectively in cranberry soils. However, with some training and patience, tensiometers can be powerful tools to schedule irrigation.

Table 1. Critical levels of tension for irrigation scheduling on cranberry beds (Lampinen and DeMoranville 2000).

	Morning tension	Midday tension	Water table level
	--------cbars--------		inches
Too wet	0 to 2	0 to 2	0 to 6
Adequate	>2 to 5	>2 to 10	>6 to 18
Too dry	>5 to 80	>10 to 80	>18

Appearance and Feel Method. Although measuring soil water by appearance and feel is not precise, with experience and judgment, a grower should be able to estimate the moisture level with a reasonable degree of accuracy.

Soil probing (using a slender metal tube to extract soil to a depth of ~6 in.) can be used to check on other monitoring methods and is especially useful in monitoring the depth of penetration of irrigation applications and rainfalls. Sometimes other problems, like compacted soil layers, can be detected from probing.

The following guideline is usually used on coarse textured soils, sandy loams and loamy sands. If soil in the hand is 1) dry, loose, flows through fingers - 0 to 25% available moisture, 2) looks dry, will not form a ball with pressure- 25 to 50% available moisture, 3) will form a loose ball under pressure, will not hold together even with easy handling- 50 to 75% available moisture, and (iv) forms a weak ball, breaks easily, will not 'slick' (will not form a smooth ball) – 75 to 100% available moisture.

WATER APPLICATION METHODS

Irrigation Automation. Irrigation automation can be of tremendous value if it based on tested scientific technology. There has been a growing interest to automate irrigation systems in cranberry production. This technology allows growers to start their irrigation pumps remotely, either through an internet or radio-based connection or they can have their pumps start automatically based on pre-set temperature thresholds. The latter is important when protecting against frost injury. The pre-set thresholds allow growers to automatically start their pumps at the proper temperature to prevent a damaging frost event.

Automation systems have the greatest impact for growers who need to travel to reach their pumping station (i.e., growers who do not live next to their bog) or for those growers with multiple pumps and/or multiple locations. By automating their pumping systems, growers conserve time, which ultimately is conserving water. The time savings enables growers to start their systems just at the right time to protect their crop from a frost event or prevents the systems from running any longer than necessary as they travel around turning off the pumps.

As automated sprinkler systems are implemented, growers will want to automate irrigation scheduling based on soil moisture and climactic monitoring. For this reason, current research efforts are focused on providing evidence regarding what instrumentation works for cranberries and how it can be integrated into automated irrigation scheduling.

Reduced water usage provides the biggest savings with automated systems. The savings vary depending on how the grower is using the system and the particular climatic conditions. With an automated irrigation system, growers are also able to save on fuel, labor, employee safety, mileage and pump longevity.

Sub-Irrigation. Best management practices guide for Massachusetts cranberry production recommends manipulation of the water table by controlling depth of water in the ditches. In so doing, water needs in the root zone may be met. Water level in the ditches is maintained at a level that is adequate to supply water to the root zone while still allowing adequate drainage from the center of the bed. In some instances, sub-irrigation may not be adequate to supply the necessary amount of water to the plant in the center section of a bed or where a bog is not level (out of grade).

FINAL REMARKS

Soil-water measurement must be an integral part of any irrigation scheduling. Soil-water monitoring can help conserve water, conserve energy, and produce optimum fruit yields.

Soil water status must be monitored for effective irrigation water management. The soil acts as a bank, storing water for use by the crop. Soil water measurement can help determine 1) how much water is available in the soil for crop growth, 2) when to irrigate and 3) how much water to apply.

All soil-water monitoring methods require experience and judgment. Current Extension programs train and encourage growers in the use of known tools such as floats and tensiometers for irrigation scheduling. As new research efforts identify new options for irrigation management, education programs will focus on training growers in the use of the new methods.

Chemigation

Hilary Sandler and Steven Ward

In cranberries, typical irrigation systems are solid-set, high-volume delivery systems. These systems consist of buried main and lateral pipes. Risers are attached to the buried pipes at predetermined spacings. Rotating impact or popup heads can be used to deliver the water to the vines. Most heads will rotate 360°, but part-circle sprinklers and sprinkler guards can be used to minimize off-target application. The typical cranberry irrigation system emits fairly large droplets, which also helps reduce drift to off-target areas. The systems operate at relatively high pressures, usually around 40-50 psi. The layout and design of a system is critical for maximal performance and should be designed by an experienced professional.

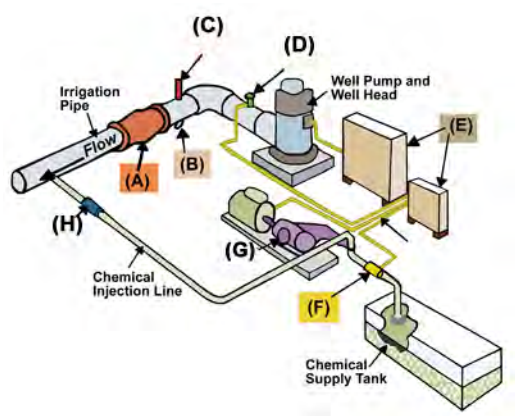
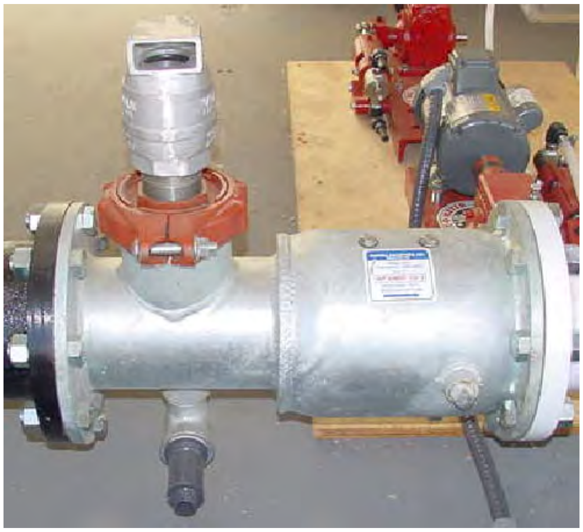


Fig. 1. Typical electrically driven chemigation system. A) check valve, B) low pressure drain, C) air/vacuum relief valve, D) pressure switch, E) interlocking system controls, F) solenoid operated valve, G) chemical injection pump, H) chemical line check valve (Harrison 2006). Some of these components may not be necessary depending on pump elevation.

In addition to providing water to the cranberry vines, irrigation systems can be used to apply chemicals (pesticides and fertilizers). Chemigation is the term used to refer to the delivery of chemicals through an irrigation system. An irrigation system that is used for chemigation has several pieces of specialized equipment designed to provide safeguards during chemical applications. These include (but may not be limited to): vacuum relief valve, interlocking pressure switch hookup, injection port, positive displacement pump, interlocking pressure switch, and a back-flow prevention device (Fig. 1).

The time that it takes for water to move through the sprinkler system has a great impact on the effectiveness of the compound that is being chemigated. Three terms are typically used to describe the movement of the water (and the compound) through the irrigation system: rinse time, wash-off time, and travel time. These terms are sometimes used interchangeably or the term 'travel' can be included in all three definitions. The interchange of these terms can be confusing. In addition, these terms are also used to measure the efficiency of irrigation events, and these may vary slightly from the measurement of chemigation events. In general, irrigations are timed from the pump. Chemigations can be timed from the pump or the injection port, depending on the distance between the port and the pump. The times are used to measure the irrigation system efficiency and vary depending on water pressure (pump rpm or irrigation line leaks).

Another point of confusion may stem from the use of the terms, 'closest' and 'furthest' head. Sometimes, the term 'longest' is used to describe the last head that receives water, and sometimes 'closest' is interchangeable with 'first'. The determination of these critical timings is based on the first and last heads to receive water. Anyone involved in timing a system should be aware that, depending on the design, the closest head to the pump may not necessarily be the first head to receive water. Likewise, the head furthest away physically from the pump may not be the last head in the system to receive water.



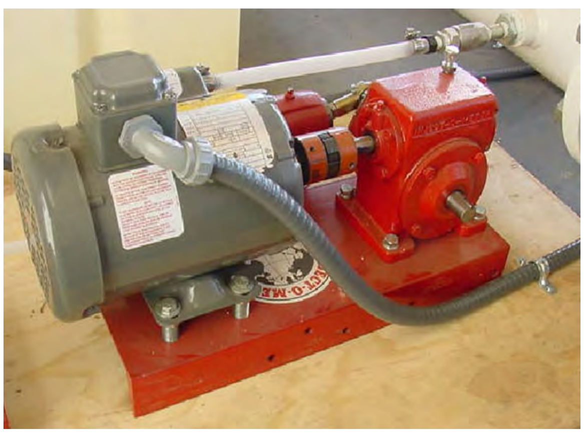


Fig. 2. (Top) Irrigation line check valve, vacuum relief valve, and low pressure drain. (Bottom) Pesticide metering pump. Diagram and photos courtesy http://www.cdpr.ca.gov/docs/emon/grndwtr/chem/chemdevices.htm.

Terminology. Rinse time is the period of time that it takes water to move from the pump or injection port, through the entire system, to the last head. It is important to know this time to properly flush the system during the final phase of the chemigation process. The grower can confirm the rinse time with a dye test, note when it changes as the system wears, and adjust accordingly.

Rinse time = Travel time + Wash-off time

Rinse time is comprised of two parts. The first, travel time, is the time it takes water to move from the pump to the first head in the system. This assumes that the injection port is next to the pump, which might not always be true. The travel time can be shortened in some cases by moving the injection point closer to the bog rather than locating the port at the pump. The second part, wash-off time, is the time it takes water to move from the first head to the last head in the system. This is the time sequence that has the greatest impact on the performance of the chemical injected into the system. If the wash-off time is long, material applied early in the delivery may be washed off the cranberry leaves, reducing the effectiveness of the chemical.

Another term used in chemigation is injection time. Injection time is a totally separate process and should not be confused with rinse, wash-off, or travel times. This is simply the amount of time needed to inject the material into the irrigation system. Customarily, this time period is 6 to 8 minutes. If chemigating with slow-turning popup heads, injection time should be adjusted to coincide with 3 or 4 revolutions of the heads.

To make pesticide or fertilizer applications as effective as possible, it is important to minimize the amount of material washed off the leaves around the first head(s). To do this, the design should aim to keep the wash-off time as short as possible, targeting between three to four minutes.

System Efficiency. Growers may be able to qualify for economic benefits based on the performance of their irrigation system. Systems must have a uniformity coefficient of at least 85% AND achieve a minimum wash-off time to qualify for USDA cost-sharing programs. For example, systems with wash-off times less than 8 minutes qualify for 50% cost-share; if less than 5 minutes, the cost-sharing increases to 75% (L. Rinta, pers. comm.).

Several factors influence the movement of water through the irrigation system. These include: 1) location of the water source and pump, 2) size and shape of the bog, 3) overall layout of the main, submains, and laterals, 4) number of laterals and the number of heads on the laterals, 5) diameter and length of the main, submains, and laterals, and 6) velocity limitations and pressure losses from friction.

The first two factors are fixed to some extent, but the others can be controlled when the system is designed. In general, system layouts that have laterals directly connected to the main, a relatively large number of laterals, long laterals with lots of heads on them, and/or laterals with a relatively large diameter, will have longer rinse and wash-off times.

In contrast, comparatively shorter rinse and wash-off times can be obtained with systems that: 1) divide the bog into sections by creating submains, 2) orient the laterals in such a way as to balance and minimize their total number and length, and 3) use as small a diameter of the laterals as velocity and friction loss considerations will allow.

The pattern of the main and submains with short wash-off times will look like an 'L', 'T', or in the best pattern, like an 'H'. These complicated looking patterns are not necessarily more expensive than traditional designs. The layout chosen will depend on the designer's expertise, the size and shape of the bog as well as any other particulars, and of course, the grower's preference.

Safeguards and Protection. It is important that the grower use the appropriate equipment (e.g., screens, part-circle heads) to avoid treating sensitive areas like adjacent wetlands, water bodies, residential areas, public walking trails, the pump house, and roadways. The injection equipment must be in good working order and properly calibrated. This equipment must also meet the backflow prevention requirements of the U.S. Environmental Protection Agency and the Massachusetts Department of Environmental Protection. Applicators should wear proper protective equipment, be familiar with the chemical's label, and understand the correct injection procedure. The Cranberry Station, independent consultants, chemical and equipment suppliers, and experienced applicators can help growers with the information they need to comply with these requirements.

New Chemistries. Many of the new pesticides that are being used in 21st century cranberry production are labeled for application rates within the range of ounces or grams per acre instead of quarts and pounds per acre. For these new compounds to work effectively, they must be delivered through a system that is operating as efficiently as possible (good uniformity coefficients), with minimum wash-off times. An efficient chemical delivery system is critical to the grower's ability to eventually harvest a sound and marketable crop.

Frost Management

Carolyn DeMoranville

Cranberries, like many other temperate crops, are sensitive to below-freezing temperatures during the active growing season. This sensitivity is an important factor in cranberry management, complicated by the tendency for temperatures on cranberry beds to be lower than those in surrounding lands.

Cranberry beds have traditionally been placed in lowland areas such as swamps and marshes. In recent years, beds have also been constructed in upland areas on mineral soils. However, all beds are constructed with the planted area at a lower level than its adjacent surroundings. This arrangement contributes to the development of temperature differentials between the bog and the surrounding uplands (Demoranville 1997). Cold air drains from the adjacent high ground into the low areas on clear, calm nights. In addition, the enormous amount of vegetation present on a cranberry bog is extremely efficient at radiating heat under clear, calm skies -- a process known as radiational cooling. Due to these factors, it is not unusual for bog temperatures to be 10ºF colder than those of nearby non-bog areas. There may be as much as a 20ºF difference in some locations. How much the bog temperature will differ from that in the surroundings depends on several weather factors, including cloud cover, wind, and dew point. In other words, the temperature differential from bog to upland is variable from night to night.

The ability to predict the minimum temperature on the beds is one of the two most important factors for frost protection. The other factor is the ability of the cranberry plant to tolerate a given cold temperature.

In addition to knowing how cold it will be on the beds, cranberry growers also need to know the ability of the plants to tolerate freezing temperatures. Cranberry plants will tolerate temperatures slightly below freezing (30ºF) at any time in the season. The ability to tolerate temperatures lower than 30ºF without damage depends on the developmental stage of the cranberry plant.

Injury from cold temperatures can occur throughout the year. However, aside from winter, the most critical times for cold injury are the spring when flower buds are sensitive to damage and the fall when fruit must be protected from freezing damage. Winter protection is accomplished with flooding and is covered in the Flood Management chapter.

In the spring and fall (and otherwise as conditions warrant), if temperatures are predicted to fall below the level that the cranberries will tolerate without damage, sprinkler irrigation (or rarely flooding) is used to protect the tender tissues.

FROST TOLERANCE

Spring Tolerance. During the season, sensitivity to cold varies by plant part and developmental stage. During the winter dormant season, cranberries are cold hardy to temperatures below 0ºF. As the plants break dormancy in the spring, the mixed terminal buds become more sensitive to freezing temperatures. Mixed terminal buds are those that contain the structures that will become the flowers and the vegetative growth above the flowers. Vegetative buds (those with no floral structures) often look more advanced than mixed buds. However, it is the tolerance of the mixed buds that is important in protecting the crop to come.

Mixed buds will survive exposure to temperatures of 12ºF and lower soon after the removal of the winter flood. By the time the foliage shows signs of re-greening in mid-April, buds are injured when temperatures fall below 18ºF. At this stage, the buds remain tight and red (winter dormant color). As the buds begin to swell, sensitivity increases dependent on cultivar. Cultivars with large buds (and large fruit later) tend to become sensitive earlier in their development compared to small-budded cultivars. For example, Ben Lear and Stevens tolerate temperatures no lower than 30ºF once the terminal bud begins to elongate, while at that same developmental stage, Early Black and Howes will tolerate 27ºF. Frost tolerances of terminal buds during spring development are listed in Table 1.

Table 1. Spring frost tolerances of cranberry terminal buds. Photos available in UMass Publ. (DeMoranville 1998).

Appearance of the bud	EB & Howes	BL	Stevens
Spring dormant (bud reddish)	18ºF	18ºF	18ºF
White bud stage (loss of dormant color in bud)	20ºF	22ºF	22ºF
Slight loosening of bud scales (no bud swell)	22ºF	25ºF	25ºF
Bud swell 2mm bud (cabbage head or popcorn stage)	25ºF*	27ºF	27ºF
Bud elongation (bud is growing out or up)	27ºF**	30ºF	30ºF
Roughneck (more than half-inch new growth) through bloom	30ºF	30ºF	30ºF

*After 5-7 days, increase to 27°F even if no change in appearance.
**After 5-7 days, increase to 30°F even if no change in appearance.

In experiments at the UMass Cranberry Station, Ben Lear was the least frost tolerant variety in early April, rapidly losing its ability to tolerate 18ºF, often prior to the complete loss of dormant color in the buds (DeMoranville and Demoranville 1995). This was likely related to the earliness and large buds of this cultivar. However, the other common early cultivar, Early Black, had the greatest cold hardiness in the early spring, often tolerating temperatures as low as 15ºF. Flower bud populations on a cranberry bog may be quite variable in the early spring, with tolerance stages from 15-20ºF all represented. By late April, both Stevens and Ben Lear become more frost sensitive than Early Black and Howes of similar developmental stage. Frost tolerances of the newly released hybrid cultivars, Grygleski-1, Demoranville, Crimson Queen, Mullica Queen, and HyRed have not been investigated thoroughly. In the absence of definitive information, it is assumed that spring tolerances for these hybrid cultivars will be similar to those of Ben Lear and Stevens.

Massachusetts cranberry growers sometimes use spring flooding (late water) for pest control. During these floods, the appearance of the terminal bud is arrested at the spring dormant stage. However, internal changes continue to occur within the bud so that when the flood is removed, the buds must be protected at higher temperatures than would be expected based on appearance alone. Research (DeMoranville 1998) has shown that a one-week flood early in the spring had no impact on frost tolerance. However, the appearance of the buds will not be an accurate predictor of tolerance following floods of any longer than one week. Even two weeks of flooding led to loss of tolerance so that the tolerance could not be predicted by the appearance of the plants. Growers using short duration late water floods (2-3 weeks) must protect the vines for 27ºF (after 2 weeks) or 30ºF (after 3 weeks or the standard 4 weeks) as soon as the flood is removed.

From the roughneck stage of development (>half-inch new growth), temperatures below 30ºF will cause damage to young cranberry leaves and flowers. Newly formed green berries are also sensitive to temperatures below 30ºF.

Fall Tolerance. Henry Franklin (Franklin et al. 1943) reported that once the berries lost their green color and took on a white appearance, they would tolerate exposure to temperatures as low as 28ºF. As the fruit surface developed a red blush, the tolerance increased to 27ºF. As the blush became uniform across the fruit surface, 26ºF was tolerated. Dr. Franklin stated that Early Black fruit could never tolerate temperatures below 23ºF, even when they had reached maximum color but that Howes could tolerate 20ºF at full maturity and perhaps lower temperatures very late in the season. It was also noted that, within a variety, small fruit were more susceptible to damage than larger berries.

In 1994, a study began at the UMass Cranberry Station to confirm late-season tolerances of Early Black and Howes fruit and compare those with tolerances of the larger Stevens and Ben Lear (DeMoranville and Demoranville 1995). We found that all four cultivars survived short exposures to 23ºF in early October and longer exposures by mid-October (exactly when in the month varied by year). Contrary to Dr. Franklin's findings, Early Black tolerated long exposures to 18ºF at full maturity (3rd week October) in 2 of 3 years. Further, Howes only developed deep tolerance (18ºF) at full maturity in one year of three. Ben Lear fruit were the least tolerant among the cultivars studied, never surviving exposures below 23ºF. Stevens only occasionally tolerated temperatures below 22ºF. Frost tolerances of cranberry fruit are summarized in Table 2.

This study also noted that tolerance was lost late in October of 1995 as the fruit became overripe. This may have been exacerbated by the drought conditions in 1995. However, it remains an important finding and a point to remember if harvest is delayed into early November.

It should be noted that each cultivar reached a given stage on a <u>different</u> date. Generally, Early Black and Ben Lear develop color early and Howes and Stevens develop color later. This tolerance chart is based on <u>color</u> development, which is used as a visual guide to ripening, a chemical and physiological process. In other words, it is not the color *per se* that confers cold hardiness or tolerance but rather that the internal biochemical and structural changes that determine tolerance generally develop along with color. In some years, lower tolerances were found for a given color stage. However, lower tolerance years are not yet predictable and conservative figures are presented here (Table 2). In each of three years, cranberries showed tolerances at least as low as these for the color stages listed.

Table 2. Fall frost tolerances of cranberry fruit. Photos available in UMass Publ. (DeMoranville 1998).

Maturity	Tolerance			
level	EB	H	ST	BL
Deep blush on exposed surface	27ºF	27ºF	27ºF	27ºF
Deep blush	26ºF	26ºF	26ºF	26ºF
Red	25ºF	25ºF	25ºF	25ºF
Deep red	23ºF	23ºF	23ºF	24ºF
Maroon (1-2 wk later)	23ºF	20ºF	22ºF	24ºF
Overripe (end October)	23ºF	23ºF*	23ºF*	24ºF

*Loss of tolerance when overripe.

In Massachusetts, there has never been a report of serious frost injury to cranberry <u>buds</u> in the fall. The exception to this is beds where a summer flood was held for pest control. On such beds, bud development is delayed and buds should be protected in the fall despite the lack of crop to protect.

FROST FORECASTING

In the early part of the 20th century, the Weather Bureau established observation and recording of weather conditions in the cranberry growing areas of New Jersey, Wisconsin, and Massachusetts. By 1920, Dr. Franklin had developed formulas for predicting frost events on cranberry beds in Massachusetts (Franklin et al. 1943). These formulas were developed by trial and error based on the available weather data and observations at several field observation sites around the cranberry growing region. Franklin's frost warning service was paid for by the growers who received the calls. Today, this service is provided by the Cape Cod Cranberry Growers' Association to its members.

Franklin's formulas continue to be used in the present day, only slightly altered in form. The formulas predict the minimum temperature that can be expected on average cranberry beds under the ideal frost conditions--clear skies and no wind. This forecasting is basic and quite simple. However, where weather is concerned, there are no sure bets. The Frost Warning Service is just a warning to watch conditions when the calculations and weather reports indicate that critical temperatures may occur.

All of the formulas depend on temperature readings at several locations. Important information includes the dry bulb (ambient) temperature, the wet bulb temperature (that of a wetted thermometer), and dew points (indicative of air moisture content). The prediction may be adjusted depending on wind and barometric pressure conditions.

GENERAL TIPS FOR USE IN PREDICTING FROST EVENTS

Dew Point. With high dew points, the danger of frost is less. If dew points around the state are variable, canopy temperatures around the region will also vary.

Wind. Cold wind during the day is a negative influence; temperatures are lowered and the wind often dies during the night, increasing the danger of frost. The presence of wind can prevent cold air from collecting in the bog and protect from frost but should not be relied upon to protect through the night. If the wind drops on a clear, dry night, bog temperatures may drop as much 10ºF in two hours. Winds of less than 10 mph associated with high pressure seldom hold through the night.

Air Masses. Cold air moving into the region from Hudson Bay generally lasts only one night, while a mass moving from the west with the high centered over the Great Lakes may bring several nights of cold. The most dangerous location for a high pressure cell is directly over the cranberry area or slightly to the south and west. As the high approaches and the winds die, quite cold temperatures may develop.

Clouds. High clouds are of little value in preventing frost conditions (radiational cooling). On the other hand, low clouds persisting until after midnight can be protective. Temperatures often drop only one degree per hour after the clouds dissipate.

Precipitation. Substantial rain (1 to 1.5 inches) within a day or so of cold conditions may prevent temperatures from reaching the critical level. However, this is not a sure thing. Drought conditions increase the danger of frost.

Timing. Critical temperature is often not reached until near dawn in the spring. In the fall, the critical temperature may be reached quite early in the evening. Late in the fall, the temperature may fall below the tolerance just after dark or even earlier.

FROST PROTECTION

Preventing frost injury to the flower buds in the spring and to the fruit in the fall is arguably the single most important cultural practice in cranberry production. Frost injury is the only hazard in cranberry production where major crop loss can occur in as little as one hour and total crop loss in one night.

Frost injury is not always visible to the naked eye, but the symptoms can be noted upon careful examination. A mixed flower bud (terminal bud) that is injured in the early spring will exhibit a brown center when cut in cross section. This injury is visible in 24 hours. Subsequently, the bud center will turn black. Buds injured later in the spring may sustain injury only to the vegetative portion of the bud. Such buds may go on to produce flowers with no vegetation above them. This appearance is termed umbrella bloom (Fig. 1). Berries that have sustained frost damage become opaque and soft. Such berries do not burst readily when squeezed, however.

Fig. 1 Example of umbrella bloom where the terminal bud is severely injured or killed (by a frost event) and no vegetative tissue is produced above the flowers. Photo courtesy C. Armstrong.

As early as 1931 (Franklin et al. 1943), a sprinkler system was in use for frost protection on a Massachusetts cranberry bog. But it was the serious frost of May 30, 1961, that provided the impetus for the rapid conversion to this method of frost protection in Massachusetts. Today, virtually all frost protection is achieved through the use of low-gallonage sprinkler systems. However, flooding for frost protection remains an option on very cold nights in early spring, when mechanical failures occur in the sprinkler system, and just prior to harvest if the sprinkler heads have been removed.

Protection from frost damage by the use of water sprayed on the plants (sprinkling) works because of a basic law of physics. As water freezes, heat is released. This phenomenon is known as the heat of fusion. Water freezes at 32ºF, two degrees above the most sensitive stage of the cranberry plants. As long as water continues to freeze and release heat, the plants are protected. Therefore, sprinklers do not need to run continuously to protect the plants but liquid water must be present on the plant surface. But, if the supply of liquid water runs out due to the cessation of sprinkling and the freezing of the water remaining on the plants, the temperature of the ice-encased plants will quickly equalize with the temperature of the air surrounding them and injury will occur. In fact, if all water freezes and windy conditions develop, the ice will evaporate and the tissue underneath will actually lose heat and drop below the air temperature. Research has shown that sprinklers applying a minimum of 0.1 inches per hour are required to afford adequate frost protection.

Sprinkler systems are activated when temperatures approach the observed tolerance of the plants. Therefore, the first rule of frost protection is to observe the bog and determine the tolerance. The system is then turned on 2-3ºF above the tolerance. This will ensure that the bog is protected even if the monitoring thermometer is not located in the coldest spot on the bog. However, all efforts should be made to locate monitoring thermometers at the coldest parts of the bog. The thermometers or sensors should be placed at the level of the vine tips (the tissue to be protected).

When using solid-set sprinklers, it may be necessary to run the system at idle when temperatures are below 25ºF so that the sprinkler heads will not be frozen when the time comes to begin protecting.

Once the action temperature has been reached, two options for frost protection with sprinklers are available:

Option 1: Running through the night. Once started (either manually or through the use of an automated system linked to sensors), the sprinklers are run until at least sunrise or ideally, until after the sun has risen and the bog temperature has risen 2-3ºF above the tolerance. As the ice on the plants melts, heat is absorbed. If the air is still cold, this heat will come from the plants and damage may occur. This phenomenon is even more extreme if the ice evaporates in windy conditions rather than just melting.

Option 2: Intermittent sprinkling. This option is most likely to be used by growers with sprinkler automation equipment. Based upon on-bog sensor data, the equipment is automated to start sprinklers at a start point set above the plant tolerance and run them until a set turn-off temperature is reached. The turn-off temperature is set several degrees above the start temperature. Through the night, the sprinklers will start and stop periodically based on the two set temperatures. Intermittent sprinkling is possible without automation but the grower would have to monitor temperatures and manually start and stop the sprinkler pump in that scenario.

On rare occasions, shallow floods (just above the soil surface) are used for frost protection. For a discussion of using floods to protect against frost injury, see "Flood Management".

Flood Management

Carolyn DeMoranville

Cranberries are native to wetland habitats, requiring plentiful water supplies for their cultivation. During most of the season, well-drained soil is required for the development of healthy, functional cranberry root systems. However, evolution in a wetland setting has resulted in the ability of cranberry plants to withstand periodic flooding without harm. In fact, cranberry growers use flooding as a management tool to protect the plants from the cold, drying winds of winter, to harvest and remove fallen leaves, and to control pests. In the past, flooding was also used for frost protection in the spring and fall and for irrigation in the summer, tasks that are now accomplished using sprinkler irrigation. Flooding is so important in cranberry cultivation that beds where flooding is not possible are no longer considered profitable.

Because of the periodic need for sizable amounts of water, impoundment of water adjacent to the beds is a normal farming practice in cranberry production. Many cranberry growers have constructed reservoirs adjacent to their beds to store the water needed for seasonal flooding and irrigation needs. As a general rule, growers plan for up to 10 acre-feet of water storage capacity to meet all production, harvesting, and flooding needs even in drought years. The actual required capacity will vary depending on the rate of recharge of the water supply, the extent of water recapture and reuse, and the efficiency of the bog system. With the implementation of appropriate BMPs, water needs may be reduced substantially.

FLOODING FOR WINTER PROTECTION

Cranberry vines may be injured or killed by severe winter weather. The injury is classified as a physiological drought where moisture lost from the vines due to wind and evaporation cannot be replaced due to freezing in the root zone. The common term used to describe this injury is winterkill. Such injury can occur within three days if the root zone is frozen to a depth of four inches, the air temperature is below freezing, and strong drying winds (10 mph or greater) occur. Injury is prevented by protecting the vines with a winter flood, which should be in place when winterkill conditions exist and should be deep enough to cover all vine tips, generally about 1 foot. It should be noted that for winterkill protection, deep and uniform snow cover can substitute for a flood. Beds that have not been harvested and new plantings (first year) are less susceptible to winterkill but should still be protected in severe conditions.

The winter flood may be applied as early as December 1 and should remain on the bog as long as winterkill conditions are present or forecast. The flood may be delayed until winterkill conditions are forecast as long as the plants are fully dormant. Exposure to moderately cold temperatures will encourage deeper dormancy leading to lower oxygen and carbohydrate demand and greater cold tolerance. However, an early cold snap following a warm fall could lead to actual cold injury in the plants. Under such conditions, the winter flood should be in place even before winterkill conditions are reached. Generally, the flood should not need to be held any later than March 15. However, holding the flood for a few days past that date will not harm the vines.

Historic research by Bergman (Franklin et al. 1943), indicated that a lack of dissolved oxygen in the winter flood water was the cause of injury to cranberry plants, resulting in leaf drop and reduced yield potential due to damage to terminal buds, damage to young flowers in the buds, a weakening of flowers such that they failed to set fruit, and the production of small berries (possibly due to weakening of the flower ovaries leading to poor seed set). Plants, like animals, use oxygen in respiration. Thus, the lack of oxygen could lead to plant injury.

Bergman stated that oxygen deficiency injury may occur when oxygen levels in the winter flood water drop below 4 mg/l (full oxygenation = >10 mg/l). Bergman further stated that lack of light penetration led to poor photosynthesis and it was the lack of photosynthesis that led to poor oxygenation in the water. The recommended remedy was to remove water from under the iced-over flood if light penetration was poor.

Removal of water from beneath the ice is standard practice in Wisconsin and in cold conditions in Massachusetts. In Wisconsin, the remaining water is removed as soon as a thick ice layer forms on the surface. Air then penetrates along edges and through cracks in the ice so that the vines are exposed to atmospheric oxygen. If the flood remains unfrozen, as is often the case in Massachusetts and New Jersey, oxygen readily mixes into the water from the surrounding air.

Recent research in both Massachusetts and Wisconsin has caused a re-examination of Bergman's theories and recommendations. Research by Justine Vanden Heuvel and Teryl Roper showed that cranberries require very little light for photosynthesis and the light that penetrates snow or sand may be sufficient for this purpose (Vanden Heuvel et al. 2006). Further, in a bog with a full layer of water beneath ice, even with 9 inches of snow on the ice, oxygen in the water beneath remained at 8 mg/l or greater. In Wisconsin, covering ice with black cloth, sand, or snow did not lead to leaf drop or crop reduction in the plants below the treatments. In Massachusetts, plants held flooded in darkness and low oxygen did not show reduced carbohydrates (the product of photosynthesis) or leaf drop.

So what is the cause of the leaf drop that is observed after the winter at certain beds? Definitely, loss of leaves is a sign of some sort of stress on the plants. It is unlikely that lack of light is the cause. Lack of oxygen remains a possibility if the levels actually become severely depleted. A likely scenario for this would be pulling the water from beneath the ice and leaving a shallow layer of water in low spots. The smaller volume of water could become oxygen depleted where a large volume had not.

As wetland plants, cranberries can survive periods of poor oxygenation during flooded conditions. In particular, the plants can tolerate low oxygen levels in saturated soil. However, survival under these conditions requires using carbohydrate (food) reserves. Plants with poor carbohydrate reserves due to large crops, poor sunshine the previous fall, or other stresses may have less ability to tolerate low oxygen stress and may show injury the next spring. In those cases, failure to prevent oxygen deficiency can result in leaf drop, inability of blossoms to set fruit, and crop reduction.

When oxygen falls below the critical level (~4 mg/l), the cranberry plants survive by switching from aerobic (oxygen-requiring) respiration to anaerobic respiration, which does not require oxygen. This has two major consequences: more rapid depletion of carbohydrate reserves and buildup of toxic byproducts. Under anaerobic conditions, carbohydrates are only partially respired, generating much less energy for each unit of carbohydrate used. Because of this, the plants must use much more of their carbohydrate reserves to generate enough energy to survive. The partially respired carbohydrate is stored as organic acids. When oxygen is returned to the system, these acids may form toxic compounds that can injure the plants. Some alpine plants survive the presence of these byproducts by a detoxification mechanism that requires the use of carbohydrates from reserve stores. If carbohydrate reserves have already been depleted, the plants may be damaged by the toxins. This may also be the case with cranberries.

In any case, depletion of carbohydrate reserves during anaerobic respiration (and possibly for detoxification) leaves the cranberry plant lacking in the energy it needs for early-season growth. Poor growth in the spring may have an impact on yield later in the season as well.

Since survival of the cranberry plants during oxygen-deficiency conditions depends on carbohydrate reserves, any factor that leads to poor reserves going into the winter has the potential to increase the danger of injury. Such conditions include poor sunshine in the late summer and fall, and large yields.

Using test kits or meters, oxygen levels in the water under the ice may be monitored. When oxygen-deficiency conditions exist, growers take steps to reintroduce oxygen to the area surrounding the cranberry plants. When the oxygen drops to the warning level of 5 mg/liter, the water is removed from beneath the ice so that air can reach the plants. This lowers the ice sheet onto the vines, flattening them but apparently doing little or no real harm. It is critical that the water be completely removed, such that no shallow puddles are trapped beneath the ice. Vines that are trapped in such shallow pools of water often show severe leaf drop in the spring.

While the ice rests on the vines, daytime melting followed by nighttime freezing usually incorporates some of the vines in the lower surface of the ice. If it becomes necessary to reflood the bog to protect against the return of winterkill conditions, the remaining ice will float and trapped vines may be uprooted. Gradual flooding will usually melt enough of the existing ice so that the vines are released unharmed.

Once the water has been removed from beneath the ice, the remaining ice may melt during a mid-winter thaw, leaving the vines exposed. Beds may be left exposed as long as winterkill conditions are not present. However, long exposures to abnormally warm temperatures (>55°F) may lead to loss of chilling hours. The result could be a reduction in hardiness and greater susceptibility to spring frost. Depending on the conditions prior to the winter flood, loss of chilling during a mid-winter thaw could also lead to reduction in bud break and flowering the following season. This is especially true if the previous fall was warmer than usual, leading to lack of chilling accumulation. To guard against these possibilities, growers reflood their beds if a long warm spell is forecast during mid-winter. The water will cool at night and re-warm slowly during the day, buffering against the warm daytime temperatures.

LATE WATER FLOODS

In the early days of commercial cranberry growing in Massachusetts, growers used flooding for pest control. With the advent of readily available chemical pesticides, such cultural practices were generally abandoned. With the resurgence of interest in farming with minimal pesticide use since the 1990's, interest in these practices has increased. One of the common historic water management practices is known as late water. Used in cranberry production since the 1940's, late water floods protected the bog from spring frost (the vines were under water) and was found to reduce the incidence of storage rots, extending the shelf life of harvested fresh berries. However, late water at that time often meant holding the winter flood continuously from early winter until late in May.

In modern cranberry production, holding late water refers to the practice of withdrawing the winter flood in March and then reflooding the bog in late April for the period of one month. Study of the use of late water in current cranberry production at the UMass Cranberry Station began in 1990 and has continued into the 21st century (Sylvia and Guerin 2008). This research has confirmed that late water can play an important role in the management of mites, spring caterpillars, cranberry fruitworm, and cranberry fruit rot disease (Averill et al. 1994).

After removal of a 30-day late water flood, cranberry buds are sensitive to frost injury. During late water, the appearance of the terminal bud is arrested at the spring dormant stage. However, internal changes continue to occur within the bud so that when the flood is removed, the buds must be protected at higher temperatures than would be expected based on appearance alone. Even after two weeks of flooding, the tolerance could not be predicted by the appearance of the plants. Growers using short duration late water floods (2-3 weeks) must protect the vines for 27ºF (after 2 weeks) or 30ºF (after 3 weeks or the standard 4 weeks) as soon as the flood is removed.

Flowers on late water beds open about 10 days later than those on nearby early water beds. The bloom period tends to be compressed and synchronized. There are usually fewer flowers per flowering upright and fewer flowering uprights on a late water bog. Often, a larger percentage of flowers on late water beds set more fruit than those on early water beds. The newly set berries quickly assume a pear-shape, and in maturity are conspicuously elongated in comparison with the more spherical early water berries. The berries in a late water crop tend to be of uniformly large size. These factors explain why late water beds yield as well as early water beds despite having fewer flowers.

Beneficial aspects of the use of late water:

1. Late water controls or suppresses insects and mites including cranberry fruitworm, early-season cutworms and Southern red mite. Southern red mite may be suppressed for two seasons.

2. Late water reduces the incidence of fruit rot disease. Fungicide use for fruit rot control can be reduced or eliminated in the year of late water with no adverse effect on fruit quality. In fact, late water beds had lower incidence of fruit rot at harvest and after storage than early water beds despite 25-75% fewer fungicide applications. The number of fungicide applications and fungicide rates can be reduced or eliminated in the year following late water as well.

3. Late water floods reduce pressure from spreading perennial weeds particularly in the genus, *Rubus* (dewberries).

4. Late water floods stimulate cranberry plant growth (upright length). Fertilizer nitrogen applications could be reduced 30% on late water beds with no impact on current or subsequent crop. Larger reductions may be associated with decreased crop the following year.

Growers have reported that late water could be used one year in three without yield reduction, but more frequent use of late water led to elongated uprights with little growth from lateral buds. However, organic producers often use late water yearly since it is an excellent option for controlling many key pests without chemical inputs.

It should be noted that on occasion, crops on late water beds are poor. A likely cause is depletion of carbohydrate reserves during the late water flood. Any factor that leads to low carbohydrate reserves prior to the late water flood may affect subsequent yield. Possible negative factors include: lower than average sunlight the previous summer and fall, heavy crop the previous season, and winter injury.

The most important negative factor during a late water flood is high water temperature. Research by Vanden Heuvel showed that during a 4-week flood, cranberry plants lost significant amounts of carbohydrate reserves when flooded at 68ºF and very little reserves when flooded at 52ºF (Vanden Heuvel and Goffinet 2008).

Specific recommendations for management and benefits of late water floods can be found in the Cranberry Chart Book (Sylvia and Guerin 2008).

HARVEST FLOODS

The practice of harvesting cranberries in flood waters began in the late 1960's and now, approximately 90% of the crop is harvested this way. Cranberries harvested in water have limited keeping quality, so berries are cleaned, dried, and either frozen or processed as soon as possible after they are detached from the vines.

Water harvest is a two-stage process. A shallow flood is put onto the bog and 'beaters' move through the vines to knock the berries loose from the plants. The water level is then raised so that the berries float free of the vine tips and can be moved to an edge of the bed. The berries are then removed from the water using pumps of elevators and into trucks for delivery to the handlers (see Harvest chapter also). During this activity, debris (stem pieces, tiny fruit, fallen leaves) that was stirred into the flood during harvest is separated from the fruit.

In order to conserve water, harvest floods are managed so that water is re-used to harvest as many sections of bog as possible before the water is released from the system. Harvest water flow from bog to bog is planned so that, whenever possible, water is not moved from diseased or weed-infested beds into clean beds. If water supplies are limited in late September and October, it is possible to flood for the harvest over a period of a week without serious deterioration of the fruit. Rot develops rapidly only after the berries are detached and floating on the flood surface.

Generally, flood harvesting is used only after the berries are well colored and flood waters have lost their summer heat. A survey of 29 harvest flooded beds (Botelho and Vanden Heuvel 2006) showed that flooding for harvest can have a large negative impact on the carbohydrate reserves in the cranberry plants potentially affecting their ability to tolerate the winter flood and yield in the following season. The most negative impacts were associated with time of flooding (earlier worse than late), temperature of flood water (higher worse than cooler), oxygen concentration in the flood (lower worse than higher) and flood duration (longer worse than shorter).

Interestingly, flood duration is also of importance in regards to water quality in the flood discharge. Before discharging harvest flood water back to a stream, river, or pond, the water is held for at least two days to allow organic matter or other particles, along with associated nutrients, to settle out. However, holding the flood for an extended duration can lead to movement of phosphorus from the bog soil into the flood water. In a field study, after approximately 10-12 days, phosphorus concentration in the flood water increased substantially (DeMoranville 2006). Laboratory studies confirmed that the phosphorus flush into the flood water was related to soil anoxia that developed during the flood (DeMoranville et al. 2008).

Current recommendations for harvest water that is to be released to any phosphorus-sensitive water body call for a 2-5 day settling period after harvest, followed by a gradual release that is completed within 10 days.

CLEAN-UP (TRASH) FLOODS

Water supplies permitting, dry-picked cranberry beds are flooded immediately after harvest to rehydrate the plants, but primarily to remove debris from the field. Dead cranberry leaves, twigs, and any remaining berries float to the surface and are wind-driven to the bog edge where they can be skimmed from the flood for disposal. By removing fallen cranberry leaves, the grower may not need to sand as frequently. These leaves are a source of disease inoculum as well as a habitat for insect pests and are best removed from the bog. If the water supply is adequate, a second trash flood may be applied to remove additional debris. Trash floods may also be used on water-harvest beds if conditions warrant.

LESS COMMON FLOODING PRACTICES

Floods for Pest Management. Flooding can be used to control insects or reduce weed populations without the use of pesticides under certain conditions (e.g., a 12-hour flood in mid-May can reduce populations of blossomworm and false armyworm). When such floods are used, the depth of flood and duration of flood are key. Failure to manage these floods properly may result in lack of control or damage to the plants and crop. Spring flash floods (2-3 days maximum in the first half of May) were generally not detrimental to the carbohydrate stores in the cranberry plants (Botelho and Vanden Heuvel 2006).

Even with correct timing, certain floods for pest management will always reduce yields. For example, long summer floods (May 12 to mid-July) for grub control or dewberry (running bramble, *Rubus* sp.) reduction result in crop loss for that season.

Use of flooding in the fall for insect control on cranberry beds was recommended as long ago as 1924. At that time, a two-week flood for the control of cranberry fruitworm was recommended. The fall flood was thought to smother the insects in their pupal cases on the floor of the bog. Inability to confirm this in the laboratory in the 1950's led to this practice falling into disfavor. Recently, the use of the fall flood for cranberry fruitworm management was revisited (DeMoranville et al. 2005). Holding the harvest flood for 3-4 weeks resulted in 100% mortality of cranberry fruitworm hibernacula (overwintering forms).

Fall flooding in late September for cranberry girdler is an historic practice that remains a recommended option for its control. Cranberry girdler can be controlled with a fall flood beginning between September 20-30 and lasting one week.

However, as noted above, the risk of carbohydrate depletion is greatest in early harvest floods and increases with flood duration. This should be considered when using fall floods for insect management. In addition, long fall floods carry the risk of mobilizing phosphorus and degrading water quality.

Flooding for Irrigation. Flood irrigation is no longer used -- sprinkler irrigation has replaced this method. As part of irrigation management, water is brought up into the drainage ditches to maintain a level water table beneath the beds (subirrigation) but not high enough to constitute a flood.

Flooding for Frost Protection. While sprinkler irrigation is the method of choice for frost protection, flooding may also be used for this purpose. Indeed, this was the standard method prior to the introduction of sprinkler irrigation systems. Today, it is rarely used. However, in the early spring, it is a superior method if temperatures are very low and below the bud tolerance and conditions are windy. Under such circumstances, sprinkler heads will freeze up, and water cannot protect the buds. High winds can also distort sprinkler patterns, which causes some vines to remain unprotected. A flood may also be necessary if there is a failure in the pump that runs the irrigation system.

Probably the most important consideration in flooding for frost protection is the fact that water must be present on the soil surface under the cranberry vines <u>before</u> the occurrence of critically low temperatures. This requires sure knowledge of the length of time required to put the protecting flood in place. It is practically useless to apply the frost flood after the arrival of critically low temperatures.

Early in the spring frost season, and until the frost tolerance of the cranberry buds is as high as 25°F, the frost flood may be held over as a safeguard against the frost hazard of the next night or two. The advantages of this management in saving water and labor are obvious. But later in the frost season when the new growth has lengthened to 0.5 inches or more, it is necessary to remove the flood promptly and early in the morning after a frost. If this is not done and a shallow flood remains on the bog during the heat of the next day, injury is likely to occur. This appears as a wilting of the new growth, and when this happens (even if the wilting appears remedied), the flowers from those wilted uprights will usually fail to set fruit.

Flooding for frost protection in the fall is very unusual. However, a flood may be applied to a bog a day or two ahead of harvest to protect it from frost if the sprinkler heads have been removed in preparation for harvest.

SOURCE MATERIALS

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Cranberry Cultivars

Frank Caruso

INTRODUCTION

Cultivation of the American cranberry, *Vaccinium macrocarpon* Ait., began in the early 1800's with the selection of vines from the wild that possessed qualities considered favorable by the collector. These vines were usually transplanted to a swampy area where they were cultivated and the berries were eventually harvested. As the vines produced more runners and uprights, they were transplanted to other sites by the original cultivator or given or sold to other individuals who desired the characteristics of that particular selection. This vine selection process primarily occurred in Massachusetts, New Jersey and Wisconsin, but limited selection also occurred in Ohio, Michigan, Nova Scotia, and anywhere the plant was native. The plant is not native to Oregon, Washington and British Columbia where significant acreage is now cultivated.

The American cranberry is native in bogs from Newfoundland south to North Carolina and west to Minnesota (Dana 1990). Although a closely related species, *Vaccinium oxycoccus* L., the European cranberry, occurs in part of its range, this other cranberry species has never been cultivated in North America. This latter species differs in that it possesses smaller, pointed leaves, more thread-like stems, smaller and more highly colored flowers, and smaller, round fruit, which is often speckled.

Blueberry is in the same genus as cranberry and offers health benefit traits that could complement cranberry's traits. Crosses with blueberry have traditionally failed to produce viable offspring (e.g., *V. corymbosum* x *V. macrocarpon*). However, recent research indicated recovery of a viable hybrid between *V. darrowi* (field evergreen blueberry) and a *V. oxycoccus* x *V. macrocarpon* interspecific hybrid (Vorsa et al. 2008).

As certain selections gained notoriety or popularity, they were eventually given a cultivar designation. Some cultivars were selected in two different locations, and consequently, were known by two different names (e.g., Holliston and Mammoth). The cranberries discovered in North America were initially divided into three groups based on general berry shape: 1) bell, 2) bugle, and 3) cherry (Eastwood 1856).

CULTIVARS GROWN IN THE DIFFERENT PRODUCING AREAS DURING THE EARLIER YEARS

As the cranberry industry began its development, there was initially a great diversity of cultivars in production in all regions. As the performance of certain cultivars proved consistent over an extended time period (whether considering production, pest resistance, color, quality, or other factors), more growers planted these cultivars and the acreage increased. There was always a considerable number of acres planted to natives in each region, but these natives were diverse and probably consisted of quite a large number of individual cultivars or genotypes. As the industry entered the 20th century and during the first 40 years of the 20th century, the following cultivars were particularly popular:

Massachusetts: Bugle, Centennial, Early Black, Holliston, Howes, Matthews, McFarlin, Round Howes, Shaw's Success, Vose's Pride.

New Jersey: Centennial, Champion, Early Black, Howard Bell, Howes, Natives (Jerseys).

Wisconsin: Bennett Jumbo, Berlin, Howes, McFarlin, Metallic Bell, Natives (Bell, Cherry), Prolific, Searles.

British Columbia, Oregon, Washington: McFarlin.

Cranberry acreage also existed in Maine, New York, and Rhode Island using the cultivars popular in the northeast.

CULTIVARS CURRENTLY GROWN IN THE DIFFERENT PRODUCING AREAS

Cultivars with significant acreage in the different growing areas are listed in the box below (data collected via pers. comm. with regional cranberry scientists, Fall 2007). Chile is listed in the table but no percentage estimates were available from other cranberry scientists.

Stevens has emerged as a popular hybrid release, with many new and renovated beds being planted to this cultivar (Roper 1999; Roper 2001). Ben Lear, a native Wisconsin selection that was nearly discarded as an unacceptable genotype earlier in the 20th century, has also become very popular in some growing areas.

FALSE BLOSSOM DISEASE

The disease false blossom, caused by a phytoplasma and vectored by the blunt-nosed leafhopper, *Euscelis striatulus*, forever changed the cultivar situation in all growing areas with its arrival on the scene in the early 1900's. The disease apparently originated in Wisconsin and was introduced to Massachusetts and New Jersey on imported vine cuttings. By 1915, the disease was causing a significant impact on the production in both areas. Studies were initiated to determine the cause of the disease (originally categorized as a viral pathogen), different aspects of its etiology and epidemiology, its means of spread, and control strategies (Dobroscky 1931). It was noted that cultivars showed great diversity in their susceptibility to the disease in the field. In 1931, N.E. Stevens (Stevens 1931) summarized the common cultivars as outlined on the following page.

Percentages of acreage of varieties grown in various cranberry regions in the U.S. and Canada.

	Variety (% of acreage)									
Location[z]	Early Black	Howes	Stevens	Ben Lear	McFarlin	Pilgrim	Searles	Crowley	Bergman	Others
MA	40	30	15	5	•	•	•	•	•	10
WI	•	•	60	10	5	5	12	•	•	8
NJ	50	3	28	12	•	•	•	•	•	7
WA	•	•	45	•	40	8	•	•	•	7
OR	•	•	77	•	7	3	•	4	•	9
BC	•	•	65	5	6	4	•	•	17	3
Quebec	•	•	76	13	•	7	•	•	•	4
NB	•	•	90	5	•	4	•	•	•	1
NS	6	•	58	15	•	•	•	•	12	9
Chile	•	•	X	X	•	X	•	•	X	•

X = varieties grown but exact percentages unknown.
• = either not grown or negligible.

[z] Small acreages exist in Maine, Michigan, Ontario, Prince Edward Island and Newfoundland, planted with the cultivars listed above.

Range of varietal susceptibility to false blossom:

Susceptible: Bell, Berlin, Centennial, Howes, Metallic Bell, Palmeter, Prolific, Searles, Wales Henry

Moderately susceptible: Bennett Jumbo, Vose's Pride

Moderately resistant: Early Black

Resistant: McFarlin

This resistance was primarily due to the preference of the leafhopper to feed on the cranberry tissue of the different cultivars, rather than resistance to the pathogen itself. Producing acreage in both Massachusetts and New Jersey declined due to the serious incidence of the disease and affected beds with susceptible cultivars were replanted with more resistant cultivars. Howes acreage, in particular, declined from this point onward in New Jersey. As a result, there is very little acreage planted to this cultivar today in New Jersey. The damage caused by false blossom also sparked quite an interest in the development of a cranberry breeding program.

USDA CRANBERRY BREEDING PROGRAM

Because different degrees of field resistance to false blossom disease existed in known cranberry cultivars, a breeding program was deemed necessary for long-term management of the disease. In 1929, the USDA started programs in cranberry breeding in cooperation with the agricultural experiment stations in New Jersey (under the direction of C.S. Beckwith), Massachusetts (under H.F. Bergman), and Wisconsin (under H.F. Bain). The initial crosses were made during 1929-1931 by Bain and Bergman using the following cultivars as parents: Aviator, Bennett Jumbo, Berry Berry, Centennial, Early Black, Howes, Mammoth (Holliston), McFarlin, Paradise Meadow, Potter, Prolific, Searles, Shaw's Success, Stanley, and Whittlesey. Early Black and McFarlin were used in a large majority of the crosses due to their resistance to false blossom. Shaw's Success was found to be even more resistant than McFarlin in evaluations subsequent to N.E. Stevens' evaluations, and this was an important parent as well.

To obtain crosses between two cultivars, pollen from the flowers of one was applied to the stigmas of flowers of the other, and the resulting seeds, each carrying characters from both parents in various combinations, were grown to maturity to give expression to the characters resulting from the crosses. There were 10,797 seedlings at the start of the program from crosses made in Massachusetts, New Jersey, and Wisconsin. The seedlings were planted in field trials in New Jersey and Wisconsin. The primary nursery was at Whitesbog, NJ at the Joseph J. White Company because the disease pressure from false blossom was highest in New Jersey (Wilcox 1932). Seedlings that looked promising were planted at the nursery at the Biron Cranberry Company in Biron, Wisconsin (Peltier 1970). Approximately 1,600 seedlings fruited in 1938-1939.

Records were kept of vine type and vigor, productivity, berry size, berry shape, and berry appearance, susceptibility to field rot, and keeping quality (or storage rot) of the fruit (Bain 1940). They were also tested to determine their relative attractiveness to the blunt-nosed leafhopper. In this cafeteria test, caged blunt-nosed leafhoppers had the choice of feeding on the test seedlings or two named cultivars used as a standard. The number of insects feeding on the test seedlings in a day was compared to the number feeding on the standard cultivars. These standards included Early Black, Howes, McFarlin, and Shaw's Success.

The first selection of 40 seedlings (numbered selections from #1 - #40) was made in 1938-1940, and in 1943 another 93 seedlings (lettered selections designated as AA, AB, AC, etc.) were selected for further study (Chandler et al., 1947). Some of the promising seedlings of both collections were initially planted at a bog located at Oak Swamp of the A.D. Makepeace Co. in Wareham, MA in the 1940's. These same seedlings were eventually planted at State Bog of the UMass Cranberry Station in East Wareham, MA in 1959.

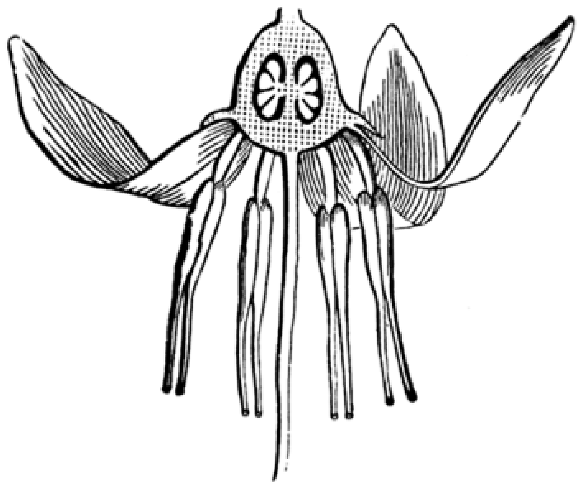


Fig. 1. Cross-sectional diagram of a cranberry flower, showing four large anthers (top portion of stamen that holds the pollen; male part), 3 of 5 petals, lower portion of the style (female part, stalk in center) connected to an inferior ovary with seeds. Courtesy unknown.

HYBRID CULTIVARS

Three of the first 40 seedlings selected were shown to be promising enough in test plots in New Jersey (Whitesbog and Pemberton) that they were formally named Beckwith (#15), Stevens (#33) and Wilcox (#36). There were very little data on these three seedlings from test plots in Massachusetts, Washington and Wisconsin when they were named. The three hybrids are described below:

Beckwith. Cross of Early Black and McFarlin; No. 15 of the 40 selections; ripens late; shape oblong-oval; no bloom on the fruit; stem end broadly rounded; stem pith large; color deep red and glossy; calyx end rounded; calyx lobes medium and open; cup count 50-60; vines medium with tall uprights; production poor; poor coloring in storage; keeping quality good; medium juice yield; average pectin content; specific gravity lighter than Early Black and much lighter than Howes; high resistance to false blossom; seeds per gram of berry weight less than Early Black, but more than Howes.

Stevens. Cross of McFarlin and Potter; No. 33 of the 40 selections; ripens a few days before Howes; shape round-oval; no bloom on berries (occasionally a light bloom); stem end broadly rounded; stem pit large; color deep red; calyx end broadly rounded to slightly protruding; vines coarse texture; tall uprights; leaves medium green and large; cup count 65-85; keeping quality good to very good; only fair coloring in storage; production excellent; vines vigorous; good juice yield; low pectin content; specific gravity less than Early Black and Howes; many seeds; less resistant to false blossom than Early Black but more resistant than Howes.

Wilcox. Cross of Howes and Searles; No. 36 in the 40 selections; ripens a little later than Early Black; shape oval; berries without a bloom, but may have a bloom around calyx; stem end pointed; stem pit small; color deep red, but is sometimes striped or mottled; calyx rounded to slightly protruding; calyx lobes open; vines medium coarse texture; tall uprights; leaves medium size and dark green; cup count 73-98; keeping quality fair; fair coloring in storage; production very good; average range of seed counts 8-12; medium juice yield; medium weight (similar to Early Black); resistant to false blossom.

Because effective control strategies (primarily insecticides) were established to control false blossom disease through the management of the leafhopper vector, the emphasis in the breeding program in the late 1940s shifted to the development of cultivars that possessed superior yield, larger-sized berries, and excellent fruit quality. Other qualities of interest were early ripening, high sugar content, low acid content and large amounts of anthocyanins. Towards this end, in 1959, more crosses were made using Black Veil for low acid and early maturity of fruit, Centerville for high total sugars and a pleasing flavor, Centennial for high total sugar, Stanley for high total sugar and an excellent yield, Selection 28 for pleasing flavor, Selection 8 for excellent yield and earliness, and Searles for excellent yield (Chandler and Demoranville 1961b).

Definition of Descriptive Terms

Accession: unique identifier given to a seedling cross resulting from two cultivars.
Bloom: waxy exterior coating.
Calyx end: part of the fruit opposite of the stem end; part of the flower consisting of the sepals.
Calyx flaps: tissues found around the calyx end.
Clone: vegetatively propagated plant material; plants coming from a single plant.
Cup count: number of berries that fit into an industry standard cup. The lower the cup count, the larger the berry.
Genotype: genetic composition of an individual.
Germplasm: a collection of genetic resources for an organism.
Phenotype: physical appearance of an individual.
Specific gravity: the ratio of a density of a solid or liquid to the density of water. High SG will sink in water; low SG will float.
Stem pith: the tissue occupying the center of the stem within the vascular cylinder, usually the parenchyma, although other types of cells may also occur.
Stolon: a stem that grows horizontally on the ground; runner.

In 1961, three more seedlings from the original 40 selections were named: Bergman, Franklin, and Pilgrim (Chandler and Demoranville 1961c). Unlike the first three releases, these three cultivars were especially productive under Massachusetts conditions. These three hybrids are described below:

Bergman. Cross of Early Black and Searles; No. 8 in the 40 selections; ripens mid-season (between Early Black and Howes); shape short pyriform; no bloom on fruit; color bright red and glossy; very attractive; cup count 65-80; vines have a fine texture with uprights of medium length; few runners; leaves medium size, medium green and hug the stem (similar to false blossom uprights); production high; good coloring in storage; good storage for late shipping; susceptible to field rot; average pectin content; average juice yield; specific gravity similar to Early Black; resistant to false blossom; makes a good whole berry sauce.

Franklin. Cross of Early Black and Howes; No. 31 in the 40 selections; ripens early; shape nearly round; no bloom (or very light bloom) on berries; color red to very dark red; berries glossy; cup count 57-90; stem end rounded; stem pit very small; calyx lobes small and open; calyx end somewhat flattened; vines medium texture; medium length uprights and few runners; keeping quality good to excellent; colors very well in storage; production very good; low juice yield; very high pectin content; makes an excellent strained sauce and a very good whole sauce; berry weight similar to Early Black; similar to Early Black in resistance to false blossom; has a high seed count (12-19).

Pilgrim. Cross of McFarlin and Prolific; No. 17 of the 40 selections; ripens late; shape oval, similar to McFarlin but without the strongly protruding calyx; moderate to heavy bloom on berries; stem end broadly rounded; deep red, almost purplish with a yellow undercolor; calyx end slightly protruding; vines with a coarse texture; medium to tall uprights; large leaves; cup count 43-66; keeping quality good; susceptible to field rot; good coloring in storage; very good production; high juice yield; low pectin content; makes a juicy strained sauce; resistant to false blossom; light specific gravity; may possess some frost resistance.

Washington initiated a breeding program in the early 1940's through the supervision of D.J. Crowley, the superintendent of the Coastal Washington Research and Extension Unit, which was revived in the early 1960's. One of the original 13 seedlings selected from the early breeding program was named Crowley and released by Washington State University in 1970.

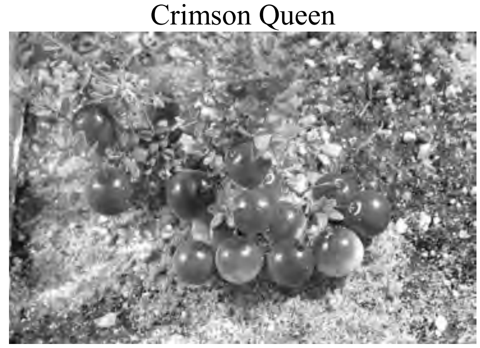
Crowley. Cross of McFarlin and Prolific; WSU No. 72; ripens early; shape round-oblate; light bloom on berries; stem end rounded; color generally dark red; calyx end flattened; cup count 60-70; vines medium texture; excellent producer; susceptible to field rot; poor keeping quality; berries fairly heavy; medium to good juice yield; high anthocyanin counts.

This was the last hybrid released from any cranberry breeding program until 2003 when the breeding program of Dr. Brent McCown in the Department of Horticulture at the University of Wisconsin released the cultivar HyRed. This breeding program was established in 1990 with the goal of developing cultivars for Wisconsin and other regions with short growing seasons. These hybrid cultivars should produce dependably high yields of early-maturing, high color fruit. HyRed originated from a cross of Stevens and a seedling selection designated as Ben Lear #8 that was selected for its early color and high fruit bud set in 1993 (McCown and Zeldin 2003). The fruit ripen early, are elliptical in shape often blocky with squared shoulders, are deep red in color, and the vines are very vigorous in nature.

Although cultivar evaluations still exist in Massachusetts, Wisconsin and Washington, the only formal cranberry breeding program is at the Rutgers Blueberry and Cranberry Research/Extension (Marucci) Center in Chatsworth, NJ. Dr. Nicholi Vorsa currently oversees the breeding program that was formerly directed by Dr. Eric Stone during the late 1970's - early 1980's. The Rutgers breeding program has amassed a large collection of cranberry cultivar germplasm from cultivated beds as well as wild native beds. The major objectives of the program are to obtain reliable productivity, good anthocyanin production, stolon and upright vigor, soluble solids (°Brix), titratable acidity, proanthocyanidin content and resistance to the important fruit rot fungal pathogens in Massachusetts and New Jersey (Johnson-Cicalese and Vorsa 2006). It is important to realize that it takes a very long time (decades) from the point of initial crosses to the time that new varieties are released (Chandler and Demoranville 1958; Chandler and Demoranville 1961c; Roper 2001).

Demoranville

Crimson Queen



Mullica Queen

Fig. 2. Berries of the three newly released varieties from the Rutgers breeding program. Photo courtesy N. Vorsa.

Three new cultivars bred at Rutgers were released in 2006. The first of these, Crimson Queen, resulted from a cross between Stevens and Ben Lear in 1988, was first established in the field in 1993 and has been evaluated for 12 years in multiple locations. It was specifically selected for its high yield, good anthocyanin production and higher stolon vigor. A second new cultivar, Mullica Queen, resulted from a cross between LeMunyon and #35 (one of the original 40 selections in the USDA breeding program) and represents a genetic composition totally unrelated to Crimson Queen. This cultivar also offers excellent yield potential with good anthocyanin production, excellent runner vigor and fruit rot resistance equal or better than Stevens. The third new cultivar, Demoranville, resulted from a cross between Franklin and Ben Lear. Similar to the other two new cultivars, this one offers excellent fruit production, superior anthocyanin levels, but may have the least fruit rot resistance (Vorsa, pers. comm.).

Three selections named Grygleski-1 (a.k.a. GH-1), Grygleski-2 and Grygleski-3 were made by Wisconsin cranberry grower Ed Grygleski from crosses of Rezin and Searles in 1980 and selected in 1982. They incorporate the desirable characteristics noted in the newer cultivars from New Jersey.

Individual native selections and the initial hybrid releases chosen from the 130 known named cultivars (Eck 1990) are summarized in Table 1. When information is unknown or undocumented, (**) denotes this omission. This table has been adapted from Chandler and Demoranville (Chandler and Demoranville 1958).

PRESERVATION OF GERMPLASM

Many cranberry cultivars are being preserved and maintained at the USDA-ARS National Clonal Germplasm Repository, Corvallis, Oregon. In addition to obtaining plant material of the native selections and hybrids from cranberry researchers, wild collections have also been made from several locations within the range for *V. macrocarpon*. As of 2007, 70 cultivars and 140 wild selections are in the collection (K. Hummer, pers. comm.). Native cranberries (presumably *V. macrocarpon* and *V. oxycoccus*) have been collected from the northern United States, Alaska and Siberia.

The primary collection of cranberry clones are maintained as potted plants under screen and some are located in field plantings in 1 x 1.5 m wooden framed plots. Species seeds are stored in envelopes in freezers maintained at -7°C. The clones are also maintained as tissue cultured plantlets as a secondary short-term back-up. These plantlets can be stored under refrigeration for as much as five years without reculturing. The plant material is preserved for long-term storage by freezing tiny shoot meristems and pollen in liquid nitrogen. The meristems are first pretreated with a cryoprotectant (an antifreeze agent), and then frozen in a very controlled manner before being plunged into liquid nitrogen. In liquid nitrogen (-196°C), plant tissue can be stored indefinitely in a state of suspended animation.

The Corvallis Repository distributes limited quantities of plant materials for research and breeding. Cranberry clones can be shipped as dormant season cuttings or tissue culture plantlets. Seed is available for species accessions. The Repository has an active plant pathology program, and pathogen testing status of a specific accession can be provided upon request. These plantlets can be sent to scientists throughout the world who wish to use them for subsequent research projects.

It is essential that the genetic material of each cranberry cultivar be maintained in this fashion for the long-term. Some of the less desirable cultivars may possess the gene for a particular character (e.g., insect resistance, disease resistance, etc.) that would forever be lost were it not preserved. That gene may be very important in the future.

DNA FINGERPRINTING

Some cranberry beds in Massachusetts and New Jersey have the same vines that were planted more than 100 years ago. If a bog is sanded regularly, the weed populations are limited, and production is consistently good, there is no reason why renovation of the bog is necessary. Because cuttings from hundreds (if not thousands) of plants were originally used to plant the bed, there was no true genetic uniformity even when the bed originated. Also, vines pruned from one bed may respond and grow very differently when they are planted in two beds having very different environments (e.g., upland versus wetland sites).

Furthermore, the cranberry cultivar may undergo changes during the life of the bog. Many cranberry fruit are left in the leaf trash layer after harvest, despite the presence of a flood for harvest, trash flow, or winter protection. The seeds in these fruits will often germinate, and although these offspring are similar to the parent cranberry plants, they may be different for certain characteristics. Once these seedlings have matured enough to exchange pollen with other plants, further genetic variation will result in the offspring.

Some of these volunteer seedlings may be more vigorous than the surrounding plants and they may rapidly overgrow the cranberry bed, resulting in a very different population of plants than was present 10 to 15 years earlier.

Cranberries are not available from nurseries in true genetic stock as are blueberries, grapes, raspberries, strawberries or other small fruits. The methods by which the vines are moved around the industry (intrastate and interstate) and by which they are propagated, means that it is highly likely that there is much genetic diversity for different strains that appear to be the same cultivar. Until recently, cranberry cultivars could only be identified by their qualitative traits, such as fruit shape, fruit size, fruit color, and vine and leaf texture (although this latter characteristic is more difficult for the untrained eye).

Scientists can now identify differences among individuals or genotypes using biochemical markers. DNA (deoxyribonucleic acid) analysis has proven to be a useful means of differentiating between cultivars of a wide variety of different plants. The environment has very little direct impact on the DNA in an individual. One method of DNA analysis that has proven to be very useful is termed Random Amplified Polymorphic DNA (RAPD) technology. RAPD analysis uses small DNA chains having various nucleotide sequences called primers that serve as probes. Vorsa and Novy (Vorsa and Novy 1995b) used particular sequences of 10 nucleotides (a nucleotide consists of a sugar molecule, attached to a phosphate group at one end and one of four bases attached to the other end) as primers to target cranberry DNA from individuals under analysis. This procedure generated DNA band patterns that can uniquely identify or fingerprint a particular cultivar.

In one study, 22 cultivars were analyzed using RAPDs. Only 17 unique cultivars were identified, which indicated that several cultivars were misidentified when using their physical traits (Novy and Vorsa 1995). Another study compared the four most common cultivars: Early Black, Howes, McFarlin, and Searles. These four cultivars accounted for over 80% of the total commercial cranberry acreage in 1990 (Eck 1990). Of eight clonal accessions of Early Black, five distinct fingerprints were obtained. Of seven clonal accessions of Howes, five unique fingerprints were obtained. Of six clonal accessions of McFarlin, results were inconclusive, but a subsequent larger sample of 64 accessions yielded 15 DNA fingerprints (Novy et al. 1996). Two clonal accessions of Searles were found to be unrelated to each other (Vorsa and Novy 1995a).

These results confirmed that a cranberry cultivar may be actually comprised of several genetic variants, primarily due to volunteer seedlings becoming established in a cranberry bed. These variants may possess less desirable characters such as reduced productivity, fruit rot susceptibility, and others. It also raises the question: What is a true McFarlin or Early Black? What is disturbing is that two cultivar accessions appeared to produce berries that were identical in appearance, yet based on the DNA fingerprints, they were not even closely related. There is much sorting out of the cultivar situation needed at this point, and it may get more confusing before the picture gets clearer again.

FUTURE DIRECTIONS AND PROSPECTS

It is important that the cranberry industry diversify the cultivars that are planted in each growing region. Despite the confusion raised by the DNA fingerprinting, too few cultivars are planted in each area; this is certainly illustrated by the dominance in acres planted to Stevens. This situation is dangerously close to a monoculture for cranberry farming. If a new pathogen (like the false blossom phytoplasma) or a new insect pest is introduced to an area, it is very likely that significant damage could occur in those cultivars susceptible to the pathogen or pest.

Growers may not be able to respond quickly enough and the consequences could be serious. For growers to replace a bed of Early Black vines with Black Veil vines, it needs to be proven beforehand that 1) Black Veil is resistant to these pathogens and those insects, and that 2) it is consistently productive. Research will be focused on cultivar resistance in the future because it cannot be assumed that certain fungicides and insecticides will continue to be available to growers. Biologically based pesticides may also not be consistent from year to year.

It is important that germplasm not be lost forever. Many beds have small patches of mongrel vines. Although the great majority of these mongrels have poor productivity and are often strictly vegetative, there may be individuals with especially good characteristics. The plant may be resistant to upright dieback disease, or suffer minimal damage from fireworm, or have an especially attractive berry. This mongrel may be a genotype worth saving for one of these character traits. One never knows what will be needed down the road as cranberry growing evolves in the 21st century. Growers are urged to contact someone from the Cranberry Station to collect vines and fruit from interesting patches of these oddball cultivars so they are not lost forever when the bed is renovated.

Table 1. General description of cranberry varieties.

VARIETY	HARVEST SEASON	BERRY COLOR	BERRY SIZE/CUP COUNT	BLOOM ON FRUIT	RELATIVE PRODUCTION	COLORING IN STORAGE	KEEPING QUALITY	PREDOMINANT SHAPE	OUTSTANDING CHARACTERS	TEXTURE OF VINES	LENGTH OF UPRIGHTS	LEAF SHADE (GREEN)	LEAF SIZE	DISCOVERY	ORIGINAL PLANTING
ATWOOD	EARLY	BLACKISH RED	90-100	NONE	EXCEL.	FAIR-GOOD	GOOD	ROUND	CALYX END FLATTENED	COARSE	MEDIUM-TALL	MEDIUM	LARGE	S. ATWOOD 1889	S. CARVER
AVIATOR	LATE	LIGHT RED	76-90	NONE	FAIR-GOOD	GOOD	FAIR-GOOD	SPINDLE	PROTRUDING CALYX END	MEDIUM - COARSE	SHORT - MEDIUM	MEDIUM	LARGE	L.S. ROGERS **	S. CARVER
BASS RIVER	LATE	DEEP RED	100-120	HEAVY	FAIR-GOOD	**	GOOD	OBLONG-OVAL	SQUARISH CALYX END	COARSE	TALL	LIGHT	LARGE	J. SMALLEY **	S.YARMOUTH
BEAVER	EARLY	BLACKISH RED	90-100	NONE	FAIR	**	GOOD	NEARLY ROUND	CALYX END FLAT	MEDIUM	SHORT	MEDIUM	MEDIUM	E.L. EATON 1956	NOVA SCOTIA
BECKWITH	MID-LATE	DEEP RED	50-60	LIGHT	V. GOOD	FAIR	FAIR-GOOD	OVAL-OBLONG	NONE	MEDIUM	TALL	LIGHT	MEDIUM	H.F. BERGMAN 1940	WHITESBOG, NJ
BEN LEAR	EARLY	DEEP RED	70-90	LIGHT - MEDIUM	V. GOOD	GOOD	POOR	LONG PYRIFORM	POINTED STEM END	MEDIUM	MEDIUM - TALL	DARK	MEDIUM	D.R.BURR 1900	BERLIN, WI
BENNETT JUMBO	LATE	DEEP RED	70-80	NONE	POOR-FAIR	GOOD	GOOD	OBLONG	STEM END FURROWED	COARSE	TALL	DARK	LARGE	A.C. BENNETT 1875	FREMONT, WI
BERGMAN	MID	BRIGHT RED	65-80	NONE	V. GOOD	GOOD	GOOD	SHORT PYRIFORM	NONE	FINE	MEDIUM	MEDIUM	MEDIUM	F.B. CHANDLER 1940	WHITESBOG, NJ
BERLIN	MID	MEDIUM RED	80-90	HEAVY	FAIR	GOOD	V. GOOD	ROUND - OBLONG	POINTED STEM END	MEDIUM	MEDIUM	DARK	**	**	BERLIN, WI
BERRY BERRY	LATE	DARK RED	55-65	LIGHT - MEDIUM	GOOD	GOOD	POOR-FAIR	NEARLY ROUND	CALYX END FURROWED	MEDIUM-COARSE	MEDIUM - TALL	LIGHT	LARGE	A. BERRY 1883	MARTHA'S VINEYARD
BLACK VEIL	EARLY	BLACKISH RED	75-100	NONE	GOOD	GOOD	GOOD	ROUND	CALYX END FLAT	COARSE	TALL	DARK	LARGE	J. McFARLIN 1890	S. CARVER
BRADDOCK BELL	MID	DEEP RED	85-105	NONE	GOOD	GOOD	GOOD	PYRIFORM	NONE	COARSE	TALL	LIGHT	LARGE	**	MEDFORD, NJ
BUDD'S BLUES	LATE	BLACKISH RED	100-135	HEAVY	POOR	GOOD	V. GOOD	ROUND-OVAL	WRINKLING AROUND CALYX	VERY COARSE	TALL	DARK	LARGE	T.H. BUDD 1880	PEMBERTON, NJ
BUGLE	LATE	DARK RED	73-90	HEAVY	POOR-FAIR	FAIR	EXCEL.	SPINDLE	STEM & CALYX ENDS POINTED	MEDIUM	TALL	DARK	SMALL	F. DILLINGHAM 1875	SANDWICH
CENTENNIAL	LATE	MEDIUM RED	47-75	NONE	GOOD	POOR	POOR-FAIR	NEARLY ROUND	STEM END FURROWED	COARSE	V. TALL	LIGHT	V. LARGE	G. BATCHELDER 1876	HOLLISTON
CENTER-VILLE	LATE	MEDIUM RED	46-60	NONE	GOOD	POOR	POOR-FAIR	OVAL - SPINDLE	STEM END POINTED	MEDIUM	SHORT	MEDIUM	MEDIUM	P.A. FULLER 1882	CENTERVILLE
CHAMPION	LATE	MEDIUM RED	70-90	MEDIUM	GOOD	POOR	FAIR	ROUND-OVAL	NONE	FINE	SHORT	LIGHT	MEDIUM	E.W. SHAW **	CARVER

Table 1 (con't). General description of cranberry varieties.

VARIETY	HARVEST SEASON	BERRY COLOR	BERRY SIZE/CUP COUNT	BLOOM ON FRUIT	RELATIVE PRODUC-TION	COLORING IN STORAGE	KEEPING QUALITY	PREDOMINANT SHAPE	OUTSTANDING CHARACTERS VINES	TEXTURE OF UPRIGHTS	LENGTH OF (GREEN)	LEAF SHADE	LEAF SIZE	DISCOVERY	ORIGINAL PLANTING
CHIPMAN	LATE	DEEP RED	110-140	HEAVY	POOR	GOOD	FAIR	SPINDLE	STEM & CALYX ENDS POINTED	COARSE	TALL	DARK	MEDIUM-LARGE	G.H. NYE 1860	E. SANDWICH
CROCKER	VERY LATE	**	100+	**	**	**	**	ROUND	CALYX VERY PROMINANT	FINE	SHORT	LIGHT	SMALL MEDIUM	**	**
CROPPER	MID	MEDIUM RED	95-105	NONE	GOOD	**	FAIR	ROUND-OVAL	NONE	COARSE	MEDIUM-TALL	DARK	LARGE	A. JONES 1930	TABERNACLE, NJ
CROWLEY	EARLY	DARK RED	60-70	LIGHT	EXCEL	GOOD	POOR	ROUND-OBLATE	CALYX END FLATTENED	MEDIUM	SHORT	MEDIUM	MEDIUM	D.J. CROWLEY 1940	LONG BEACH, WA
CUMBER-LAND	LATE	DARK RED	60-80	MEDIUM	GOOD	**	**	NEARLY ROUND	STEM END ROUND TO SOMEWHAT FLATTENED	MEDIUM	SHORT	MEDIUM	MEDIUM	**	NOVA SCOTIA
EARLY BLACK	EARLY	BLACKISH RED	90-130	NONE	GOOD	GOOD	GOOD-V. GOOD	PYRIFORM	STEM END POINTED	FINE	SHORT	LIGHT	SMALL	N.ROBBINS 1852	HARWICH
EARLY OHIO	EARLY	DEEP RED	80-90	NONE	FAIR	FAIR	POOR	NEARLY ROUND	NONE	COARSE	TALL	MEDIUM	LARGE	L.P. HASKINS 1904	WALTON, MI
EARLY RED	MID	MEDIUM RED	67-84	LIGHT	GOOD	GOOD	POOR-FAIR	ROUND-OVAL	CALYX END FLAT	MEDIUM	SHORT-MEDIUM	DARK	LARGE	H. SWIFT **	FALMOUTH
EARLY RICHARD	EARLY	DARK RED	82-102	NONE	GOOD	GOOD	POOR-FAIR	NEARLY ROUND-OVAL	STEM END FURROWED	COARSE	TALL	DARK	LARGE	A. RICHARD 1870	HAMMONTON, NJ
FOXBORO HOWES	LATE	MEDIUM RED	80-110	NONE	GOOD-V GOOD	GOOD	GOOD	OBLONG-OVAL	NONE	MEDIUM	MEDIUM	MEDIUM	MEDIUM	L.HANDY 1932	WILMINGTON
FRANKLIN	EARLY	DARK RED	57-90	LIGHT	V. GOOD	GOOD	V. GOOD	NEARLY ROUND	CALYX END FLATTENED	MEDIUM	MEDIUM	DARK	MEDIUM	F.B. CHANDLER 1940	WHITESBOG, NJ
GARWOOD BELL	LATE	DARK RED	100-110	NONE	GOOD	GOOD	GOOD	SPINDLE	STEM & CALYX ENDS POINTED	MEDIUM	TALL	LIGHT	MEDIUM	I. GARWOOD 1875	MEDFORD, NJ
GEBHARDT BEAUTY	EARLY	DEEP RED	80-90	NONE	GOOD	GOOD	GOOD	NEARLY ROUND	CALYX END FLAT	COARSE	SHORT	LIGHT	LARGE	H. BATCHELDER 1893	BLACK RIVER FALLS, WI
HOLLISTON	LATE	DEEP RED	50-75	MEDIUM	GOOD	POOR	POOR-FAIR	OBLONG	CALYX END FURROWED	COARSE	TALL	LIGHT	LARGE	G. BATCHELDER 1885	HOLLISTON
HOWARD BELL	LATE	MEDIUM RED	90-100	LIGHT	GOOD-V. GOOD	POOR	FAIR	OVAL-SPINDLE	CALYX END POINTED	FINE	TALL	LIGHT	SMALL	M. HOWARD 1875	HOWARDVILLE, NJ
HOWES	LATE	MEDIUM RED	80-115	NONE	GOOD	GOOD	EXCEL	OBLONG-OVAL	NONE	COARSE	TALL	DARK	LARGE	E. HOWES 1843	E DENNIS
HOWLAND	MID-LATE	MEDIUM RED	**	NONE	**	**	**	OBLONG-OVAL	WHITE RING AROUND CALYX	COARSE	MEDIUM	DARK	LARGE	**	**

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IMPROVED HOWES	LATE	MEDIUM RED	75-82	NONE	GOOD	GOOD	POOR-FAIR	PYRIFORM	STEM END POINTED	FINE	SHORT	MEDIUM	MEDIUM	A.D. MAKEPEACE 1890	S. CARVER
JUNEAU	EARLY	DEEP RED	95-105	MEDIUM	GOOD	GOOD	FAIR	OVAL-OBLONG	STEM END POINTED	COARSE	TALL	DARK	LARGE	T.F. HAMILTON 1893	BERLIN, WI
KEYSTONE	MID	DARK RED	120-130	LIGHT	FAIR-GOOD	FAIR	POOR	OVAL	STEM END POINTED	FINE-MEDIUM	SHORT	DARK	MEDIUM	J.T. McFARLIN 1893	S. CARVER
McFARLIN	LATE	DEEP RED	60-80	HEAVY	GOOD	POOR	GOOD	ROUND-OBLONG	CALYX REGION PROMINENT	COARSE	SHORT	LIGHT	MEDIUM	T.H. MCFARLIN 1874	S. CARVER
MATTHEWS	LATE	MEDIUM RED	59-80	HEAVY	GOOD	FAIR	POOR-FAIR	PYRIFORM	STEM END POINTED	FINE	SHORT	LIGHT	SMALL	I. MATTHEWS 1880	S. YARMOUTH
MAXIM RANDALL	LATE	DEEP RED	70-90	HEAVY	GOOD	POOR	GOOD	OBLONG SPINDLE & FURROWED	STEM END POINTED	FINE	MEDIUM	LIGHT	SMALL	L. RANDALL **	ROCHESTER
METALLIC BELL	EARLY-MID	DEEP RED	60-95	MEDIUM-HEAVY	FAIR-GOOD	FAIR	POOR	ROUND-OBLONG	STEM END POINTED	COARSE	TALL	MEDIUM	LARGE	T.F. HAMILTON **	SHENNINGTON, WI
MIDDLE-BORO	LATE	DEEP RED	54-80	NONE	GOOD	GOOD	POOR	OVAL-SPINDLE	CALYX END POINTED	FINE-MEDIUM	TALL	MEDIUM	MEDIUM	J.W. HOWES 1885	MIDDLEBORO
MIDDLESEX	LATE	DEEP RED	90-100	NONE	FAIR-GOOD	FAIR-GOOD	GOOD	OVAL	STEM END POINTED	MEDIUM-COARSE	TALL	DARK	VERY LARGE	G. BATCHELDER **	HOLLISTON
MURDOCK	EARLY	DARK RED	80-90	NONE	V. GOOD	**	**	OBLONG-OVAL	STEM END ROUNDED	COARSE	TALL	MEDIUM	LARGE	**	**
NORMAN LEMUNYON	MID	**	**	**	V. GOOD	**	**	OBLONG	NONE	MEDIUM	SHORT	LIGHT	MEDIUM	**	**
PALMETER	EARLY	MEDIUM RED	95-105	NONE	POOR	GOOD	POOR	NEARLY	CALYX END ROUND	MEDIUM FLAT	TALL	LIGHT	SMALL	D.C. PALMETER **	BERLIN, WI
PARADISE MEADOW	LATE	MEDIUM RED	59-68	HEAVY	FAIR-GOOD	POOR	GOOD	ROUND-OVAL	NONE	COARSE	TALL	LIGHT	LARGE	W.P. TURNER 1873	SHARON
PERRY RED	EARLY	BLACKISH RED	80-110	HEAVY	GOOD	GOOD	POOR	ROUND	CALYX END FLAT	COARSE	TALL	DARK	LARGE	J. PERRY 1888	MARION
PILGRIM	LATE	PURPLISH	43-66	HEAVY	V. GOOD	GOOD	GOOD	OVAL	STEM END BROADLY ROUND	COARSE	MEDIUM-TALL	DARK	LARGE	F.B. CHANDLER 1940	WHITESBOG, NJ
PLUM	MID	DARK RED	75-100	MEDIUM	FAIR	FAIR	GOOD	OBLONG	NONE	COARSE	TALL	DARK	LARGE	E. STATEN 1872	TOMS RIVER, NJ
POTTER'S FAVORITE	EARLY-MID	DEEP RED	50-70	NONE	GOOD	FAIR	V. POOR	ROUND-OVAL	STEM END POINTED	COARSE	TALL	LIGHT	LARGE	M.O. POTTER 1895	WISC. RAPIDS, WI

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PROLIFIC	EARLY	BLACKISH RED	70-80	NONE	POOR-FAIR	FAIR-GOOD	POOR	ROUND-OBLONG	CALYX END FLAT	COARSE	TALL	MEDIUM	LARGE	L.P. HASKINS 1904	WALTON, MI
ROUND HOWES	LATE	LIGHT RED	70-80	HEAVY	V. GOOD	POOR	FAIR	ROUND-OVAL	NONE	MEDIUM - COARSE	MEDIUM - TALL	LIGHT	LARGE	H.W. CHAPMAN 1910	S. YARMOUTH
RUTHERFORD HOWES	LATE	DARK RED	73 - 98	LIGHT	FAIR-GOOD	FAIR	GOOD	SPINDLE	BOTH ENDS POINTED	MEDIUM	SHORT	MEDIUM	MEDIUM	**	E. FALMOUTH
SEARLES	MID	DEEP RED	50-85	NONE	EXCEL.	GOOD	POOR-FAIR	ROUND - OBLONG	PROTRUDING CALYX	MEDIUM - COARSE	TALL	LIGHT	MEDIUM	A. SEARLES 1893	WISC. RAPIDS, WI
SHAW'S SUCCESS	MID	BLACKISH RED	85-130	NONE	GOOD	GOOD	V. GOOD	SPINDLE	BOTH ENDS POINTED	FINE	SHORT	LIGHT	MEDIUM	A.M. SHAW 1890	S. CARVER
SMALLEY HOWES	LATE	MEDIUM RED	80-125	NONE	GOOD	GOOD	FAIR	PYRIFORM	STEM END POINTED	MEDIUM	MEDIUM	DARK	MEDIUM	J.A. SMALLEY 1853	E. DENNIS
SMITH	LATE	DEEP RED	80-115	MEDIUM	GOOD - V. GOOD	GOOD	FAIR	ROUND-OVAL	STEM END POINTED	COARSE	TALL	DARK	LARGE	R. SMITH 1880	CHATHAM
SNIPATUIT RED	**	MEDIUM RED	**	MEDIUM	**	**	**	ROUND	CALYX PROTRUDING	**	TALL	**	**	**	**
STANKAVICH	MID - LATE	DEEP RED	50-70	NONE	V. GOOD	GOOD	GOOD	NEARLY ROUND	FLAT ON BOTH ENDS	MEDIUM	TALL	MEDIUM	LARGE	J. STANKIEWICZ 1917	BANDON, OR
STANLEY	LATE	LIGHT RED	55-75	HEAVY	EXCEL.	POOR	POOR	PRYIFORM - SPINDLE	STEM END POINTED	FINE - MEDIUM	MEDIUM	MEDIUM	MEDIUM	J.W. SHAW 1890	CARVER
STEVENS	MID	DEEP RED	50 - 65	NONE	EXCEL.	FAIR	GOOD	ROUND-OVAL	NONE	COARSE	TALL	MEDIUM	LARGE	H.F. BAIN 1940	WHITESBOG, NJ
TAYLOR	EARLY	DULL RED	90-110	MEDIUM	FAIR - GOOD	FAIR	GOOD	ROUND-OVAL	NONE	FINE	SHORT	LIGHT	SMALL	G. TAYLOR 1905	INDIAN MILLS, NJ
VOSE'S PRIDE	MID	MEDIUM RED	80-100	NONE	V. GOOD	POOR	GOOD	PYRIFORM	STEM END V. POINTED	MEDIUM	MEDIUM	DARK	MEDIUM	B. VOSE 1873	MARION
WALES HENRY	LATE	MEDIUM RED	70-90	HEAVY	GOOD	GOOD	FAIR-GOOD	ROUND-OVAL	CALYX END FLAT & STRIPED	COARSE	TALL	DARK	LARGE	W.A. ANDREWS 1887	N. CARVER
WHITING RANDALL	VERY LATE	MEDIUM RED	111 - 140	LIGHT	GOOD	GOOD	EXCEL.	SPINDLE	BOTH ENDS POINTED	FINE	SHORT	LIGHT	MEDIUM	G. RANDALL 1888	PLYMPTON
WILCOX	EARLY	DEEP RED	73 - 98	NONE	GOOD-V. GOOD	FAIR	FAIR	OVAL	STEM END POINTED	MEDIUM - TALL	TALL	DARK	MEDIUM	H.F. BAIN 1940	WHITESBOG, NJ
WOOLMAN	MEDIUM	DEEP RED	95-115	MEDIUM	GOOD-V. GOOD	POOR	FAIR	SPINDLE	BOTH ENDS POINTED	MEDIUM	MEDIUM	MEDIUM	LARGE	A.W. WOOLMAN 1897	INDIAN MILLS, NJ

Integrated Pest Management

Hilary A. Sandler

INTRODUCTION

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 2007, estimates indicate private consultants, company personnel, and individual growers combine to scout more than 80% of Massachusetts' cranberries (>10,000 acres). 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.

IPM IN MASSACHUSETTS

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).

Fig. 1. Using a sweep net to monitor for insects. Courtesy J. Mason.

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.

HISTORY OF CRANBERRY IPM IN MASSACHUSETTS

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 16 acres were scouted under the UMass IPM program. The number of acres covered by the program peaked in 1985 at just over 600 acres, hovered around 400 acres 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 acres managed using IPM philosophy has increased in the last two decades from several hundred acres to more than 10,000 acres. 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 $75-100 per acre. 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 and crop observations to develop and implement nutrient management plans; 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.

MANAGING CRANBERRY PESTS IN MASSACHUSETTS

The principle 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. 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 2008). The large number of pathogens makes understanding the biology of this disease complex challenging. 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 combines knowledge of the biology of the 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.

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 (see Weather chapter).

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 (e.g., Bravo) was the most widely used fungicide (in terms of producing acres that received at least one application), followed by the ethylenebisdithiocarbamate (EBDC) fungicides and the copper fungicides. For postemergence herbicides, glyphosate (e.g., Roundup) was applied to 55% of the production area; clopyralid was used on only 8%. The top two preemergence herbicides used were pronamide (Kerb; 46%) and dichlobenil (Casoron or Norosac; 23%). Diazinon was the most widely applied insecticide (84%), followed by carbaryl (e.g., Sevin; 72%) and thiamethoxam (Actara; 54%).

Chemigation remains the delivery mechanism of choice for insecticides and fungicides in Massachusetts. However, 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 AND DEVELOPMENT OF PEST MANAGEMENT PRACTICES

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 Specific 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 received (but are in the process of obtaining) a full EPA registration. The outbreak of organophosphate-resistant weevils in the 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.

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. 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.

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 B.t. 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.

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 considered plant pathogens. Beneficial nematodes do not harm the cranberry plant, whereas the plant-parasitic nematodes do feed on or infect roots and runners.

A biological insecticide (Biosafe-N, BioSys, Inc.) that used the nematode, *Steinernema carpocapsae* as the active ingredient, was registered for use in cranberry farms in the mid-1980s. Projects researching the efficacy of this product began in 1985. The product is nontoxic to plants, animals, and most beneficial insects and does not contaminate groundwater supplies. The cranberry industry was the first food crop in North America to employ beneficial nematodes as a biological control agent on a commercial basis. Use recommendations for managing soil insects have been 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). The two primary targets of beneficial nematodes (black vine and strawberry root weevils) are not significant pests in Massachusetts. The lack of pest pressure and sporadic availability of commercial product in the Northeast has limited the incorporation of beneficial nematodes into standard IPM programs in Massachusetts.

Pathogens. *Alternaria destrucens* has been identified as a pathogen of dodder (Bewick 1987). The commercial availability of the mycoherbicide based on this organism 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 continued into 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). Results from 2007 studies in WI and MA indicated that Smolder did not perform reliably in the field. The future use of this product for control of dodder in cranberry is unknown as of this writing. *Colletotrichum gloeosporioides* has also been identified as a pathogen of dodder (Mika and Caruso 1999), but no attempts have been made to commercialize this fungus.

Predators and Parasitoids. Published research on the potential use of parasites and parasitoids in cranberry production has focused on those infecting black-headed 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).

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 (due to low pest pressure) and its production was discontinued in 2004 (Averill and Sylvia 2008).

PHEROMONES, TRAPS, AND MATING DISRUPTION

Research on the identification of sex pheromones for several cranberry pests has led to the incorporation and adoption of pheromone traps (Fig. 2) 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. 1994b), and *Sparganothis* (Cockfield et al. 1994a) 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 2008).

Fig. 2. Example of a pheromone trap used to monitor black-headed fireworm moths. Photo courtesy A. Averill.

Applied research on mating disruption is another outcome stemming from the identification of sex pheromones. 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.

CULTURAL CONTROL OPTIONS

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 (see Flooding and Water Use chapters). 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* sp. 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 2003a; Sandler and Mason 2004). Short (3 to 7 days) late summer floods can also be used for management of cranberry girdler (Beckwith 1925; Fitzpatrick 2007), 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). 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 (TNSC) concentration of the vines (Botelho and Vanden Heuvel 2006). TNSC are the energy currency of the plant. 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 were 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.

Flood duration is also of importance with regards to water quality in the flood discharge, particularly around harvest (see Flooding chapter). Before discharging harvest water back to a stream, river, or pond, the flood is held for at least two days to allow organic matter or other particles, along with associated nutrients, to settle out. However, holding the flood for an extended duration can lead to movement of phosphorus from the bog soil into the flood water (DeMoranville 2006; DeMoranville et al. 2008). The use of flooding in cranberry production has numerous interactions and impacts that should be considered whenever utilizing this cultural option for pest management.

Sanding. Sanding, i.e., the application of a thin (0.5 to 2 inches) 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. 1996b). Sanding can suppress 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 C FW (A. Averill, pers. comm.). Uniform sand applications can also inhibit emergence of dodder seedlings (Sandler et al. 1997).

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 (i.e., dodder).

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 is becoming more important to Massachusetts growers as local sand (available on-site) resources decrease and the cost of sand increases. 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 beds 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. 2004a). 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. 1996b). From a p est 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 1992b). 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 h igh leaching potential.

Phosphorus (Roper et al. 2004a) and nitrogen (Davenport and Vorsa 1999; Hart et al. 2000) are important elements of interest in Massachusetts due to increased concern for protection of water quality, both on s tate 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; Davenport et al. 2008; DeMoranville et al. 2008; Roper 2008). 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.

CONCLUSIONS

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, has prevented 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 IPM and 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.

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Weed Management

Hilary A. Sandler

Weeds can cause serious yield loss in cranberry production. Since cranberry vines are perennial plants, most of the weed species found in commercial cranberry production are also perennial species. Management on cranberry farms (or other perennial crop systems) is quite different than that used for annual crops. Cranberry farmers cannot use rotation or in-row hoeing or other cultivation options that are quite useful in annual crops. Perennial plants typically have underground storage organs that provide reserve energy that allow them to rebound from injury caused by herbicides or other control strategies. Once established on the farm, populations will tend to expand and crowd-out cranberry vines. On the other hand, since the weed populations tend to occur in the same place year after year, the use of techniques such as weed mapping become quite useful. Once the locations are known, this information may be integrated into the decision-making process. Growers can then track the success of their weed management efforts over time.

Identification. Certainly, one of the most important steps in successful weed management is correct identification of the weed in question. Many resources are available, both in print and on-line, to assist growers in identification. University of Wisconsin and University of Maine offer images of cranberry weeds at www.hort.wisc.edu/cran/mgt_articles/articles_pest_mgt/weeds/cranweeds.html and www.umaine.edu/umext/cranberries/weedsPhotoLibrary.htm. UMass publications are available at the Cranberry Station (Sandler and Else 1995; Sears et al. 1996) and Extension specialists can help identify weeds one-on-one. Once the weed is correctly identified, then management options can be explored.

INTEGRATED WEED MANAGEMENT

Weed Science is the scientific discipline that deals with managing weeds. As with the areas of insect and disease management, the early years of Weed Science emphasized complete eradication of all plants other than the crop. However, scientists and farmers realized that in most cases, eradication was not a reasonable goal. The presence of most weed populations is often tolerated in modern cranberry production.

Definitions of key plant terms.

Monocots. The abbreviation of the term used to describe the group that contains the grasses, sedges, and rushes. The leaves of these plants are strap-like and have parallel veins.

Dicots. The abbreviation used to describe the group known as broadleaved plants. Dicots have many different leaf shapes and the veins are netted.

Annual Plants. Plants that emerge, grow, produce flowers and seeds and then die within the course of a year or single season.

Perennial Plants. Plants that live for many years and produce flowers and seeds year after year. Perennials have specialized structures such as rhizomes, tubers, or bulbs, which enable them to survive year after year.

The concept of Integrated Weed Management (IWM) has been developed over the last 30 years and now is the accepted philosophy. IWM is similar in philosophy to Integrated Pest Management (IPM) and Integrated Crop Management (ICM). These philosophies use combinations of economic and ecological concepts to help farmers decide if it is ‘worth it’ to control a pest species (Metcalf and Luckman 1975). Worth may be assessed economically, environmentally, ecologically, socially, politically, or in some combination of factors (Prokopy 1990; Cardina et al. 1999;

Hollingsworth and Coli 2001; Buhler 2002). A balance must be struck between the cost of weed damage and the cost of weed control. In practical terms, IWM involves prevention, prioritization, and mapping (Zimdahl 1999).

> **How weeds differ from insects and how this affects IPM**.
>
> 1. From year to year, insects may or may not be present in numbers to cause economic damage, but most cranberry weeds are perennials and are present all the time.
>
> Effect: 'Scouting' in the traditional sense (determination of numbers and action thresholds) is less useful for weeds.
>
> 2. Impact on yields by weeds largely depends on weather factors that affect the interaction of cranberry vines and weeds (e.g., drought stress, nutrient competition). Insect damage is usually less dependent on weather.
>
> Effect: Precise action thresholds are difficult to establish for many weed pests. However, some weeds (e.g., dodder) are considered to have zero tolerance.
>
> 3. Weeds and cranberry vines are both plants and thus, are more similar to each other than insects and cranberry vines.
>
> Effect: It is more difficult to develop control methods that will harm weeds, but not harm cranberry vines.

Prevention. Prevention is a critical aspect for successful weed control in cranberries. Weeds can colonize open ground in newly planted cranberry farms. Colonization of either vines or weeds is impacted by fertilizer, weed management choices and planting density (Sandler 2004; Sandler et al. 2004a). It is much easier to keep weeds out from the very start rather than trying to manage them once they have become established. To minimize long-term management of heavy infestations, many growers invest hours and hours of hand-weeding new plantings to manage weed populations early.

Prioritization. All weeds are not created equal. Some are quite aggressive, hard to control and significantly reduce yield. Some are very poor competitors and are really not much more than a nuisance. Most species fall somewhere in between (Else et al. 1995). The current management guide published by the Cranberry Station categorizes many problematic species into 4 priority groups (Sandler 2008). This priority system helps growers organize their weed management efforts. In most cases, control efforts must be diligently conducted over many years before the weed populations can be reduced. Some weeds are so tenacious that even multi-year efforts may not be enough.

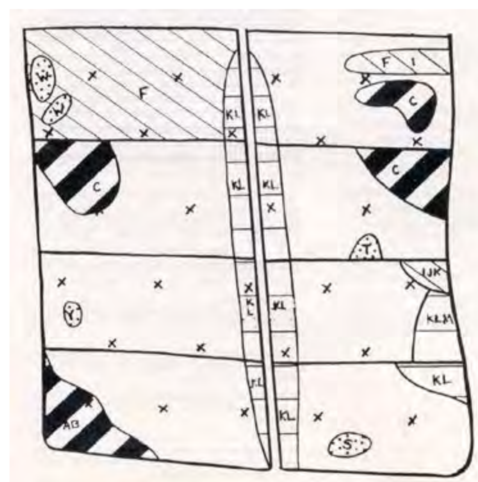

Fig. 1. Example of a weed map for a commercial cranberry farm. Striping and stippling indicate different priority ranks and letters denote weed species (Else et al., 1995). Sprinkler heads are marked with an "x".

Weed Mapping. Weed mapping (Fig. 1) involves surveying the populations of weeds in a cranberry bog to determine the type, size of the infestation, and location of all the weeds. Weed mapping requires that the farmer is able to accurately identify the weeds present in the bog.

As discussed above, it may be very difficult to have an action threshold for a particular weed; many aspects are taken into account when deciding weed management options. Knowing the locations of weed infestations allows the farmer to apply herbicides or other control measures to one part of the bog without treating another part that might not be at risk. Once an accurate weed map has been made, a farmer also can prioritize which weeds need to be controlled based on which ones have the highest risk of causing yield loss. Weeds that pose little or no risk to cranberry yield can be left untreated (Else et al. 1995).

MAJOR WEED PESTS

Dodder (*Cuscuta gronovii*). Dodder is an annual plant known by several common names, such as strangle weed, angel's hair, and golden thread (Yuncker 1965). It is an obligate parasite and must infect a host to survive and complete its life cycle. Seedlings consist only of stem tissue and have no leaves or roots. Stems are slender strands, usually yellow to orange in color. Although dodder relies on its host for nutrients and water, some species do contain small amounts of chlorophyll. Although considered an annual plant, it can survive as haustoria (specialized organs that can extract water and nutrients from the host plant) if the host plant lives through the winter.

Dodder reproduces by seed, but these are not easily dispersed by animals or wind. The fruit capsule contains large air spaces making it buoyant, so the capsules are easily dispersed in flood waters. Dodder seed can also be moved on equipment, so growers should carefully clean harvesters and other machinery when moving between beds.

Dodder can cause 80-100% yield loss in heavy patches of infestation and is a weed of great concern in current cranberry production. Dodder management demands use of an integrated approach as no one control strategy is fully effective in reducing the weed pressure (Sandler and Ghantous 2006). The best management strategy for dodder is prevention of

Prioritization groupings of common cranberry weeds (Else et al., 1996).

Priority 1 - Very Damaging Weeds
Dewberries, *Rubus hispidus, R. flagellaris*
Dodder, *Cuscuta gronovii*
Poison ivy, *Rhus radicans*
Sawbrier, *Smilax glauca*
Wild bean, *Apios americana*

Priority 2 - Serious Weeds
Asters, *Aster ericoides* and *A. novi-belgii*
Common sawbrier, *Smilax rotundifolia*
Narrow-leaved goldenrod, *Solidago tenuifolia*
Upright bramble, *Rubus allegheniensis*
Yellow loosestrife, *Lysimachia terrestris*

Priority 3 - Weeds of less importance
Black chokeberry, *Pyrus melanocarpa*
Nutsedge, *Cyperus dentatus*
Leatherleaf, *Chamaedaphne calyculata*
perennial sedges and grasses
Red maple, *Acer rubrum*
Rushes, *Juncus* sp.
Sheep laurel, *Kalmia angustifolia*
White clover, *Trifolium repens*

Priority 4 - Weeds of little concern
annual broadleaf weeds (e.g., ragweed, smartweed)
annual sedges and grasses
Arrow-leaved tearthumb, *Polygonum sagittatum*
Blue-eyed grass, *Sisyrinchium* sp.
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
Pitchfork, *Bidens frondosa*
Sheep sorrel, *Rumex acetosella*
Sweet pepper bush, *Clethra alnifolia*
White violet, *Viola lanceolata*

infestation from the very beginning. All efforts should be made to reduce seed production and dispersal on an annual. If a farm is already infested, practice good sanitation (as mentioned above) in addition to removing seed pods in postharvest (trash) floods. Control of early season hosts, such as young succulent weeds, can hamper dodder infestations; control of alternate hosts is strongly encouraged. Preemergence and postemergence herbicides may offer some control of infestations; check the Cranberry Chart Book for current and specific recommendations.

Dewberries and Brambles (*Rubus* sp.). Two different species of *Rubus* commonly occur on commercial cranberry beds: bristly dewberry (*R. hispidus)* and prickly dewberry (*R. flagellaris*). These species and other Rubus that occur in nature can hybridize with each other, so the characteristics that distinguish bristly from prickly may become less evident in the field (Sandler 2001). Though cranberry growers may call a wide variety of weeds, 'brambles', the conventional approach across many commodities is to use the term, brambles, to describe *Rubus* species only.

Dewberries are perennial plants that produce upright and arching trailing stems that arise from root buds (Uva et al. 1997). Dewberries spread rapidly on cranberry farms by rooting at the tips of their stems. Dewberries will form a dense thicket and kill cranberry vines if left unmanaged. Patches tend to occur on high, dry edges of the farm. The reproductive potential of dewberries is quite great. One crown can produce 3-7 stems or canes in one year. Then each of these canes can root to form another crown, which can then produce more stems. Stems are known to grow over 15 feet long.

It is best to eliminate individuals and small patches as they invade the farm. Late water floods (DeMoranville et al. 1998) and fall floods (DeMoranville et al. 2005) may reduce populations. Growers should consider the risks involved with fall floods (e.g., impact on carbohydrates of the vines and P mobilization) when choosing this option (see Flood Management section). Chemical controls (Roundup wipes) are minimally effective against dewberries; wiping is also very labor intensive. A new herbicide, Callisto, may slow the spread of dewberry infestation (Sandler, unpublished); check the Cranberry Chart Book.

Sawbriers (*Smilax glauca* and *S. rotundifolia*). Several common names are associated with these troublesome weeds including silverleaf sawbrier (but not to be confused with the silverleaf in Washington state, which is a *Potentilla* species), glaucous sawbrier (or sometimes, greenbrier), common greenbrier and bullbrier. Silverleaf (*S. glauca*) or glaucous sawbrier is considered a Priority 1 weed whereas common greenbrier (*S. rotundifolia*) is rated as a Priority 2. Common greenbrier has an upright habit and can be controlled somewhat easily with herbicide wipes. Silverleaf, on the other hand, is very difficult to control due to its extensive underground storage organs and by the fact that the plant tends to grow close to the canopy of the cranberry vines (making herbicide wiping difficult). Silverleaf spreads rapidly and causes significant yield reductions. Pulling or digging the plant out of the farm is not practical and damages the vines. Like dewberries, infestations of sawbrier tend to occurs on high dry edges. Flooding is not effective against *Smilax* species. Infestations of sawbrier and dewberries are often the cause that prompts renovation of cranberry farms.

Poison Ivy (*Toxicodendron radicans*). Poison ivy has ascended the priority scheme over the past 10 years and is now ranked as a Priority 1 weed. It is imperative to treat young infestations early! The vertical growth of poison ivy is stunted on cranberry farms (due to the low pH) and the weed tends to grow only as tall as the vine canopy. Although stunted vertically, poison ivy patches continue to expand if left untreated. Herbicide wipes do work, but vine injury may (and usually does) occur since the weed is so close to the cranberry vines. Preemergence herbicides do not control poison ivy. In addition, flooding has no impact on poison ivy.

Control of poison ivy has the additional complication that many people are quite allergic to the oils of the plant and are hesitant to apply postemergence controls. Protective lotions (applied either pre- and postexposure, or both) are available that minimize the irritation.

MANAGEMENT OPTIONS

Scouting, identifying, and mapping weeds on active cranberry farms are the first important steps towards selecting an appropriate management option. Present weed management revolves around the use of preemergence and postemergence herbicides, flooding or other cultural practices, and hand-weeding. Herbicides are manufactured in many formulations. Formulations used in cranberry production include granular, dry flowable, and liquid products. Granular herbicides are typically applied with a ground rig applicator, such as a Gephardt or other device. Some herbicides may be injected and applied through the irrigation system (chemigation). Others may be applied as spot-treatment with hand-held wipers or backpack sprayers.

Several preemergence products are currently registered: dichlobenil (Casoron), napropamide (Devrinol), norflurazon (Evital), and simazine (Princep or Caliber). Several products are available for use after weeds have emerged (postemergence) including glyphosate (e.g., RoundUp), sethoxydim (Poast), clethodim (Select), clopyralid (Stinger), and mesotrione (Callisto).

Casoron is a granular material that controls grasses, sedges, broadleaved weeds, and dodder to some extent. It should be used on vines with well-established root systems and should not be used on vines that will be or have been recently mowed. Evital is also a granular formulation. It seems to be most effective when applied in the fall. Its target species includes sedges, grasses, and rushes. Some varieties, such as McFarlins and Stevens, can be very sensitive to Evital.

Devrinol is a dry flowable formulation that can be chemigated. Devrinol works best as a preventative measure on weed-free surfaces and is an excellent choice for newly planted farms.

Fig. 2. Examples of different herbicide applicators (from top): wick wiper (courtesy L. Huffman); alternate wick wiper (courtesy tractorbynet.com/forums/members/billbobtlh.html); backpack sprayers (courtesy www.sunsprayers.com).

Roundup is a product that is familiar to many people. In cranberry production, it is usually applied as a wipe and under certain circumstances, can be applied as a spray application. Poast and Select are spot-treatment products, applied as a spray, which will only control grasses. Other spot-treatment products include Stinger, which controls members of the pea and aster family, and Callisto, which controls grasses, sedges, and some broadleaved plants. Cranberry vines are very sensitive to Stinger and great care must be used to minimize injury to the vines while still obtaining good weed control. Cranberry vines are very tolerant to applications of Callisto.

Fig. 3. Gephardt drop spreader delivering granular herbicide to the cranberry farm surface. Note white droplet of foam at left, which helps to guide the driver. Photo courtesy R. Gilmore.

Flooding can be used to manage some weed populations (see dewberries, mentioned earlier). Short (24-48 hr) spring time floods can suppress dodder populations (Sandler 2003b; Sandler 2003a). Flooding is ineffective against most other weed species.

Uniform applications of sand can suppress dodder germination (Sandler et al. 1997; Hunsberger et al. 2006). Sanding is not known to impact any other weed pest that occurs regularly on cranberry farms. To minimize additional introduction of weeds, clean sources of sand should always be used (for horticultural or pest management) as sand piles are reservoirs of weed seeds (Mason et al. 2006).

Hand-weeding is still used extensively in cranberry farming. In addition to the judicious use of preemergence and postemergence herbicides, hand-weeding is particularly important in the first two years of a new planting. Hand-weeding is also used for dodder control. Growers are willing to commit the time to remove infected weed hosts and even infected uprights as needed.

No biological products are currently viable for control of cranberry weeds. A biological control product, Smolder, is registered for use in cranberry in Massachusetts. The active ingredient is a fungus (*Alternaria destrucens*) that infects dodder. Unfortunately, recent research in Massachusetts and Wisconsin indicated poor field performance (Caruso, Sandler, and Colquhoun, unpublished). Future research efforts may be directed towards another fungus (*Colletotrichum* sp.) that has shown promise in recent field studies.

CHALLENGES IN CRANBERRY WEED MANAGEMENT

Weeds will always be challenging to control in cranberry production since many of the methods that growers use to foster cranberry vine growth also favor weed growth. In addition, the expectation is that the number of new compounds that will be fully developed into commercial herbicides will be limited. This is due mostly to the high cost associated with product development and the uncertainty of return revenues from sales. To compound this impact, the likelihood that a product will be made available for a minor crop such as cranberries, which are grown in a location that has increasing housing pressure and environmental concerns, is not as great as for an agronomic crop that is grown on millions of acres far from dense population clusters.

For these reasons (and certainly others not discussed), efforts must be made to maximize and maintain the utility of <u>all</u> available weed control methods. Education and research are needed to ensure that growers properly use the available methods, integrating techniques whenever possible, to manage the weed populations that significantly impact vine health and yield production.

Disease Management

Frank L. Caruso

There are several major and minor diseases that affect the cranberry plant. Major diseases include fruit rot, Phytophthora root rot, upright and runner dieback, and fairy ring disease. Minor diseases include false blossom, Protoventuria and Pyrenobotrys leaf spots, red leaf spot, rose bloom and ringspot. Some diseases are prevalent in other regions where cranberries are grown, but are rarely or not found in Massachusetts. These include cottonball (found in Wisconsin and, to a lesser extent, in the Pacific Northwest) and Lophodermium twig blight (found in Washington and Oregon).

Detailed descriptions and excellent photographs of cranberry disease symptoms may be found in publications published by the American Phytopathological Society (Caruso and Ramsdell 1995). A revision to the 1995 publication is expected to be available by late 2009, edited by F. Caruso, A. Schilder, J. Polashock, and A. Averill. These may be purchased directly from APS Press (http://www.shopapspress.org). In addition, current recommendations for fruit rot and disease control in Massachusetts are published each year in the UMass Cranberry Chart Book. Copies are available directly from the Cranberry Station or on the Cranberry Station web site (look under "Grower Services").

DISEASE DEVELOPMENT

Three things are required for a successful infection by a plant pathogen. The results are visible symptoms such as tip dieback or a rotted berry. The components of the disease triangle are:

- a susceptible host plant,
- a virulent pathogen, and
- a favorable environment.

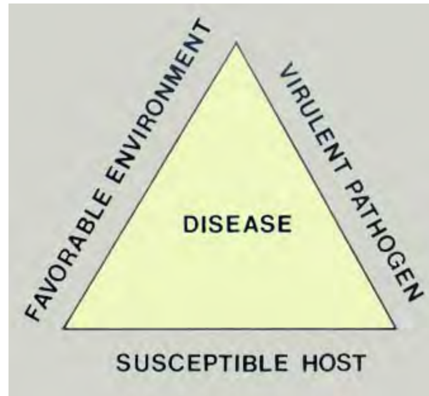

Fig. 1. The disease triangle, a central concept in plant pathology. Courtesy www.apsnet.org.

This concept is the foundation of plant pathology. Many virulent pathogens come into contact with a susceptible host plant, but no disease results due to an unfavorable environment. The most important components of the environment are related to weather.

Temperature. As pathogens (primarily fungal and bacterial) go through their life cycle, temperature affects which life phases will occur at any particular time. Pathogens overwinter on plant tissue or in the duff layer on the soil or in the soil in an inactive state. They will be stimulated to come out of dormancy as the daily temperature increases in the late winter and early spring. The development of many pathogens is closely linked to the development of its host plant species.

As the pathogen becomes active and resumes its growth, the rate of growth will be determined by the daily temperatures. Fluctuations in the temperature will result in bursts of activity by the pathogen, or it may not develop at all for several days. Of course, the same will be true for its host. Certain pathogens will develop at cooler temperatures, while other pathogens will only develop at warmer temperatures. Different strains of an individual pathogen may respond differently to a given temperature. For a fungus, the maturation and expulsion of spores from a fruiting body may be very closely linked to temperature.

Once spores land on the host, it is critical that the temperature be within a certain range when the spore is infective. If it is too cool or too warm, infection may not occur. Conversely, temperature is also critical for the host plant in expressing its defenses against a pathogen. If a host plant is subjected to temperatures outside the optimal range for its successful resistance to a pathogen, normally resistant plants can also be infected by certain pathogens. For pathogens that are able to reinfect their host plants several times during the course of the growing season, the temperature must be favorable at each point. If a pathogen encounters favorable temperatures at every turn, the result may be a serious disease outbreak or an epidemic. At the end of the growing season, cooler temperatures will trigger the pathogen to develop the stages of its life cycle that begin the overwintering or dormancy process.

Precipitation. Adequate rainfall during the growing season will allow the cranberry plant to grow and develop normally, and its plant defenses will be at an optimal level. Inadequate rainfall or circumstances leading to a drought condition will put a significant amount of stress on the plant. In most cases, a stressed plant will be more susceptible to injury caused by pathogens, insects, or other factors.

Upright dieback and fairy ring disease often occur at a higher incidence during years when a period of drought conditions has occurred. However, the symptoms of these diseases may not be evident until the following growing season. Conversely, excessive rainfall will result in areas of the cranberry bog being puddled or flooded for a certain duration. The cranberry vines in these areas will be weakened by the accumulated water, grow at a slow rate, and be more susceptible to other stresses. If the fungus *Phytophthora* is introduced to the bog or already present in the soil or water used in that bog, root rot will likely occur where the drainage is poor. The longer the areas remain wet, the worse the damage will be due to Phytophthora root rot.

Snow can form an important insulating layer on the vines in cranberry beds that do not receive an adequate winter flood. The snow cover will prevent windburn or winter injury, and consequently, the vines will not be predisposed to other stresses.

Humidity. Fungal pathogens require a film of moisture on plant surfaces for the spores to germinate and penetrate into their host plant. High humidity can allow moisture (due to rain or sprinkler application) to remain on the plant surface for a prolonged period, thus allowing the fungi to infect the plant. In southeastern Massachusetts, it is common to have extended periods of several days (sometimes more than a week) of relative humidity higher than 70% (and dew points over 60°F). The humidity from 8 PM until 8 AM may be close to 100%, as fog often develops due to the presence of the ocean and its cooler water temperatures. These conditions may also result in guttation (droplets of water exiting from leaf tips or margins) occurring in the plant.

Usually water is lost from the plant as water vapor through transpiration. Under conditions of high humidity, water may be exuded from the plant on the tips and margins of the leaves as droplets. These droplets can serve as points of infection for several pathogens, primarily fungi and bacteria. Leaf spots that occur on cranberry leaves are often caused by fungi that are normally fruit rot pathogens, but under the conditions described above, can also infect the succulent leaves. This normally occurs in newly planted cranberry beds where excessive fertilization leads to rapid growth of the runners. This whole scenario is why growers should not irrigate late in the day during the summer months, but should irrigate during the early morning hours. This practice minimizes the length of time the moisture film is present on the surface of the cranberry vines, and allows the sun to dry out the vines in the morning. This is also why vine overgrowth is not recommended. The foliage and fruit within the vine canopy will never dry out, and the conditions for infection will persist for an extended time period.

Sunshine. As mentioned above, the sun is important in drying out the cranberry vines during those periods of high humidity and when growers must use their sprinklers for irrigation or frost protection. Sunshine is also important in that it allows the plant to be functioning at its most efficient level. When the plant is photosynthesizing, respiring, and metabolizing efficiently, it will be most resistant to infection by plant pathogens.

FRUIT ROT

This is the most prevalent disease problem that cranberry growers face from season to season (Oudemans et al. 1998). Cranberry fruit can be infected by a large number of different fungal pathogens. A list of important pathogenic fungi are listed in Table 1. Not all of these fungi will be present in a given bog during a particular growing season. The individual fungi and their population levels will vary from year to year (Polashock et al. 2008).

The degree of fruit rot that occurs in different beds during different growing seasons is dependent on many factors. Weather is probably the most important variable that affects the amount of rot that occurs. Temperature, humidity, rainfall, as well as special events such as hailstorms, are important on a regional basis. Local microclimatic variations can also lead to particular sections of a bog that are more prone to the development of rot. The density of vine growth and drainage are important because they have a direct bearing on the length of time vines remain wet from rain, fog, dew or irrigation. Excessive vine growth and poor drainage prevent rapid drying and favor the infection by rot fungi. Practices that promote rank (excessive) vine growth, such as excessive fertilizer, frequent late water, too frequent sanding or too heavy sand on muck bottom, holding water high in ditches, and too frequent irrigation should be avoided to lessen conditions favorable for fruit rot development.

Table 1. List of names and pathogens associated with common cranberry diseases.

Fruit rot, various pathogens include:
Allantophomopsis lycopodina and A. cystisporea (black rot)
Botryosphaeria vaccinii (Botryosphaeria fruit rot)
Coleophoma empetri (ripe rot)
Glomerella cingulata (bitter rot)
Fusicoccum putrefaciens (end rot)
Penicillium sp. (Penicillium rot)
Phomopsis vaccinii (viscid rot)
Phyllosticta vaccinii (early rot or bull's eye rot)
Physalospora vaccinii (blotch rot)

Other diseases:
Fairy ring, exact causal agent known, but uncharacterized
False blossom, phytoplasma
Leaf spots, *Pyrenobotrys compacta* and *Protoventuria myrtilli*
Phytophthora root rot, *Phytophthora cinnamomi*
Red leaf spot, *Exobasidium rostrupii*
Ringspot virus
Rose bloom, *Exobasidium oxycocci*
Upright and runner dieback, *Phomopsis vaccinii*, *Fusicoccum putrefaciens*, and *Synchronoblastia crypta*

Most berry infection occurs during the bloom period. Spores of the fungi are dispersed from overwintering sources by wind or wind-driven rain. These spores land on the blossom or small developing fruit and, if there is a suitable layer of moisture present for 6-8 hours, the fungi will be allowed to penetrate into the plant tissue. If conditions are favorable and the cultivar is susceptible, development of the fungus may be rapid and berries showing symptoms typical of one of the rots may be apparent within a week. If conditions are unfavorable and if the cultivar is less susceptible, development of the infection will be slow. Many of the fruit rot fungal pathogens infect the berry but remain latent in the plant until the berry reaches a certain maturation or physiological stage, at which point they will further infect the tissue, resulting in visible symptoms. Symptoms may not be visible until later in the growing season, or they may not be visible until after the berries have been harvested and held in storage.

Some fungi (*Phyllosticta, Physalospora*) are solely responsible for rot occurring in the field, whereas other fungi (*Allantophomopsis*) are responsible for rot occurring in storage. Infection by this latter fungus (and some others to a limited extent) largely occurs during the water harvest operation when the berries are injured by the water reels or by their removal from the bog. The stem end of the berry is accessible to spores floating in the flood water, and skin punctures are also easily invaded by the spores. Infections such as these are the primary reason why water-harvested fruit must go into processing; these berries can not be put in long-range storage to be used for fresh fruit.

Certain fungi are more responsible for rot occurring in storage. These primarily include *Coleophoma*, *Fusicoccum* and *Phomopsis* in Massachusetts. Each of these fungi infect the fruit during bloom and early fruit development and remain as latent infections until the fruit advances to a specific physiological stage, at which point the fungal growth resumes and the resultant symptoms can be observed.

Fungicides are an important strategy for the control of fruit rot (Caruso 2008). Applications typically begin during early bloom. Once the fruit has set and begun to increase in size (mid-late July), further fungicides are no longer necessary. The choice of fungicides, the rate of the fungicide, and the time interval between applications are dependent on the individual bed and its past incidence of fruit rot.

Fruit rot can be reduced by certain cultural practices: removal of the trash piles from the dikes, sanding, vine pruning, proper fertilizer schedules, and late water. When these are employed, fewer applications may be necessary or lower fungicide rates may be used. There is a great variation in the susceptibility of cranberry cultivars to fruit rot. Of the most commonly encountered cultivars in Massachusetts, the most susceptible to the most resistant are listed: Crowley, Ben Lear, McFarlin, Early Black, Bergman, Franklin, Howes, and Stevens.

Newly planted beds (even for the "resistant" varieties) are especially susceptible to infection by the fruit rot fungi, particularly because fungicides are not extensively used in most instances. Leaves will be infected resulting in spotting and subsequent leaf drop. These fallen leaves are the first step in the buildup of fungal inoculum when fruit are eventually produced in subsequent growing seasons. In these early years in the establishment of a bed, all cultivars show susceptibility to the fungi.

Newly planted beds are very susceptible to fruit rot. Temperatures during the summer are usually higher at vine level due to the exposed sand, and fertilizer rates are very high, making for increased susceptibility of the plant tissue to fungal infection. Even when fungicides are applied to these beds, many of the berries may rot. More fungicide applications may be necessary at shorter intervals to keep rot under control in these beds. Younger beds are also more prone to blossom blast infection of the flowers caused by *Phyllosticta*, *Phomopsis*, and *Glomerella*.

Berries may rot in the bog even when fungi are not responsible. Physiological rot is most likely due to nutritional deficiencies or excesses in the plant, which is reflected in a berry that is not properly developed. Berries (especially in newly planted beds) are also subject to scald during the hottest summer days. The side of the berry in direct contact with the sun's rays may suffer damage while those berries buried under the foliage will be protected from this type of injury. Despite the fact that the damage to the berry is not induced by the fungal pathogens, the fungi can very easily infect these damaged fruits, leading to further deterioration of the berry.

PHYTOPHTHORA ROOT ROT

This disease is caused by a soilborne fungus that thrives in poorly drained areas in beds (Caruso and Wilcox 1990; Polashock et al. 2005). The pathogen, *Phytophthora cinnamomi*, was probably not native to Massachusetts but was brought in on plant material imported from one of the southern states, possibly on rhododendrons or azaleas. It is a subtropical fungus that does not normally survive winter conditions. It is able to survive because beds are normally flooded during the winter, and this protects the fungus from severe cold temperatures.

The fungus causes plant dieback in areas of the bog where water accumulates after prolonged rainfall, irrigation, frost protection, or flooding. Root systems of infected plants are poorly developed, having few feeder roots and showing necrosis. Plants are stunted, leaves are fewer in number, and off color. They may turn red prematurely in the late summer or they may be delayed in turning green in the spring. Few berries are produced on infected plants, and these will be small in most instances. If the outer layer of the underground runner is scraped off, the internal tissue will be discolored olive green to dark brown.

Phytophthora can produce numerous different types of spores during its life cycle. It probably overwinters as hyphae in infected root systems. It produces sporangia (that contain sporangiospores) in early spring during the last part of the winter flood and in the fall when the bog is flooded for water harvest or for a trash flow. These spores disseminate readily to healthy vines in the same bed, and when the water is withdrawn, to other beds that may utilize the same source of water. When these spores come in contact with susceptible plant roots, they infect the plant and invade the root system thoroughly. To date, no cultivar appears to be resistant to the fungus, although certain cultivars appear to be less susceptible to attack by the pathogen.

Control of the disease can be achieved only through several integrated strategies. It is essential that drainage be improved in low areas of the bed. Tile, stones or other materials can be utilized, and new ditches can be dug. Existing ditches should be maintained to the proper depth as well. Areas of dieback should receive a uniform addition of sand to get the areas up to grade with the remainder of the bed. Stressed plants on the margin of dieback areas should be given an extra dose of fertilizer to stimulate root growth. After the drainage has been improved, fungicides should be applied several times per season until the vines have completely filled in the bare spots. Once this has been achieved, only a single spring application should be necessary.

Precautions should be taken to avoid spread of the pathogen from infested beds to uninfested beds. Machinery, equipment, footwear, etc., should be sterilized using steam, bleach, or alcohol. If possible, the sequence of flooding the beds during water harvest should be adjusted to flood heavily infected beds last. When vines are purchased from other growers, the grower should be certain that they have not come from infected beds. Though very few roots are present in such vine deliveries, it only takes a few infected roots to initiate infection in a new location.

UPRIGHT AND RUNNER DIEBACK

Cranberry plants affected by this disease typically have individual uprights that die back from the growing point toward the runner. Every upright may be infected on some runners, while other runners may only have one or a few infected uprights. In severe cases, the entire runner will be stressed or dying. Scattered uprights may be infected in the bed or whole patches of dieback may show up, particularly in younger beds. There are three phases during the season when symptoms appear: one shortly after the winter flood has been withdrawn; another in June and early July; and another phase in late August and September.

Damage caused by this disease appears to be worse during growing seasons that have prolonged periods of drought or heat stress. This weakens the vines making them more susceptible to infection by fungal pathogens. The only cultivar that has shown potential resistance to this disease is Franklin, but to date, this has not been proven by artificial inoculation with the pathogens.

Most damage is probably caused by three different fungi. *Phomopsis vaccinii* (the fungus that causes viscid rot in fruit) is routinely isolated from symptomatic uprights and has been proven to cause symptoms by artificial inoculations (Catlin and Caruso 2003; Catlin 2005). *Fusicoccum putrefaciens* (often) and *Synchronoblastia crypta* (rarely) are also isolated from infected uprights and have been shown to cause symptoms in artificial inoculations.

Other fungi that may possibly infect uprights are *Aureobasidium*, *Colletotrichum*, and *Pestalotia*. Infection by these fungi in the field probably occurs at or shortly after bud break when the tissue is particularly susceptible. Infection may also occur during the entire growing season. Symptoms do not appear, however, until weather-related stresses weaken the plants. At this point, the tips are killed at the growing point and the symptoms progress downward on the upright.

The disease can be partially controlled through avoidance of stress on the plants through the hottest (and potentially the driest) portion of the growing season. Early-season fungicide applications at bud break and/or early bud expansion have given excellent control of the disease. Spores of the primary causal agent *Phomopsis* begin to be produced from overwintering cranberry tissue in April and May and the emerging buds are particularly susceptible to the infection. Fungicides targeted for fruit rot control also provide a degree of protection against this disease during early and mid-season infection periods.

FAIRY RING DISEASE

The basidiomycetous fungus, *Psilocybe agrariella* var. *vaccinii* for many decades was thought to be the causal agent of fairy ring, although it had never been proven in artificial inoculations and the fruiting bodies (mushrooms) had not been observed in affected areas since the early 1900's. Another fungus (genus still to be determined) has been cultured from symptomatic plants in Massachusetts and New Jersey and shown to cause the typical symptoms and is likely the true causal agent. Initially, a small area of weak or dead vines occurs, usually in higher spots in the bog or near the ditches. The area of dead vines expands outward in all directions (one to two feet per year) when environmental conditions are favorable for the fungus. The expanding arc of dead vines appears distinctly as the outward edge of the ring. Vines ahead of the advancing ring are under stress and are unproductive. As the fungus moves outward (and the dead area expands), the area previously killed is fertilized by the remains of the pathogen. The area may be recolonized by vines, however in many cases, weeds will tend to colonize this area. In heavily infected beds, numerous rings will be present and they may overlap or combine, resulting in whole sections that are devastated by the disease.

The disease was a minor problem until the widespread use of mechanical dry-picking machines in the 1950's. It is likely that this was due to the uprooting and transport of the vines by the picking machines from infected areas to healthy areas as harvesting progressed. As the vines were relocated to new spots, new infections were initiated during the succeeding growing season.

The disease is sporadic in occurrence. It is present in many beds in the same spots from year to year with limited expansion and little effect on the overall productivity of the bog. In some growing seasons, there will be severe expansion of these rings and new spots will show up in that area and previously unaffected areas will show symptoms. Damage caused by this fungus is usually worse during growing seasons with limited rainfall and hotter than normal temperatures. Stevens, Ben Lear and Howes are highly susceptible, while Early Black is less susceptible but not resistant.

Control strategies for this disease have still not been worked out thoroughly. During those summers with low rainfall, plants should be properly irrigated. Sprinklers should be run for several hours in the early morning hours, when there is little evaporation, to insure that the root systems are properly watered. Raising the water level in the ditches can help in this regard. This can be a problem, however, if there are low areas in the same bed where Phytophthora root rot may also be present. The grower should try to get the bed properly graded.

Applications of Sul-Po-Mag, lime and/or urea have shown a degree of control of the disease. This is due to nutritional assistance to the vines rather than an adverse effect on the fungal pathogen. Fungicide applications in May through late June help to reduce populations of the fungus in the soil, and are much more effective than a post-harvest application when both the vines and the fungus are entering dormancy. In May through late June, the pathogen is more vulnerable to the fungicide, and the vines are able to make some recovery during the growing season.

MINOR DISEASES

A few comments will be made on the minor diseases listed previously. False blossom disease was a major disease problem earlier this century. The causal agent is a phytoplasma (similar to a virus) and it is vectored by the blunt-nosed leafhopper. Howes is very susceptible, whereas Early Black has a good degree of resistance to the disease. The disease has been eliminated (although it still is present in wild cranberry beds) through the control of the leafhopper with various insecticides.

Protoventuria and especially Pyrenobotrys leaf spots (formerly called Gibbera leaf spot) are widespread throughout Massachusetts cranberry beds. Leaf spots are caused by the fungi *Protoventuria myrtilli* and *Pyrenobotrys compacta*. Symptoms are only induced on the leaves; vines and berries remain healthy. Productivity of the vines does not appear to be affected. The disease is most likely kept in check by the normal fruit rot fungicide program.

Red leaf spot is hardly ever encountered in Massachusetts. It is caused by the fungus, *Exobasidium rostrupii*, and may cause numerous leaf spots in limited areas of the bog. Symptoms are usually associated with vines that have especially lush growth due to over-fertilization. Ben Lear appears to be particularly susceptible. This disease is also probably controlled by the fruit rot fungicide program.

Rose bloom occurs regularly on Nantucket Island but has not been observed on the mainland since the 1940's. The fungus *Exobasidium oxycocci* causes secondary buds to develop fleshy, abnormal branches with swollen pink leaves that look like miniature roses. Fruit production is reduced on affected vines. Howes is particularly susceptible. Fungicide applications used for fruit rot control the disease.

Ringspot also has been observed to a very limited extent in Massachusetts. It is caused by a virus, and symptoms are expressed as rings on the berries and the leaves. Howes appears to be particularly susceptible, although the yields are not seriously reduced.

Insect Management

Anne L. Averill and Martha M. Sylvia

Over the long term, the most effective programs that minimize yield loss due to insect or mite injury utilize the principles of Integrated Pest Management (IPM). IPM relies upon knowledge of the pest species together with utilization of sampling techniques and application of an array of tactics (e.g., cultural, biological, behavioral, and chemical). The goal is to keep pest populations below an economic (damage) threshold, while at the same time, weighing the impact of management choices on environmental quality.

Within IPM, there are two main strategies: therapeutic and preventive. The therapeutic approach usually involves application of insecticides and other products, but this tactic is often rendered ineffective in the long term (e.g., as a result of insecticide resistance, cranberry weevil and *Sparganothis* fruitworm are resistant to Guthion, Diazinon, and Lorsban in Massachusetts). In contrast, the preventive approach seeks to avoid pest outbreaks and to provide a more long-term solution to insect problems. This latter approach leads us away from pursuit of a 'silver bullet' product to manage high pest numbers, and towards a preventive, ecologically based approach that results in the moderation of pest population numbers to levels below action thresholds. According to Lewis (Lewis et al. 1997):

> We must go beyond replacing toxic chemicals with more sophisticated, biologically based agents and re-examine the entire paradigm around the therapeutic approach including how and why those therapeutics are used. Truly satisfactory solutions to pest problems will require a shift to understanding and promoting naturally occurring biological agents and other inherent strengths as components of total agricultural ecosystems and designing our cropping systems so that these natural forces keep the pests within acceptable bounds.

In cranberry, this could involve: late water, used every few years, to reduce cranberry fruitworm, Southern red mite, cutworm, and gypsy moth numbers; sanding and trash removal to limit cranberry girdler, green spanworm, black-headed fireworm, and cranberry tipworm; conservation of natural enemies to impact *Sparganothis* fruitworm; and proper fertilization to limit lush growth favored by flea beetle and to maintain healthy, dense stands of vines that can tolerate root-feeding insects.

The purpose of this section is to provide key points in cranberry insect management. To effectively manage pest populations, growers not only must carry out proper identification, but also be aware of the life stage or stages present at any given point in time. Growers should consult the most current <u>Cranberry Chart Book--Management Guide for Massachusetts</u>, which is updated annually. Color photographs of most of the insects described in this section are contained in <u>Cranberry Insects of the Northeast</u> (Averill and Sylvia 1998). Several classic references were authored by H. Franklin (Franklin 1948; Franklin 1951).

IDENTIFICATION OF CRANBERRY INSECTS AND MITES

The success of any IPM program depends on the correct identification of the pest. Insects and mites belong to the group of animals called arthropods. Injury caused by the pest may often be indicative of the species that caused it, and in some cases, will allow immediate identification. However, care must be taken when management decisions are being considered because damage may not appear until the pest has already completed development.

There are many arthropod species that are known to occur on cranberry, but only about two dozen insects and a single mite are known to be of economic importance. It is usually advisable to be highly familiar with these pest species and not to be distracted by small numbers of non-pest insects that are picked up during scouting.

INSECT LIFE HISTORIES

Insects undergo substantial change as they grow and undergo a process called metamorphosis. Nearly all cranberry insect pests undergo complete metamorphosis. In complete metamorphosis, there are four distinct stages: egg, larva, pupa, and adult (see Fig. 1). Larvae hatch and molt and grow through several instars. The larva bears very little resemblance to the adult, and it is only during this stage that the insect grows in size. Depending on the insect order, the common term for the larva will be ‘caterpillar’ (moth), ‘grub’ (beetle), or ‘maggot’ (fly). The pupal stage follows the larval stage; during this time, the pupa is inactive and adult structures are formed. The final stage is the adult, which emerges from the pupal case. Most adults continue to eat, but they no longer molt or grow. The adults mate and reproduce.

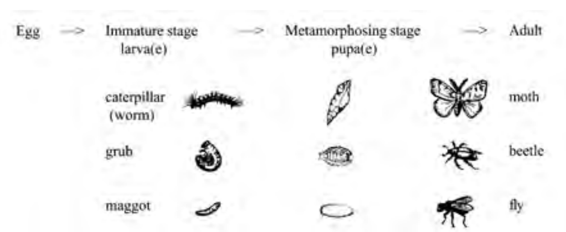

Fig. 1. Life stages for insects undergoing complete metamorphosis (Averill and Sylvia 1998).

It is also important to understand the life history of each insect, which includes not only the life cycle, but also the number of generations per year, the point in the year when the life cycles occur, and the overwintering stage and location. When utilizing management measures, targeting the vulnerable life stage of the insect pest is very often vital. Some cranberry pests move into beds from outside overwintering sites (e.g., cranberry weevil) while other pests remain in the beds continuously (e.g., Sparganothis fruitworm). For both cases, the pest insect population is usually vulnerable to management within given windows of time.

Most pest insects in cranberry complete a single generation each year, although several carry out two or more. Insects are not active during the winter, and each species has one life stage that is adapted for survival through the winter. For example, black-headed fireworm and gypsy moth overwinter as eggs, Sparganothis fruitworm overwinters as a small larva, cranberry fruitworm overwinters as a last instar larva, brown spanworm overwinters as a pupa, and cranberry weevil and false armyworm overwinter as adults.

DETECTING PEST INSECTS

Sampling and monitoring of acreage, or scouting, allows recognition of a pest problem and is an essential activity in insect management. Through scouting, we can accurately determine the presence or estimate the density of a pest. Detection of pests utilizes visual assessments of the bog as well as sampling with a sweep net. Typically, a sweep net is a fine mesh net attached to a 12-inch diameter ring that is fixed to a long wooden handle (Fig. 2).

Number of sweep sets for a given acreage for single, continuous pieces of bog (management unit):

1-10 acres	1 sweep set/acre
10-20 acres	at least 10 sweep sets
> 20 acres	1 sweep set per 2 A

Sweep netting involves sweeping back and forth across the vines. A single sweep is a 180-degree arc over the vines using a 12-inch diameter sweep net. Sweeping should be done as one walks across the bog, covering as much area as possible. A sweep set consists of 25 sweeps.

The net should be dug into the vines to pick up caterpillars that are clinging to the lower portion of the stem. Weed s patches and bare spots should be avoided. Sweeping should start at least 10 feet in from the bog edge. A fter completing the last sweep of the set, the rim should be tapped so the insects fall down into the net. The contents should then be inspected carefully. The insects should be properly identified (use a 10X magnifier), counted, and recorded. We ekly sweeping activity typically begins the second week of May. Scouting should continue at least until bloom, but note that some pests are active during bloom (e.g., brown spanworm) or after bloom (e.g., cranberry weevil and flea beetle).

Fig. 2. Dr. Henry Franklin using a sweep net on cranberry vines. Courtesy unknown.

Large beds may be subdivided and managed as smaller units depending on cultivar, chemigation design, or ability to treat aerially. I n these instances, specific data should be collected and management decisions evaluated for each management unit.

Pest levels of insect caterpillars should be evaluated in their early stages for two reasons. First, most species are easier to manage when the larva is small, and the most effective use of the new insect growth regulators (IGR, e.g., Intrepid) targets small larvae. Second, as the caterpillars of some species grow larger, they are harder to pick up in sweeps. They cling to the vine or hide in the daytime (e.g., false armyworm). Thus, they are less likely to be gathered in the sweep net over time.

Some pests (such as black-headed fireworm, cranberry weevil, gypsy moth, and brown spanworm) may be very patchy on a bed or may occur in high numbers in coves or on edges. Thus, thorough assessment of total acreage is essential.

Table 1. Action thresholds for common cranberry pests, based on average numbers of insects in sets of 25 sweeps.

Insect	**Threshold**
Black-headed fireworm Action should be considered relative to a past history of infestation.	1 to 2
Sparganothis fruitworm Visual search for webbed vines or leaves should also be carried out.	1 to 2
Cranberry weevils These small, reddish snout beetles may play dead; thus, the net should be left undisturbed for awhile. Sweeping picks up higher numbers when it is warm and sunny.	4 to 5
Cutworms (false armyworm, cranberry blossomworm, humped green fruitworm, gypsy moth caterpillar) Add up the numbers for these caterpillars as if they are the same kind of insect. Do not include cranberry sawfly in your cutworm counts.	4 to 5
Green and brown spanworm Small caterpillars will cling to side of the net.	18

Treatment of a pest population is often based on scouting. When pest insect numbers are evaluated by sweep netting, management may be considered when the insect numbers exceed an established action threshold (Table 1).

Cranberry thresholds are based on the average number of insects in sets of 25 sweeps. The average number of insects at a site is calculated by adding up all counts in all sweep sets and dividing by the number of sets conducted. This average number should be compared with the threshold values listed in Table 1. If the average number of a given pest on a bog is greater than or equal to the threshold, management measures should be considered.

Threshold levels for pest insects in Massachusetts cranberry have been shown to be valuable in insect management for many decades. They represent the level of insect pest pressure that experienced workers have determined to be sufficiently high to be of concern. Thus, the decision whether to treat when a threshold is exceeded, particularly with synthetic insecticides, should not be made without bringing many other external concerns to bear (e.g., crop value, cost of management tactic, water concerns, weather, neighbors, resistance management).

Pheromone trapping. Pheromones are chemical signals that are emitted and received by members of the same species, allowing communication. Sex pheromones serve to attract members of the opposite sex for mating. For cranberry pest species, the female is always the emitter of long-range sex pheromones. Synthetic compounds that copy these sex pheromones are available for several pests in cranberry including Sparganothis fruitworm, cranberry girdler, and black-headed fireworm. Traps containing these pheromones are regularly employed in IPM programs. Traps are also available for cranberry blossomworm and cranberry fruitworm, but these have limited use in Massachusetts cranberry. The sex pheromones of all scarab beetle pests of cranberry (this includes cranberry root grub and cranberry white grub) have also been identified, but only that of oriental beetle is commercially available. The pheromone is placed on a rubber septum that is used as a lure in sticky traps to monitor moth populations or in non-sticky catch-can traps for oriental beetle adults.

Each trap is specific to only one pest species (although one should check descriptions of adults because non-pest species are sometimes caught in fairly large numbers in both the cranberry girdler and black-headed fireworm traps). Further, when interpreting results of trap data, it should be kept in mind that only males are captured in these traps, and that female activity may or may not be comparable.

For all of these pests, we do not have sufficient information to correlate trap captures with an action threshold level. Pheromone traps are utilized in cranberry to time application of a treatment, usually not to trigger the need for a treatment, and sometimes to gauge whether pest pressure is high (e.g., for Sparganothis fruitworm or black-headed fireworm).

For the moth pests, traps should be deployed prior to onset of adult flight. One trap per 10 acres should be used and placed on the upwind side of the bog. They should be checked weekly and the number of insects captured carefully recorded. For sticky traps, the bottoms should be kept free of debris and be changed if necessary. Further, the pheromone lure should be changed every three weeks, or as recommended.

Pheromone traps can be employed to time applications of insecticides. Depending on the insecticide choice, different trap information is used. Check recommendations to see what point in the moth flight is critical for a given insecticide choice. It may be: 1) onset of significant flight (*biofix*), 2) peak trap capture, or 3) end of flight. For example, if using an insect growth regulator (IGR, e.g., Intrepid) to manage Sparganothis fruitworm in summer, the target is larvae just as they hatch from the egg. Thus, the recommendation is to determine the biofix, based on trap captures, and to apply Intrepid three weeks later and again in 10 days. As another example, to manage oriental beetle with Admire, an application should be made 3 weeks after peak flight of beetles (Averill and Sylvia 2008).

BEHAVIORAL CONTROL

Mating disruption. When large quantities of synthetic pheromone are deployed in the crop, the habitat is permeated and the frequency of successful mating is lowered. The pheromone application interferes with the male's proper functioning and his normal in-flight location of females. Mating disruption has been shown to be effective for oriental beetle (Wenninger and Averill 2006), black-headed fireworm, and Sparganothis fruitworm.

A technique for pheromone release systems involves retrievable point source dispensers (e.g., pheromone impregnated ropes or twist ties) and another is aerosol canisters that emit high rates of pheromone (MSTRS or 'Metered semiochemical timed release system' http://www.mstrs.com). While there has been considerable work in this area, particularly for black-headed fireworm, the mating disruption tactic has not been widely adopted. This has led to patchy availability of commercial systems. For the latest updates, contact the UMass Cranberry Station.

CULTURAL CONTROL

Late water floods (April 15 - May 15) can be used to manage the following pests: cutworms, gypsy moth, cranberry fruitworm, and Southern red mite (SRM). Late water is especially effective against SRM; populations may be lowered for two seasons (Averill et al. 1997).

Summer floods (May 12 to July 20) may be used to eliminate cranberry root grubs and white grubs. This is a drastic measure since the crop for that season will be lost and may be reduced in the following year.

Harvest floods and fall floods historically have been important in soil insect management. For cranberry girdler (see following section on girdler), using a harvest flood on early cultivars, together with regular removal of trash, can usually keep the insect in check. A longer fall flood is highly effective for suppressing black vine weevil and strawberry root weevil. However, research by Vanden Heuvel showed that the carbohydrate reserves in the vine decrease during extended fall floods and as a result, yield may decrease in the following year (Vanden Heuvel and Botelho 2005).

Sanding. Sanding on a regular basis suppresses cranberry girdler, green spanworm, and cranberry tipworm.

INSECTICIDES

The primary site of action differs among the various insecticides used in cranberry (IRAC Mode of Action Classification v. 5.3 July 2007, http://www.irac-online.org/). This activity is used to group insecticides into various classifications.

Carbamates and Organophosphates. These groups include the conventional active ingredients that have been used for many years in cranberry insect management. Sevin, Diazinon, Orthene, and Lorsban are in these groups. They are broad spectrum (often toxic to bees and natural enemies) in activity and often have high toxicity to humans. They target the nervous system and are acetycholinesterase inhibitors. Most members of these groups are being reduced (in terms of usage) or phased out.

Insect Growth Regulators (IGR). This group interferes with molting or metamorphosis**.** In cranberry, IGRs include Confirm and Intrepid, which are caterpillar specific, conserve bees and beneficial insects, and have low human toxicity. These compounds are most effective when applied multiple times and in low gallonage against small caterpillars feeding on foliage. Intrepid has higher activity than Confirm, but Intrepid is a restricted use compound and is Zone II restricted. Thorough coverage is essential and new growth is not protected; rain, irrigation, or chemigation washout will remove active material. Death may not be observed until a week or more has passed.

Spinosyns (e.g., spinosad, spinetoram). These target the nervous system, interfering with the insect's normal functioning at the synapse, causing paralysis and death. They work via contact and ingestion and have low non-target impact. This group includes the products, Delegate, SpinTor, and Entrust.

Indoxacarb. Avaunt, which acts against the nervous system, leads to nerve dysfunction in the insect. It is particularly effective against caterpillars.

Neonicotinoids. This group targets the nervous system and the mode of action is similar to the natural insecticide, nicotine. Their action causes excitation of the nerves, paralysis and death. They exhibit systemic activity in the plant. In other plant systems, studies suggest increased numbers of mites with the use of neonicotinoids, but this is not documented in cranberry. This group includes Actara and Admire.

Microbial Disruptors of Midgut Membranes. These are the *Bacillus thuringiensis* (B.t.) products that works as a stomach poison specific only to moth larvae. They must be eaten to be effective, applications must be well timed against small larvae, and be applied in low gallonage. B.t. products have not been widely adopted in Massachusetts cranberry, largely because other reduced-risk options perform better.

BIOLOGICAL CONTROL

Beneficial nematodes can be applied to manage cranberry girdler, black vine weevil, and strawberry root weevil, but availability is not always guaranteed. Application timing for cranberry girdler is based on moth flight data collected from pheromone traps. Nematode applications for black vine weevil and strawberry root weevil management are made in May and/or September. Nematodes need moist conditions. Irrigation should be carried out before the nematode application to thoroughly wet the bog and immediately after the application for four to five hours (1/2 inch). A recently discovered nematode species, *Steinernema scarabaei*, shows high mortality against scarab beetle larvae, but rearing and production difficulties currently limit its use. Check with the UMass Cranberry Station for updates.

Natural populations of beneficial organisms can also help to manage insect pests. Predators and parasitoids that coexist in the bog environment play an important role in regulating pest levels. This role should be enhanced wherever possible by avoiding unnecessary insecticide treatments to encourage natural enemy populations through conservation. Broad-spectrum clean-up sprays destroy natural enemies, so these should be avoided. Whenever possible, if there is a control option that will preserve beneficial species, it should be utilized.

REVIEW OF CRANBERRY INSECTS

CRANBERRY WEEVIL
***Anthonomus musculus* (Say)**
Coleoptera: Curculionidae

Description. This is a key pest. Cranberry weevils are very small reddish-brown beetles that are ca. 1/16th inch long. The weevil has a slightly curved snout about a third as long as the rest of the body.

Damage. Adult weevils are found on the bog throughout the growing season. Both larvae and adults injure the cranberry vine. Adults feed on the foliage, terminal buds, and blossom buds in the spring and on fruits, foliage, and terminal buds in the summer. Feeding injury often appears as small irregular holes on leaf undersides or small fruit. Because the female often severs the bud from the plant following egglaying, clipped pedicels are an indication of possible weevil infestation.

Life History. There are one or two generations per year. Adults emerge from overwintering sites in April and feed on blueberry prior to new growth appearing on cranberry. Adults appear on the bog from mid-May through mid-June (Fig. 3), likely flying in from the surrounding woodlands. Once on the bog, the weevils feed on the tender new growth, including blossom buds. Later in the spring, mated females insert eggs between the petals of the developing blossom buds. Usually, a single egg is placed inside each blossom and the white, legless larva eats out the internal flower parts. Following pupation, which also occurs within the bud, the adult exits the bud and feeds on foliage and newly set fruit. The life cycle from egg to adult is completed in less than two months.

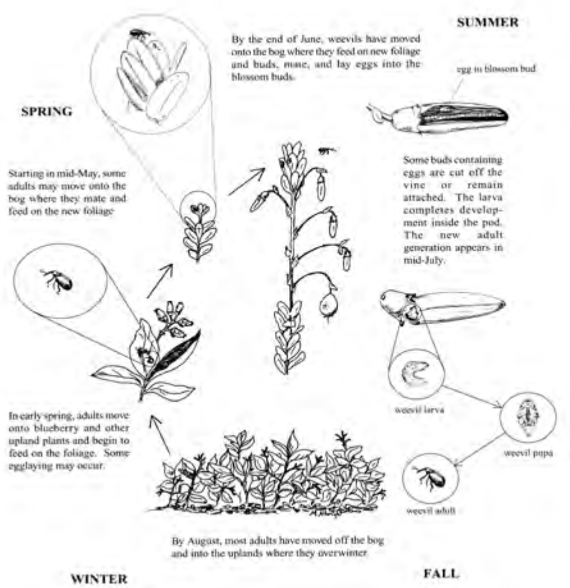

Fig. 3. Cranberry weevil life cycle (Averill and Sylvia 1998).

Management. Beds should be monitored with sweep nets through early spring into June on warm, calm days. Adults may immigrate onto beds non-synchronously over an extended period. If the action threshold is exceeded early, it may be advisable to hold off on an insecticide application and continue sweeping to determine if weevil numbers continue to rise. However, waiting becomes risky as soon as blossom buds appear, because females will begin to lay eggs. For weevil management, it helps to have a compilation of sweep records over time; population trends are often consistent among years. Populations on the bog are often concentrated in neck areas near wooded uplands, allowing the option of localized spraying. Over the years, weevils have become resistant to most insecticides used in management programs.

CRANBERRY FRUITWORM
***Acrobasis vaccinii* Riley**
Lepidoptera: Pyralidae

This insect is a key fruit pest. It is one of the most common pest species in Massachusetts and has the potential to cause significant losses in cranberry production.

Description. The larva is usually green with a tan head capsule, although as it reaches full size at about ½ inch, the green color is often tinged with red/pink on the back. The moth is light-dark grayish, often with white triangles on the forewings; it is about 3/8 inch long.

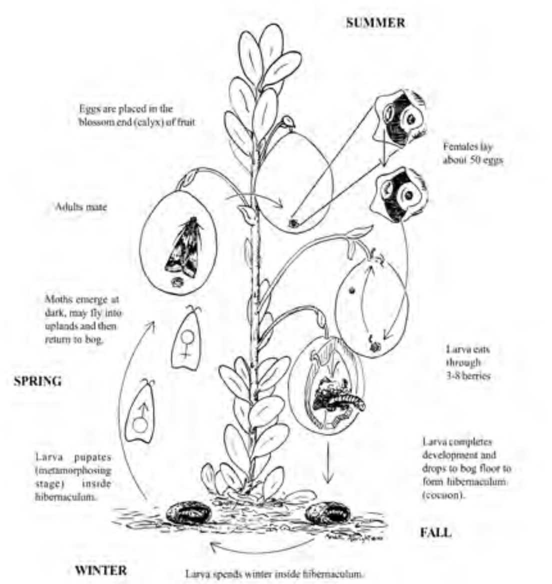

Fig. 4. Cranberry fruitworm life cycle (Averill and Sylvia 1998).

Life History. Around mid- to late-June, moths begin to emerge and mate. The moths fly at dusk and are highly secretive and inactive during the day. The female moths deposit eggs singly at the blossom end, or calyx, of the developing cranberries; the eggs are placed inside the rim of the calyx cup. Females discriminate against pinheads, and will deposit large numbers of eggs only after the pinheads begin to enlarge.

The flattened, oblong eggs develop through several stages, green to yellow to orange-lined, in five or six days and then hatch. The newly hatched larva typically crawls over the surface of the fruit from its place of emergence at the blossom end, and enters the fruit close to the stem. Its entrance is so small that it is barely visible to the unaided eye. It eats the seeds and usually much of the fruit flesh prior to moving to a new berry. One larva usually eats the interior of about three to six berries (the number varying with berry size). When small through medium size, the larva usually covers its entrance into the fruit with white silk. The larva frequently moves from one berry directly into another at the point of berry contact. As the berry becomes full of the larva's brown excrement (frass), it turns red prematurely. These red fruit are usually the first sign of infestation. Damaged berries gradually dry and shrivel like raisins. They may cling to the vines as husks until the next year.

The larvae are generally most active from mid-July to mid-August. When feeding is completed, a larva exits the fruit, enters the bog soil to a depth of ca. 1 inch, and spins a hibernaculum (protective covering) of sand and trash in which the pre-pupa overwinters. The average cocoon is about 3/8 inch long. In late spring, the pre-pupa forms a pupa and the first moths emerge in June (Fig. 3). The moths move extensively throughout the uplands.

Cranberry Fruitworm Management. Cranberry fruitworm management should target eggs only. The first one or two sprays should be carefully timed based on phenology (% out-of-bloom) of the cranberry plant. For the standard practice, to time the first spray application, calculate the percent out-of-bloom (%OOB) every few days as pinheads start to form, usually around the end of June. For each acre of bog, randomly collect 10 uprights and record the number of flower buds, flowers, pinheads, and fruit. Calculate % OOB using the following:

$$\frac{\text{No. pinheads + fruit}}{\text{No. buds + flowers + pinheads + fruit}} \text{ X 100}$$

If treating with insecticides, timing of the first fruitworm spray is often critical; it occurs at the point of peak egg-laying. The first treatment should be applied 7-9 days after 50% out-of-bloom (half the blossoms have lost all petals to become fruits) for Howes and Early Black. This interval should be shortened to 5-7 days for Ben Lear and 3-5 days for Stevens. Female moths typically wait until pinheads have begun to enlarge to lay eggs. Because the newer large-fruited cultivars may size up more rapidly, fruitworm sprays may be tricky, and it is important to keep an eye on these beds. A second treatment should be made about 10 days after the first treatment.

Table 2. Action thresholds for cranberry fruitworm.

No. of acres	No. of berries checked	No. of viable eggs needed to consider spray
0-5	200-250	1
5-7	251-350	2
7-9	351-450	3
9-11	451-550	4
11-13	551-650	5
13-15	651-750	6
each add'l 2 acres	add 100 berries	add 1 egg

After the first two spray applications using the standard practice based on crop phenology, Table 2 can be utilized to determine the necessity of additional sprays for sites that have moderate to high fruitworm populations. At these high pressure sites, moths may be present and egg-laying may continue right into August. A week after the second treatment, 50 randomly picked berries per acre (with a minimum of 200 berries per piece, no matter how small) should be inspected for eggs. If no egg is found, berry inspection should be repeated every three to four days until August 15.

For sites with low cranberry fruitworm pressure, the second treatment may be eliminated through examination of fruit for eggs, also using the action threshold values found in Table 2. In this instance, the first spray is applied based on crop phenology as described above. However, rather than applying the second spray in 10 days, fruit inspection begins 5 days after the first spray. The guidelines for the number of unhatched, viable eggs are used as the determinant for any additional sprays.

Sprays made in an attempt to control larvae in the fruit have been shown to have very limited impact. Research shows that once the larvae burrow into the berry, sprays are minimally effective.

In blueberry plantings, moth emergence usually coincides with the start of bloom and pheromone traps may be employed in management recommendations. However, in cranberry, onset of moth emergence occurs prior to onset of bloom and there is little relationship between moth captures and egg-laying activity.

SPARGANOTHIS FRUITWORM
Sparganothis sulfureana (Clemens)
Lepidoptera: Tortricidae

This species is a key pest. Because it has a broad range of natural enemies, we may see lowered populations as broad-spectrum insecticide sprays in early and mid-season are eliminated and beneficial parasitic wasp and fly species increase in number.

Sparganothis fruitworm goes through two generations each year. Moths are very rarely captured in sex pheromone traps deployed in the uplands around Massachusetts beds, suggesting that they do move much outside of the bog.

Description. The first instar is a black-headed larva resembling a black-headed fireworm. However, when the larva molts to the second instar, it loses the black head; it now has a yellow head and the body is yellow or greenish-yellow and is impossible to distinguish from yellow-headed fireworm with the naked eye. They wriggle fiercely when disturbed, similar to their fireworm relatives. The moths are 2/3 to 5/8 inch long, and have highly distinctive sulfur-yellow wings with a brown "X" shaped mark when at rest.

Life History. The first generation spends the winter as a tiny larva (first instar) on the bog (Fig. 5). The larva becomes active as soon as new tip growth appears in the spring in mid to late May. It webs together two leaves, often like a sandwich, within which it feeds. Since the larvae are already on the bog in mid-May, they can be sampled by sweep netting. Sparganothis caterpillars can also be found in loosestrife, where they fold and web the leaves. As larvae become larger, they web together cranberry uprights in tent-like fashion. In June and July, the larvae pupate and emerge as moths. The female moths lay eggs in masses of 10-30 on leaves, fruit, and weeds.

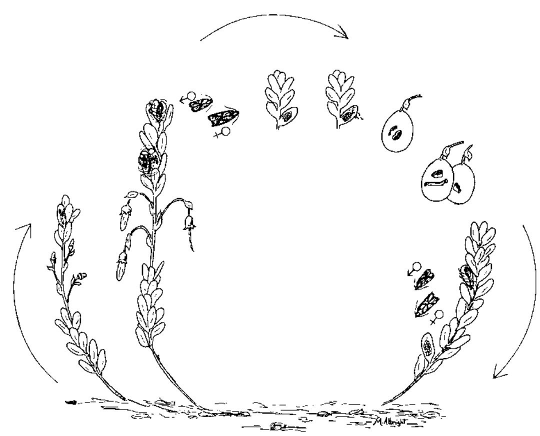

Fig. 5. Depiction of the life cycle of Sparganothis fruitworm (Averill and Sylvia 1998).

Damage by the second generation begins when eggs hatch, usually 9-12 days after being laid. These larvae feed on both foliage and fruit. They do the most damage by partially feeding on many berries (scoring) and, particularly on Ben Lear, may feed inside the fruit. In berries, it is possible to distinguish between the two fruitworms by the type of damage: cranberry fruitworm fills the berry with brown frass, and the berry becomes mushy while Sparganothis tends to be a much tidier feeder. These larvae feed into August and September, pupate, and emerge as moths in the fall. The female moths then lay eggs that hatch, and the tiny larvae overwinter.

Management. The spring generation is monitored during sweep netting. Because of their webbing behavior, only small numbers of larvae are picked up. If treating the second generation, pheromone traps should be utilized to time an insecticide two weeks after peak moth flight (or earlier, based on biofix, if using growth regulators) (see Pheromone trapping section above). With both generations, treatment should target the small caterpillars.

Sparganothis fruitworm management is often difficult. Resistance to organophosphate insecticides has appeared in the last 20 years and new alternatives have replaced them. Late water has not been shown to be effective in killing this insect, but the flood may synchronize the population following the removal of the flood. Larger larvae are difficult to kill, and sprays aimed at them may aggravate the situation by killing off parasitoids that are important in keeping numbers in check naturally.

FIREWORMS
Lepidoptera: Tortricidae

Black-headed Fireworm
Rhopobota naevana (Hübner)

The black-headed fireworm, a common and highly damaging pest species in most other cranberry growing regions, has recently reemerged as major problem in Massachusetts after several decades of low pest status. Damage from black-headed fireworm infestations can spread very quickly and unchecked summer populations can devastate beds.

Black-headed fireworm typically has only two generations a year, but a partial third may occur. The small moth is 3/8 inch long and is dark grayish brown, with silvery markings. The round and yellow overwintering eggs start hatching in early to mid May. The newly hatched caterpillars may burrow into the cranberry leaf or terminal buds. Then, on the new shoots, older caterpillars will web a few leaves together. As it matures, larger larvae web several uprights together, and create several of these tents before feeding is completed.

The caterpillar has a highly distinct shiny black head, black neck, and a dingy green body. Mature caterpillars are 1/3 – 1/2 inch long. First generation moths appear in June and second generation larvae then appear during bloom and fruit set in July. The moths of the second generation lay overwintering eggs singly on the bottom of leaves in late July through August.

Because they are webbed up in the vines, sweeping misses many larvae, particularly when they are small. If the vines are overgrown, populations may become very asynchronous. Because eggs are on the underside of leaves, they may be transported to new locations on vines used for new plantings.

Yellow-headed Fireworm
Acleris minuta (Robinson)

Typically, yellow-headed fireworm is found on bed edges where there was an incomplete winter flood. There are three generations a year. The moths of the first two summer generations are orange-yellow (and fly in June and August) and the third generation moths are slate-gray. The moths overwinter.

Eggs may be laid in April and hatch in May. Larvae are very similar in appearance to Sparganothis fruitworm. A larva feeds intensively in a messy tent comprised of many uprights and is associated with abundant silk and frass.

CUTWORMS
Lepidoptera: Noctuidae

A number of different caterpillars attack cranberry vines in May and June. The best-known and most-damaging species are false armyworm, cranberry blossomworm, and humped green fruitworm.

False Armyworm
***Xylena nupera* (Litner)**

Cranberry Blossomworm
***Epiglaea apiata* (Grote)**

Humped Green Fruitworm
***Amphipyra pyramidoides* (Guenée)**

Other cutworm species may only occur from time to time, frequently as a result of highly mobile moths dropping their eggs into the moist, favorable environment of the cranberry beds.

Description. Young cranberry blossomworm caterpillars are mostly green with a tinge of pink or purple but as they grow, they become mostly red or purple with a white stripe along the side. Young false armyworm caterpillars are more difficult to identify. They are grey-green with small black dots with slender hairs only visible under magnification. Tiny caterpillars loop like spanworms, but the older caterpillars do not. They are easily identified as they become larger (3/8 inch) with lime green bodies and white lines along each side of the body. The caterpillar of the humped green fruitworm is similar to false armyworm but has a prominent hump on its back section. The humped green fruitworm caterpillar is apple green and has a thin continuous white line running down its back along with a patchy yellow line down the side.

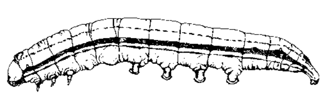

Fig. 6. Illustration of a cutworm (Averill and Sylvia 1998). Note five pairs of hind legs.

Life History. Both cranberry blossomworm and humped green fruitworm moths fly during harvest and lay eggs that overwinter on the bog. In comparison, false armyworm overwinters as a moth and lays masses of eggs in the spring. Regardless of when eggs were laid, they begin hatching in early May and feed on the cranberry vines. Cutworm caterpillars can be distinguished from spanworm caterpillars by the five pairs (versus two pairs; Fig. 6 and 7) of hind legs that appear in their midsection. Cutworms are large-bodied, almost bloated-looking caterpillars that can reach 1.5 to 2 inches long when mature.

Young cutworm caterpillars, particularly false armyworm, often do great harm by eating out the hearts of the terminal buds before new growth starts. They develop with the new growth and feed more and more voraciously as they mature, devouring leaves, buds, and flowers. They feed freely in the daytime as young caterpillars. Unlike blossomworm and false armyworm, which are nocturnal in the later instars, humped green fruitworm may feed during the day even as a large caterpillar.

By the end of June, all mature caterpillars have completed development and pupate into moths later in the summer.

Management. Sprays should target small larvae. Insect growth regulator products are particularly effective against these insects when they are small. Older large caterpillars are much harder to sample and control.

GYPSY MOTH
***Lymantria dispar* L.**
Lepidoptera: Lymantriidae

Description. When young, gypsy moth caterpillars are very hairy and totally black. As they mature, they are covered with long black hairs and have prominent red and blue bumps; they have five pairs of blue spots followed by six pairs of red spots. They may be one to two inches long when mature.

Life History. The female moth does not fly and lays overwintering eggs in large masses, usually in the vicinity of where she completed larval development. Eggs are able to overwinter on the bog, even under winter floods. The eggs hatch from late April into June. Gypsy moths are particularly troublesome as they may hatch in surrounding pine trees and blow into the bog from great distances. The tiny caterpillars disperse from trees by letting out a silken thread that is picked up and blown by the wind. Older caterpillars walk onto the bog if they have exhausted the foliage in the surrounding oak-pine woods. Gypsy moth populations have declined overall in the Northeast region.

Management. Gypsy moth should be counted in with cutworm numbers during sweep counts. They behave similarly and may have potential for even greater injury. Young caterpillars eat the developing buds and as the caterpillar grows, devours leaves, buds, and flowers.

SPANWORMS
Lepidoptera: Geometridae

Another group of caterpillars that attack cranberry are called spanworms, loopers, or inchworms, because of the way they move across a surface. They stretch out at full length, take hold with the front legs, and then bring forward the hind end close to the front pairs of feet in a looping manner. This habit is due to the lack of several legs (that other caterpillars have) to support the middle of the body. The hind part has only two pairs of legs (Fig. ?). These larvae are more slender than most caterpillars. They are hairless and feed openly, never sewing leaves together. Larval defenses include both behavioral and physical traits. When disturbed, they cling to their support by the hind pairs of legs and remain straight and motionless and they typically are cryptically colored to harmonize with their background or may resemble plant parts.

Green Spanworm
Itame sulphurea (Packard)

The eggs of green spanworm hatch from May 15 to June 1, a little later than many of the cutworms. The larvae usually nip off flower buds and blossoms by severing the stem. When extremely abundant, they attack the leaves and sometimes may cause brown discoloration to a small area of bog. Green spanworms are green with several white lines along the back and sides and a narrow light yellow stripe along each side. They stop feeding when they are about an inch long and pupate in the trash layer around mid-June. The moths emerge in July and scatter their eggs among the trash litter under the vines.

Brown Spanworm
Ematurga amitaria (Guenée)

The young larvae are light brown with a whitish stripe along each side and another along the middle of the back. Full-grown larvae are a little over an inch long, usually grayish brown and may vary in markings. Brown spanworm overwinters as a pupa in the leaf litter on the bog and emerge as moths in late May. The moth lays eggs in June in clusters of up to 20 in the leaf litter of the bog floor. These eggs begin to hatch in mid-June, much later than cutworms or green spanworms. For sprays to be effective, they must target the young caterpillars (1/4 – 1/2 inch long). Brown spanworm larvae are particularly hard to manage with many broad-spectrum insecticides because their late spring appearance coincides with the placement of bee hives onto the beds. Growth regulator products are a good spray option, but may require two or more treatments. Infestations can be very severe, with the larvae nipping off many blossoms and gouging small berries.

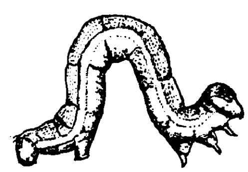

Fig. 7. Illustration of a spanworm (Averill and Sylvia 1998). Note two pairs of hind legs.

Great Cranberry Spanworm
Eutrapela clemataria (J.E. Sm.)

The moth is commonly called the 'curve-toothed geometer' and is light gray, dully variegated with rusty brown. The wings spread about 2 inches. Egg clusters hatch toward mid-June. The caterpillars are almost black at first, but as they grow they become chocolate brown. The mature larva is fully 2.5 inches long. Most of its surface is very smooth. A noticeable dark ridge bearing a few low bumps crosses the back opposite the second pair of legs. Great cranberry spanworm overwinters as a pupa, emerges as a moth late in May. The worms mature and pupate in July. They prefer to sever the flower buds and blossoms. There is one generation a year.

This species, which usually occurs in distinct patches, can be particularly destructive on rare occasions. Spot treating with a backpack sprayer has been highly effective, and saves treating larger acreage that chiefly is not infested. Because of the large size that these worms attain, their sweep net count should be weighted in sweep counts like cutworms.

Winter Moth
Operophtera brumata L.

Winter moth has only recently appeared as a pest in southeastern Massachusetts and on cranberry. This insect has long been a pest in Europe and likely made its way into the US via Canada. Unfortunately, the larvae hatch in early spring and could do much damage before sweeping begins on cranberry in mid-May.

Winter moth larvae feed on a number of deciduous trees including oak, maple, and ash. They prefer fruit trees such as apple, crabapple, cherry and blueberry. When given a choice, they abandon cranberry, but under no-choice conditions, the larvae will eat cranberry. Because the female moths do not fly, if a few develop on cranberry, many eggs will be laid there the following year. The moths are active in November and December. Female moths are gray and wingless and can be found at the base of trees. Males are small, brown to tan moths.

Larvae hatch in April, but can hatch as early as March if weather permits. On cranberry, the larvae may be delayed until the buds enlarge around May 1. The tiny larvae burrow into developing buds, preferring the flowering buds. Once they have eaten out one bud, they move onto another bud. The larvae closely resemble green spanworms seen on beds.

SOIL INSECTS

A confusing array of soil insects is known to attack cranberry roots, including scarab beetles (e.g., cranberry root grub, cranberry white grub), weevils (black vine weevil, strawberry root weevil) and a sod webworm, cranberry girdler (Dunn and Averill 1996). In the last 20 years, two additional scarab beetle species have been identified: two small brown chafer-type beetles: Oriental beetle and *Hoplia equina*, as well as a leaf beetle, striped colaspis. It is important to know the life cycle of these insects to properly time inspection of the bog soil for the immatures. For species with a single generation per year, searches in damaged areas will be futile once the adults have emerged. However, damage by insects can be distinguished from damage caused by Phytophthora root rot. Root rot occurs in poorly drained areas, frequently in inner bog areas; soil insects most frequently appear on bog edges, usually in well-drained regions.

Areas infested with the various kinds of root feeding insects are characteristic in several ways. For the soil insect species described below, the grubs feed on the fibrous roots, often so thoroughly that the vines will roll back easily like a carpet of commercial turf. Many species of grubs will be in the soil just below where the vine was rolled up, about three to four inches down. Under cold or very dry conditions, the grubs may move deeper down in the soil. In some cases, when the grubs have fed on the small roots, the vines will look sickly and weak and then will die suddenly following stressful conditions such as drought or herbicide application.

CRANBERRY GIRDLER
Chrysoteuchia topiaria (Zeller)
Lepidoptera: Pyralidae

The adult girdler is a moth. The girdler larvae live in the trash (leaf litter) layer on the floor of the bog and feed from July through September.

Unlike most of the cranberry soil insects, which are beetles, the cranberry girdler adult is a moth.

Adult moths usually emerge throughout June. The moths generally remain concealed among the vines or in the grass of dikes but are easily flushed and are day active. When disturbed, they often fly 10-20 feet with a quick, jerky flight before darting into the vines again. Female moths are more likely to drop into the bog's trash layer when disturbed and to take shorter flights than males (Fitzpatrick 2007). The moth is about 3/8 inch long, silvery with light brown outer edges, and has a snout-like 'nose' (actually the labial palps—sensory appendages associated with the mouthparts). Female moths produce on average about two hundred eggs that are scattered at random on the sand or trash under the vines.

The caterpillars have sooty-white bodies that are about 5/8-3/4 inch long when full grown and will only be found in late summer and fall. They are very difficult to detect, because of their small size and concealed feeding habits. They are found in the leaf litter where they gnaw on the bark and wood of the vine resulting in very typical plant injury. Damage becomes more apparent later in the fall when attacked vines die back. When the larva forms a cocoon in the fall, it is even more difficult to detect because it is constructed of leaf litter and sand.

Unchecked populations may result in infestation of the entire bog. Nematode applications have been used effectively, typically applied 2 weeks after the end of moth flight. Regular sanding is a very important practice in suppressing girdler. Lab studies suggest that fall flooding may be effective if: 1) the water is on for 2-3 days, 2) the water is fairly warm (ca. 68ºF) and 3) it is early enough in the season (September) such that late instars are still feeding and have not yet constructed cocoons (Fitzpatrick 2007). The standard harvest flood recommendation has called for a longer flood of one week, occurring before September 25. Recent work has shown that early harvest floods may have negative effects on the vines (Vanden Heuvel and Botelho 2005).

When an infestation is checked, a large number of vines (other than those that are dead or injured beyond recovery) are only partly girdled and will recover if they are not mistreated further. The wounds gradually heal by growth along their margins, but the scars remain for several years. Where girdler injury has not been severe enough to kill the vines, it often impairs their vitality and reduces the quantity and quality of the berries.

SOIL INSECTS — BEETLE GROUP

Scarab Beetles
Coleoptera: Scarabaeidae

If an infestation of white grubs is discovered, it is important to correctly identify the species. The cranberry root grub larva is covered with reddish-brown hairs and this allows it to be distinguished from cranberry white grub, oriental beetle, and *Hoplia equina*. These last three species are not covered with hair, are white and cylindrical and can be told apart from one another by inspecting the pattern of stiff hairs and spines found on their last abdominal segment (Averill and Sylvia 1998). These pests cause damage when the larvae feed on the roots of the cranberry plant.

Cranberry Root Grub
Lichnanthe vulpina (Hentz)

The adult beetle is about 5/8 inch long. The males have a distinctive coat of yellowish, fox-red hair, as do females, but the female's hair covering is much thinner. The wings are medium brown and do not cover the entire abdomen. Adults spend most of their time in the soil and have been reported to emerge synchronously to mate. The adults tend to hover over the ground surface when they fly, and because of their yellowish hair, may resemble bees. The grubs are usually about one inch long when full grown and are covered with reddish-brown hairs. The grub body appears slightly compressed from top to bottom and each foot has a claw on the end. Using these clues, these grubs can be distinguished from white grub when they are small. In comparison to cranberry root grub, white grubs are whiter, are not covered with hair and do not have flattened bodies; the end of the white grub foot looks like a paw, and does not have the distinctive claw of the cranberry root grub.

Since it takes several years for the grub to complete development into an adult beetle, all sizes of cranberry root grub may be found in an infestation because of overlapping broods. Cranberry root grub infestations are often found in bog margins, but infestations throughout a bog are not uncommon. The grub has only been found on cranberry and is well adapted to the wet conditions of cranberry beds.

Cranberry White Grub
***Phyllophaga anxia* (LeConte)**

The adults of the white grub are called May beetles, or more commonly, June bugs. The adult is about 7/8 inch long, reddish brown without markings. Although the larvae pupate late in the summer and emerge as adults, they stay in the bog soil and overwinter as a beetle. They emerge from the soil in early to mid-May. The beetles are active at dusk and feed (on tree foliage, not cranberry), mate, and lay eggs. The beetles attracted to lights at night may or may not be cranberry white grub adults; there are many similar-appearing species.

The C-shaped white grubs are the largest of the cranberry soil insects and are over 1.25 inches long when mature. They are white and become black toward the end. All different sizes of grubs can be seen at one time because the life cycle takes from 3-4 years, and the broods overlap. Cranberry white grub is usually found on high margins of the bog. Adult beetles may also be seen in the soil when sampling.

***Hoplia equina* LeConte**

Hoplia has a two-year life cycle (compared to the longer life cycles of root and cranberry white grub). As a result, *Hoplia* infestations seem to spread quickly.

Hoplia grubs are similar in appearance to small white grubs. For correct identification, specimens should be brought to the UMass Cranberry Station for microscopic inspection of the hair patterns on their hind ends. Full-size *Hoplia* grubs are 5/8 inch long. *Hoplia* emerge as adults in June or July of their second year. Adult beetles emerge late in the afternoon from the soil, mate, and then return to the soil to lay eggs. The adult beetle is oval-shaped, only 5/16 inches long, and vary in color from light brown to dark brown.

Oriental Beetle
***Anomala orientalis* Waterhouse**

These beetles are similar in size to Japanese beetles, about 5/8 inch long. Beetles vary greatly in color and wing pattern, ranging from straw-colored to black and may have no markings or may be covered with black markings. Adult emergence begins in June-July and peak activity occurs from mid-July to very early August with beetles emerging at dusk. The oriental beetle typically has one generation per year, with a small portion of the population taking two years. The larvae overwinter in the soil and migrate to the soil surface in the spring when temperatures reach about 50°F. They then feed for about 2 months before pupating. The adult stage is not considered a pest.

Damage can occur in patches, and damaged vine may radiate from these areas through subsequent generations. Oriental beetle grubs are similar in appearance to small white grub. For correct identification, specimens should be brought to the UMass Cranberry Station for microscopic inspection of the hair patterns on their hind ends. Full-sized oriental beetle grubs are 3/4 inch long.

CHRYSOMELID SOIL INSECTS
Coleoptera: Chrysomelidae

Striped Colaspis
***Colaspis costipennis* Crotch**

This is a distinctive, small leaf beetle that can be picked up in infested areas in fairly large numbers during daytime sweeping in June. The beetles are oval and are only 3/16 inch long. The head and back are metallic green and the wing covers are dark yellow and black striped. The legs are yellow. The adult beetles feed on the uppermost leaves of the cranberry upright, resulting in ragged notching on the leaf edges. In an area of vine dieback, this could provide a clue that damage is due to infestation by this insect. The grubs are only about a 1/4 inch long and are whitish with a yellow head. There is one generation per year. They can be seen in infested areas in the spring through May to early June and also late in the fall. They overwinter as almost fully grown grubs. Infestations are more common on upland beds.

Curculionid Soil Weevils
Coleoptera: Curculionidae

Black Vine Weevil
Otiorhynchus sulcatus (F.)

This is a key pest on the West Coast, and occasionally appears in Massachusetts beds. It is called a snout beetle because the adults have a long, curved beak. The adult is black with yellow flecks and is 2/5 to 3/8 inch long. It has a hard-shelled body and cannot fly. The adults emerge in June through July. Weeks pass before they begin to lay their eggs; in the meantime, they feed on cranberry and other plants in the area, such as dewberries (running brambles). The adult feeding creates a very characteristic notch on the leaf edge, but adults are not considered harmful. During the day, the adults hide out in the leaf litter; at night, the weevils move up on the foliage to feed. Night sweeping in June through July, particularly when it is warm, will pick up the weevils in areas of infestation. Black vine weevils feed on a range of herbaceous and woody plants such as rhododendrons, azaleas, yews, and grapes.

The larvae are yellowish white and appear C-shaped in the soil. Of the soil insects, only black vine weevil and strawberry root weevil are legless. The grubs overwinter, and may be found in the fall and in the spring. Because there is one generation per year, no grubs are found in late spring and summer. Often, vine weevil damage appears similar to cranberry girdler because the grubs feed on the bark of the vine below the trash level, although the feeding is seldom as deep as that of cranberry girdler.

Strawberry Root Weevil
Otiorhynchus ovatus (L.)

Strawberry root weevil is an occasional problem. This weevil looks like black vine weevil except that it is significantly smaller, only 1/5 to 1/4 inch long, and has a reddish to brownish coloration. Night sweeping in June-July picks up these weevils. The grubs are legless and are only 1/4 inch long when full grown. They feed on many plants, including strawberries, nursery crops, and hemlock.

In general, black vine weevil is found in beds that are seldom flooded. Strawberry root weevil populations tend to appear in beds that are winter flooded, but that have high sections. Infestations of both weevils can be managed with beneficial nematode applications or fall flooding.

OTHER MISCELLANEOUS PESTS

Southern Red Mite
Oligonychus ilicis (McGregor)
Acari: Tetranychidae

This species is not an insect but a mite that belongs in the class of animals that also includes spiders. The mites pierce the upper surfaces of the cranberry leaves and suck their juices, leaving minute brownish scars. They do not typically affect the undersides of the leaves. A severe infestation gives the foliage a characteristic dingy green appearance in summer and an orange, burnt color later in the season. Stippling, or tiny spots where the chlorophyll (or green color) is removed from the leaf, is a classic sign of Southern red mite damage. They are also a pest of broadleaf evergreens, such as azalea, holly, and rhododendron.

The mites pass the winter in the egg stage, mostly on the cranberry foliage where the first adults of the season are found in May. Once these mites complete development, the female mites lay eggs in June and July, and these hatch by mid-July. As the season continues, mites of all stages are found on the cranberry leaves.

The eggs are spherical, usually deep red, shiny, and measure less than 1/100 inch in diameter. The overwintering eggs are laid, usually singly, on the cranberry bark and leaves. The summer eggs are laid mostly on the new growth.

The mites grow considerably after they hatch, having three pairs of legs at first but four pairs later. They pass through several stages and are still so small when mature that it takes good eyes to observe them. At full size, they are still only 1/100 inch in size. They are then mostly deep reddish-brown and look like minute spiders. Hatched egg shells and white cast 'skins' on the backs of the cranberry leaves signal a current or past infestation.

Holding late water is an excellent option in southern red mite management. Late water suppresses or eliminates the mite populations in the year of the flood and suppresses populations the following year as well.

Red-headed Flea Beetle
Systena frontalis (F.)
Coleoptera: Chrysomelidae

The shiny black adult is 1/8 to 1/5 inch long with a reddish head. Like fleas, they have enlarged back legs that allow them to jump. Adults are active in late July through September. The adult beetle skeletonizes both upper and lower leaf surfaces and may occasionally gouge berries. Many beetles feed in one area, often on lush overgrowth creating patches of damage across a bog. Adult feeding can impact bud development for the following year.

Overwintering eggs are laid into the soil near the roots in August and September. Egg hatch occurs in June and the larva feeds on the roots, stems, and runners of cranberry and/or weeds. While cranberry root damage has not been documented in Massachusetts, it has been found in Wisconsin. Populations of this beetle have increased steadily in recent years in Massachusetts.

Cranberry Tipworm
Dasineura oxycoccana (Johnson)
Diptera: Cecidomyiidae

The tipworm adult is a tiny fly. Adults emerge early in May. There are several generations through the growing season with activity sometimes extending into early September. The populations peak in May and June due to the abundance of succulent new growth, which is optimal for the development of larvae.

The female lays eggs at the base of the leaves in the tips of the upright. The eggs hatch into tiny maggots that feed on the developing leaflets. These larvae are transparent when first hatching, become white in the next instar, and finally, orange. Their feeding causes a characteristic cupping of the growing tip that eventually dies and turns brown.

Results of a multi-year study show that while early-season tipworm damage may be very high, late-season infestation is generally negligible, and good vine health enhances rebudding. Appearance of damage does not mean that insects are still present. Only late-season damage appears to impact yield, and late-season populations are typically very low or nonexistent.

Leafminers

Two cranberry leafminers, *Coptodisca negligens* and *Nepticulid* sp., may be found on cranberry beds. Both leafminers are microlepidoptera, tiny moths less than 1/8 inch long. The *Coptodisca* moth is silvery black with a fringe on the base of its wings. The *Nepticulid* moth is black with a distinct silver stripe along the base of its wings.

The *Coptodisca* moths emerge during bloom and the females lay eggs by piercing the underside of the leaf. These eggs then overwinter. In the spring, the eggs hatch and the larva feeds inside the cranberry leaf. Towards the end of its development, the larva cuts out an oval case from the upper and lower part of the leaf, sewing the edges together with silk. These cases are about 1/8 inch long. Oval holes, about 1/5 of the total leaf surface, are left in the cranberry leaf.

These injured leaves tend to turn brown around the hole and drop off the vine. Numerous mined leaves may be collected in spring sweeps. There is only one generation a year.

The *Nepticulid* moths emerge in August. The larvae tunnel inside the cranberry leaf, feeding along the perimeter and forming a serpentine mine. Leafminers are apparently resistant to a number of insecticides registered for use in cranberry.

Nutrient Management

Carolyn DeMoranville

All plants require certain essential mineral elements in certain quantities to complete growth and development. These same nutrient elements are required by cranberry plants for the production of vegetation (new leaves and stems), roots, and fruit (crop). Cranberry plants get these nutrients from the soil, from water, or from fertilizers added to the bog. Additionally, as a perennial crop plant, cranberries have the capacity to store and reuse nutrients in old leaves, wood, and roots.

Commercially, cranberries are grown in either organic soils modified by surface application of sand or in mineral soils. The rooting zone typically contains about 95% sand. Average organic matter in the surface horizon of Massachusetts cranberry soils is less than 3.5% and silt and clay make up less than 3% of the soil. Therefore, cranberry soil has low cation exchange capacity, i.e., little ability to hold positively charged nutrients such as ammonium-nitrogen, potassium, magnesium, and calcium. How then can cranberries grow in these soils?

The reason is that cranberries are adapted through evolution for growth on acid, sandy soils. These soils have little nutrient content and the plants in the family Ericaceae (e.g., cranberries and blueberries) that evolved on them have correspondingly low nutrient needs. So while cranberries require the same nutrients as other plants, they are unique in that the *amounts* required are much smaller than for most crop plants. Table 1 shows a comparison of plant tissue nutrient concentrations for three important minerals in cranberry and other crop plants. Nitrogen (N) and potassium (K) concentrations in cranberry and blueberry leaves are substantially lower than those in other fruit and agronomic crops. Phosphorus (P) in cranberry and blueberry tissue is also lower than that in many crops.

Why cranberries need fertilizer. Each season nutrients are removed from the bog during harvest and detrashing (removal of fallen leaves from the bog surface). When the fruit is harvested, the elements removed in the largest quantities are nitrogen, potassium, and calcium (Table 2). The amount of nutrient removal increases with increasing crop load and is less when crops are small. In addition, hybrid cultivars tend to have larger leaves and thicker stems so that more nutrients are used to produce plant parts and more are removed with the fallen leaves (the data in Table 2 are for a native cultivar, Early Black).

Table 1. Standard concentrations of nitrogen, phosphorus, and potassium in leaf tissue of several fruit crops. Data for cranberries provided by C. DeMoranville, other fruit crop data (Chuntanaparb and Cummings 1980); agronomic crop data from Ohio State University (Vitosh et al. 1995).

Crop	Nitrogen (%)	Phosphorus (%)	Potassium (%)
Cranberry	0.9-1.1	0.10-0.20	0.40-0.75
Blueberry	1.0-1.5	0.10	0.60
Apple	2.0-2.5	0.15	3.0-3.5
Peach	2.5-3.0	0.20	3.0-3.5
Grape	2.5	0.30	2.0
Corn	2.9-3.5	0.3-0.5	1.19-2.50
Soybean	4.25-5.5	0.3-0.5	2.01-2.50
Wheat	2.59-4.00	0.21-0.5	1.51-3.00

It is to compensate for nutrient removal that cranberry growers add fertilizer to their beds. Most fertilizer added to producing cranberry bogs contains nitrogen, phosphorus, and potassium (N-P-K fertilizer). While P removal is low, some P is included in the mixture to maintain nutrient balance and because much of the P in cranberry bog soil is not available to the plants at crucial growth stages. Table 3 compares the N, P, and K recommendations for cranberry production to those for other fruit and agronomic crops. In general, cranberry production requires less fertilizer than that of other crops.

However, during establishment of a new planting or renovation, the recommended rates for N and P are higher than those for a producing cranberry bog. At planting, 20 lb/acre P and 20-30 lb/acre slow-release N are applied to the fresh sand to encourage plant rooting. During the first season of a new planting, N is applied at the rate of 5-10 lbs per acre every two to three weeks until late in the summer, alternating N-only products with N-P-K products with a 1:1:1 ratio. This regimen stimulates robust growth and the production of runners that spread quickly to cover the soil surface. Rapid filling-in of cranberry plants discourages weed infestations. In the second season, fertilizer use is reduced at around the time of bloom to encourage the formation of flower buds for the third season. Generally, an established-bog fertilizer schedule is used in the third and subsequent years.

Table 2. Nutrients (lb/acre) removed from Early Black cranberry beds (DeMoranville 1992a).

Nutrient	Removed in old leaves and stems	Removed in 200 bbl/A crop	Total
Nitrogen	13.6	10.0	23.6
Phosphorus	2.2	2.0	4.2
Potassium	3.4	17.4	20.8
Calcium	14.2	1.6	15.8
Magnesium	3.5	1.2	4.7

Table 3. Standard recommendations (lb/acre per year) for fertilizer nitrogen, phosphorus, and potassium rates for several crops. Data for cranberry from UMass Extension recommendations (DeMoranville 2008), agronomic crop data from Ohio State University Extension recommendations (Vitosh et al., 1995), tree fruit (Hanson 1996) and blueberry (Hanson and Hancock 1996) recommendations from Michigan State University Extension.

Crop	Nitrogen	Phosphorus	Potassium
Cranberry	20-60	no more than 20	40-120
Blueberry	45-65	35-45	40-80
Apple	50-60	85-175*	125-250*
Peach	80	85-175*	125-250*
Corn	160-200	25-65**	87-120**
Wheat	75-110	45-80**	70-110**

*when required based on soil and tissue test, every 3-5 years.
**based on potential yield and soil tests.

Fertilizers used on cranberries. As noted above, the predominant fertilizers applied to cranberries are complete N-P-K materials with varying ratios of the three elements. Growers apply these fertilizers based on seasonal N requirements. During the season, 20-60 lbs N per acre are applied depending on cultivar and weather conditions. N-P-K materials are chosen so that no more than 20 lb P per acre is applied. K application rates in N-P-K products are generally 1-2 times the rate of N. Additional K may be applied as a supplement. N, P, and K will be discussed further below.

While cranberries require many other mineral elements, often these are in sufficient supply in the soil to satisfy the plant needs. When testing shows that these other elements are lacking in the plants or in the soil, they are applied as needed. Calcium is applied as gypsum (calcium sulfate) since the addition of lime can adversely affect the soil pH. Magnesium is added as Epsom salts (magnesium sulfate) or in combination with K (SulPoMag). Sulfur is not used as a fertilizer in cranberry production but may be used to lower soil pH if necessary.

Minor elements such as copper, zinc, iron, and manganese are very available in acid soils. For this reason, cranberries seldom suffer minor element deficiencies, nor do they require minor element fertilizers in general. One exception is the use of minor element supplements in fertilizer blends during the first season of a newly planted mineral soil bog. Another exception is the use of calcium-boron supplements at bloom. For beds with poor yield histories, such calcium-boron supplements may increase fruit set.

NITROGEN

The single most important nutrient element in cranberry production is nitrogen (N). N is required by cranberry plants for the production of vegetation (new leaves and stems), roots, and fruit (crop). As a critical constituent of protein, N is a controlling element in the plant's nutrition. The production of the protein, chlorophyll, the green pigment essential to photosynthesis, is regulated in part by the availability of N.

Adequate N is important in the production of cranberry fruit both directly and indirectly. N makes up a portion of the dry weight of each fruit and adequate supply during fruit formation is required. However, much more of the fruit dry weight is made up of various carbohydrates. Early in the season, the presence of N promotes the growth of the new uprights. It is photosynthetic activity in the leafy tissue above the developing fruit on a fruiting upright that is the source for the carbohydrates in the fruit. If early-season N is lacking and the upright growth is stunted, the plants will lack the ability to support a large crop. Further, lack of N in the early season can lead to uprights that are pale greenish-yellow, indicating a lack of chlorophyll. This too will limit photosynthesis.

Each season N is removed from the bog in the crop and in fallen leaves. To compensate for this loss cranberry plants get N from the soil, from water (very little), or from fertilizers added to the bog. The amount of N that must be added as fertilizer depends on how much N is supplied by the soil (soil organic matter and weather dependent), cultivar requirements, and general status (length, color) of the cranberry plants.

Soil N. Approximately 95-99% of available soil N comes from the decomposition of soil organic matter. Cranberries are grown in either organic soils modified by surface application of sand or in mineral soils. Average organic matter in the root zone of Massachusetts cranberry soils, and therefore available for plant use, is less than 3.5%.

Nitrogen release from the soil organic matter depends on temperature and soil moisture status. The release process, known as <u>mineralization</u>, by which ammonium-N is released from soil organic matter depends on bacterial activity in the soil. When the soil is waterlogged, the bacteria cannot get enough air to function well. As with many biological reactions, mineralization is also temperature dependent, increasing as the soil temperature increases.

Davenport and DeMoranville (2004) studied mineralization in common cranberry soils (Fig. 1). The predominant factors that determined N release due to mineralization were organic matter content of the soil and soil temperature. Sandy soils (newer plantings) released less N compared to soils from older beds with layers of sand and organic matter. In the early spring as the soil dried after the winter flood, bacterial activity increased and there was a ‘flush’ of N release in the soil despite cool temperatures (50-55ºF). Mineralization rates were similar at temperatures from 55-70ºF. The rate increased dramatically when soil temperature rose to 75ºF. The ammonium-N released in mineralization is readily used by the cranberry plants.

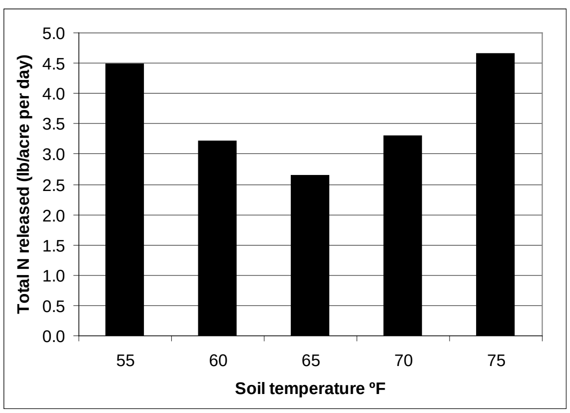

Fig. 1. Nitrogen released from typical Massachusetts cranberry soil at various soil temperatures (Davenport and DeMoranville 2004).

Based on these data, for typical cranberry beds, applications of N should not be necessary early in the spring. From flood removal until soil temperatures exceed 55°F, adequate N should be available through biological processes. Nitrogen is slowly released from the soil early in the spring when the cranberry plants are dormant (and cannot use nitrogen). This builds up in the soil leading to a flush of ammonium availability early in the spring when the plants are breaking dormancy. As soil temperatures increase from 55°F to 70°F, release of nitrogen from soil organic matter is only moderate. Fertilizer applications are then beneficial. This corresponds to the period from roughneck stage through bloom. During spells of hot weather, when soil temperatures exceed 70°F and air temperatures exceed 85°F, soil nitrogen release increases and crop development slows, so planned fertilizer nitrogen applications can be reduced, delayed, or eliminated.

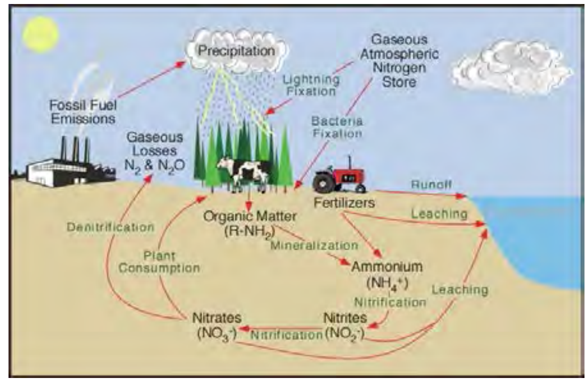

Fig. 2. Illustration of the nitrogen cycle. Courtesy www.physicalgeography.net.

However, once mineralization occurs, the resulting ammonium-N may be converted to nitrate-N in a second, bacteria-mediated reaction, nitrification. The bacteria that mediate nitrification are sensitive to soil pH. In common cranberry soil with pH 3-4.5, activity of these bacteria was minimal. However, the same soils adjusted to pH 6.5 released large amounts of nitrate-N and had high populations of nitrifying bacteria (Davenport and DeMoranville 2004). Nitrate-N is not a good source of N for cranberries (see below) and readily leaches in the soil.

Soil pH and organic matter should be tested at least once every three to five years (more often if attempting to modify pH). The biological conversion of cranberry-useable ammonium-N to less-desirable nitrate-N with increasing pH is most pronounced in bogs with high organic matter soil. Soil pH on cranberry beds with soil organic matter content of 0-5% should be between pH 4.0 and 5.0, while soils with organic matter content greater than 5% should have a pH of 4.5 or less.

N form. Unlike most horticultural crops, cranberries appear to preferentially use ammonium-N (Greidanus et al. 1972; Smith 1994). While all plants ultimately require ammonium, most take up N in the nitrate form and then convert it to ammonium once it has been transported to the leaves. In solution culture, cranberries can take up some nitrate-N, but uptake was only substantial in the presence of ammonium (Rosen et al. 1990; Smith 1994). Further, cranberries have very low activity of the enzyme (nitrate reductase) that converts nitrate into metabolically usable ammonium inside the plant (Greidanus et al. 1972). Recently, cranberry plants in culture inoculated with ericoid mycorrhizae did show the ability to take up and transport nitrate-N (Kosola et al. 2007). These specialized mycorrhizal fungi colonize cranberry roots in the field and when present, may allow uptake and utilization of nitrate.

Summary of N Fertilizer Recommendations

Nitrogen rates/form:

- Small-fruited cultivars such as Early Black and Howes require the addition of 20-30 lbs N per acre per season.
- Large-fruited cultivars such as Stevens may require more N, up to 60 lbs N per acre per season. Rates should be adjusted according to soil type and temperature. Rates higher than 40 lbs per acre should be used with caution as they may lead to vine overgrowth and reduction in fruit quality.
- Cranberries use ammonium-N efficiently. Ammonium-N is recommended for that reason and to limit concerns regarding nitrate leaching. In addition to standard soluble granular ammonium fertilizers, organic fertilizers, urea, and many slow release fertilizers can be used to provide ammonium-N.

Temperature/timing:

- Applications of N should not be necessary early in the spring. From flood removal until soil temperatures exceed 55ºF, adequate N should be available through biological processes.
- At soil temperatures from 55ºF to 70ºF, release of N from soil organic matter is only moderate. Fertilizer applications should be beneficial.
- Seasonal N application rate should be divided into three to four applications corresponding to the periods of peak demand: 20-25% at roughneck stage (½ to 1 inch new growth from the terminal bud), 30-35% at bloom, 30-35% at fruit set (about 2-3 weeks after bloom), and ~20% at bud development/fruit sizing (early August). Split timing allows for in-season rate adjustment as conditions warrant.
- During spells of hot weather, when soil temperatures exceed 70ºF and air temperatures exceed 85ºF, soil N release increases and crop development slows, so planned fertilizer N applications should be reduced, delayed, or eliminated.

Soil type and pH:

- Sandy beds have less potential for natural N release. As organic matter in the soil increases, less fertilizer N should be used.
- As soil pH rises, biological conversion of ammonium to less-desirable nitrate increases. Soil pH on cranberry beds with soil organic matter content of 0-5% should be between pH 4.0 and 5.0, while soils with organic matter content greater than 5% should have a pH of 4.5 or less.

However, based on the predominant evidence that cranberries can use ammonium-N quite effectively and since nitrate-N can leach and pose environmental hazards, ammonium is the recommended form of N for cranberry production. Ammonium is readily taken up by the plants (10 times greater uptake compared to nitrate in solution culture), is only slowly converted to nitrate in acid soils, and is lower in leachability compared to nitrate. Urea, organic fertilizers, and many slow release fertilizers deliver N as ammonium during their breakdown. An additional benefit of ammonium-N is that as it is taken up by the cranberry plant, the plant releases acid equivalents to the soil, helping to maintain the cranberry-preferred low pH.

In the soil solution of cranberry beds, N predominantly occurs in the dissolved organic form. Ammonium-N is the next most common form, followed by nitrate-N (Kosola et al. 2007; Stackpoole 2008). Other research (Stribley and Read 1974) showed that cranberries colonized by ericoid mycorrhizae could absorb and utilize organic N forms from the soil. Therefore, the dissolved organic pool of N is cranberry soil may also be a source for cranberry N nutrition even in the absence of mineralization to ammonium-N.

Fertilizer N. While soil N is an important resource to the cranberry, it is not present in sufficient quantity, particularly if the bog soil is very sandy, to meet the demands of plant growth and fruit formation during the most active portion of the growing season.

Periods of peak nutrient demand. Nutrient demand tends to be driven by production of plant biomass. In cranberry, this would correspond to extension of new growth in the spring (mid-May to mid-June), fruit formation and filling (July - September), initiation of floral buds (July and August), and root turnover. Root production occurs after the first flush of new vegetative growth and late in August after vegetative growth has ceased for the season. Seasonal patterns of above-ground biomass distribution in cranberries are shown in Fig. 3.

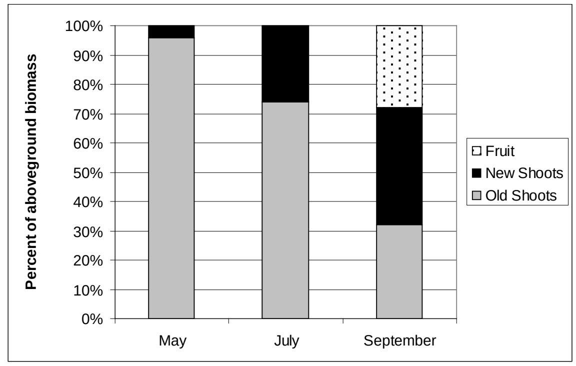

Fig. 3. Seasonal distribution of above-ground biomass in cranberry plants (DeMoranville 1992a).

Fruit filling and floral bud initiation occur during the same time period (during the summer) and so may represent a period of competition among plant parts for resources. Cranberry fruit on an upright are in competition for resources (Birrenkott and Stang 1990). When numbers of berries on an upright was high, buds produced tended to be small (Patten and Wang 1994). While it is likely that competition for carbohydrates is mainly responsible for these observations, competition for mineral elements may also play a part. It is known that nutrients are drawn from source areas (roots and storage tissues) to 'sinks', rapidly growing tissues and plant parts with high levels of plant growth regulators (hormones) such as fruit.

Fertilizer N rate and timing. The average recommended seasonal rate of N for producing cranberry beds in Massachusetts varies from 10-60 lb per acre depending on plant vigor and variety. High-vigor beds and beds with a deep organic base require the least nitrogen; beds with low vigor require more nitrogen; and beds planted to robust hybrid cultivars, such as Stevens, have the highest nitrogen requirements. The N rate within the recommended range should be chosen based on bog history of response. A good starting N rate for Early Black and Howes is 25 lb per acre; for Ben Lear, Stevens, and other hybrid cultivars, start with 30-40 lb per acre. Large-fruited cultivars such as Stevens may require up to 60 lbs N per acre per season. Rates higher than 40 lbs per acre should be used with caution, however, as they may lead to vine overgrowth and reduction in fruit quality.

N rates have been studied in several growing areas and on various cultivars. A common result in these studies was the observation that no treatment effect is apparent in the first year of the study. That is, plots receiving no fertilizer had similar yield to any of the N rate plots. This is evidence for the theory that fertilizer applied this season has little effect on this season's crop but rather is important for next year. By the third year of applications, however, separation among treatments is significant and certain trends are apparent. Almost universally, plots that receive no N for three years have poor yield. Regarding yield for the various N rates, two patterns were seen. Either yield increased to a maximum level and then declined with further increase in applied N <u>or</u> yield increased with each increase in N up to the highest rate in the study. The first pattern was the most common. The second pattern was seen with Stevens in Oregon when the highest rate in the study was 60 lb/A (Hart et al. 1994). However, in a Massachusetts study with rates up to 80 lb/A, yield decline in Stevens was seen at both the 60 and 80 lb/acre rates. In a study of several cultivars in New Jersey, applications of high N rates promoted vegetative growth at the expense of yield (Davenport and Vorsa 1999).

While high rates of N were generally not associated with high yield, they were associated with high levels of N in the leaf tissue. This may explain why as N rate increases, vegetative growth increases at the expense of yield. Excess vegetative growth may increase susceptibility to disease, spring frost, or insect feeding. High N rates may also lead to poor fruit quality and delay color development in the fruit. High N rates can have adverse carry-over effects in following years as stored excess N is remobilized.

Consistency in management is important for achieving predictable yields. Research has shown that overall N rate in the year before a crop may be a more important predictor of yield than N rate in the current season. Further, timing of N application may be even more important than rate.

Best yield results were obtained in research plots when seasonal N application rate was divided into four applications corresponding to the periods of peak demand: 20-25% at roughneck stage (½ to 1 inch new growth from the terminal bud), 30-35% at bloom, 30-35% at fruit set (about 2-3 weeks after bloom), and ~20% at bud development/fruit sizing (early August). Split timing allows for in-season rate adjustment as conditions warrant. Additional N fertilizer should be added if the cranberry plants show signs of N deficiency - poor growth, loss of leaf greenness, and/or low nitrogen content in the leaf tissue.

<u>Fertilizer N uptake.</u> A study was undertaken to discover how quickly cranberries in the field would take up labeled ammonium fertilizer (Roper et al. 2004b). Ammonium sulfate labeled with ^{15}N was applied in field locations in Oregon, Massachusetts, New Jersey and Wisconsin. In all cases, ^{15}N was detectable in the plants by 24 hours following application. Rate of uptake was temperature dependent, with more rapid uptake at the warmer sites. More N was taken up in Wisconsin and New Jersey in the first 7 days than was taken up in Massachusetts after 14 days or Oregon after 21 days. Examination of weather records suggested that the differences were likely due to temperature. The importance of soil and root temperature on rate of uptake was confirmed in greenhouse studies. The optimum root zone temperature for N uptake by cranberry vines was 65º to 75ºF.

This research suggests that ammonium fertilizers applied by growers and irrigated into the soil (solubilized) can be expected to be in green tissue and available for plant growth within a day following application.

PHOSPHORUS

Phosphorus (P) plays many roles in plant metabolism. P is involved in energy transfer as part of the ATP (the molecular energy currency within living cells) molecule. P is a primary constituent of the genetic material of plants and animals (DNA). P plays a regulatory role in photosynthesis and starch synthesis, active transport of materials across membranes, root growth and function, and hormonal balance. This last is critical to floral induction.

While only modest amounts of P are removed from cranberry beds in fallen leaves and fruit (Table 2), it is essential that soil P be available to the cranberry plants to support seasonal growth and flowering. Common characteristics of cranberry bog soil affect P availability.

Phosphorus soil chemistry. Cranberry soils are high in iron and have low pH. This chemistry leads to conditions where P is tightly bound in the soil and is to a large extent unavailable to the cranberry plants (Davenport et al. 1997). Cranberry plants with tissue P at or below the critical level (0.1%) are often found growing on soils with high P test values. When fertilizer is applied to these soils, the P in the fertilizer dissolves into the soil water and quickly becomes bound to iron; only a small percentage of the P remains dissolved and available for plant use. Of the bound P, some portion may later be released and available for uptake by the plants depending on the aerobic status of the soil (i.e., how saturated it is).

Phosphorus uptake and release in cranberry soils of varying organic matter content was investigated under flooded (anaerobic), dry (aerobic), and transitional conditions (Davenport et al., 1997). Sandy soils readily released P that had been previously applied and bound to the soil. However, the total P holding (and releasing) capacity of these soils was poor, indicating a need for low rate applications at frequent intervals. Uptake and release in sandy soils was not dependent on flooding cycles (aerobic status).

However, the results were quite different for peat and layered (sanded cranberry) soils. In the layered soil, P was released from the bound state at the highest rate as the soil moved from the flooded to the seasonal dry state (field capacity). Once the soil reached seasonal dryness (late spring), P was only released if a certain threshold amount was present in the soil, indicating the need for fertilizer applications under those conditions. This pattern was even more pronounced in highly organic (peat) soil.

Common soil tests for P indicate high P availability in cranberry soil under conditions where P has been shown to remain bound. This is related to soil iron. P bound to soil iron is generally not available to the cranberry plants. However, the chemicals used in standard soil tests strip the P from the iron giving a falsely high report of plant available P. If soil iron exceeds 200 ppm, the soil test P becomes virtually meaningless.

Fertilizer P. Despite the presence of bound P in the soil, research has shown that cranberry yield increases in response to the addition of P fertilizer (Greidanus and Dana 1972; DeMoranville and Davenport 1997). However, as seen in Fig. 4, the response is not linear. While yield was greater with the addition of 20 lb P per acre per season (compared to no P), higher rates did not significantly improve the response above that with the 20 lb rate.

Further research with a broader P rate range in Wisconsin and Massachusetts has confirmed that there is no experimental evidence for a cranberry yield response to P rates above 20 lb acre and in many cases, good yield response was found with even lower rates (DeMoranville et al. 2008; Roper 2008). The addition of more than 20 lb P per acre in a season is only justified if tissue P is <0.1% or during the establishment of new or renovated plantings.

The use of 20 lb P per acre at the time of planting increased the percent of coverage by cranberry plants at the end of the first season compared to those receiving no P or higher P rates. The beds also received 31 lb per acre slow release N at the time of planting. On the basis of this research, 20 lb P per acre (100 lb per acre triple super phosphate) is recommended at planting for vine establishment. Additional P is then applied during that first season in N-P-K fertilizers.

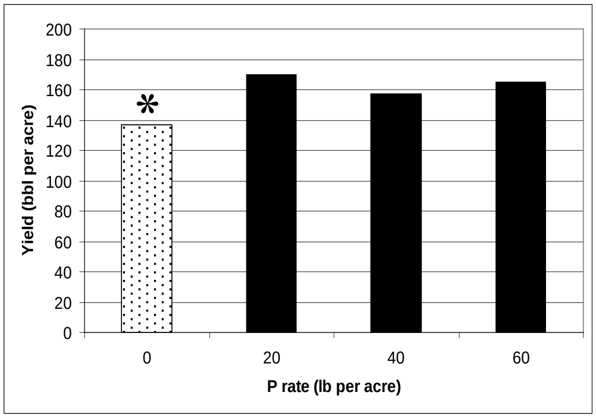

Fig. 4. Response of cranberry to added phosphorus fertilizer. Fertilizer was split-applied in 4 applications. Star indicates significant difference from other treatments ($p<0.05$) (DeMoranville and Davenport 1997).

P Interaction with Cranberry Soil Type

Sandy soils. P readily attaches to the soil and is completely released for plant use throughout the growing season. However, the total holding capacity of these soils is low, indicating the need for low rate, frequent P applications during the growing season. However, in the absence of tissue deficiency, do not exceed 20 lb per acre per season.

Layered (sanded peat) soils. P is available under flooding conditions and during the transition from wet to dry soil conditions (early spring). Fertilizer additions should be delayed until seasonal dryness at which time moderate rates are suitable. However, in the absence of tissue deficiency, do not exceed 20 lb per acre per season.

Peat soils. P is somewhat available under flooding conditions only. Once the soil begins to dry, additions of P may be beneficial. However, this soil type showed even stronger tendency to bind small additions of P compared to layered soil.

P forms and rates. Most Massachusetts cranberry growers add inorganic phosphate to the soil in N-P-K fertilizer or as triple superphosphate. The P in the N-P-K fertilizers is generally derived from ammonium polyphosphate (used in ammoniated fertilizers), monoammonium phosphate (MAP) or diammonium phosphate (DAP). Fertilizers containing MAP are an excellent choice for cranberry production as the fertilizer particles form an acid zone in the soil, helping to maintain the low pH preferred for cranberry production. Slow release P forms are available. They perform similarly to soluble granular forms -- at the same rate of applied P, yield and tissue P were similar with either fertilizer type (DeMoranville and Davenport 1997; Roper 2008).

Since in producing cranberry beds, P is added in N-P-K materials and the material rate is selected based on N requirement, the N:P ratio in the fertilizer is critical if no more than 20 lb P per acre is to be applied. For beds with sufficient tissue P (0.1-0.2%), the recommended ratio of N:P is no greater than 1:2 with 1:1 or 1:<1 preferred if high N rates are required. An example of a 1:<1 material used on cranberries is 18-8-18. One hundred pounds of this fertilizer would supply 18 lb N, 3.5 lb P, and 15 lb K. An example of a 1:1 material is 13-13-13. One hundred pounds of this fertilizer would supply 13 lb N, 5.7 lb P, and 10.8 lb K. Note that due to fertilizer conventions, the percentages in the bag analysis are not the actual percentages of P and K. Actual P and K are calculated by multiplying the second number by 0.44 and the third number by 0.83, respectively.

P timing. P is generally applied with N and therefore is split-applied in up to four applications at roughneck stage (½ to 1 inch new growth from the terminal bud), bloom, fruit set (about 2-3 weeks after bloom), and bud development/fruit sizing (early August). This corresponds to the period of seasonal soil dryness when existing soil P is tightly bound to soil iron and poorly available for plant uptake (see above). If slow release P materials are used, they may be applied in a single application early in the season (roughneck stage). Prior to roughneck stage, there is no need for P applications as bound P is released from the soil as it transitions from saturation to seasonal dryness in the early spring.

POTASSIUM

Potassium (K) is the only major element with no structural role in the plant. However, K is involved in the movement of sugars and starch in the plant and may play a role in resistance to disease, drought, and cold temperatures. K also has a major role in preserving plant turgor (water relations) and in osmoregulation (regulating water movement across plant membranes). Cranberries have a much higher percent of K in the fruit and seeds than in the leaf tissue. As a result, seasonal removal of K in crop and fallen leaves is about equal to the removal of N.

Fertilizer K. Due to its role in plant turgor (hydration of the tissues, preventing wilting), K fertilizer is added to cranberry beds when vines are brittle and dry, most often in the spring. Otherwise, K is generally added in the N-P-K fertilizer applied to satisfy N needs. Common cranberry fertilizers supply K as a 1:1 ratio with N. Seasonal rates of K applied to cranberry beds are in the range of 40-120 lb per acre. Field plot research did not show any measurable benefit to the addition of higher K rates (Roper 2008).

<u>K form -- sulfate vs. chloride.</u> Fertilizer K is most commonly available as sulfate or chloride. A body of evidence exists that indicates cranberries are sensitive to chloride (Davenport et al. 2001; Roper et al. 2001; DeMoranville and Roper 2004). Salt injury to cranberry vines has been observed following east coast hurricanes and in areas that receive highway treatment overspray in the winter. In both instances, the salt in question is sodium chloride (NaCl). Growers have also reported that they can 'shut down' cranberry growth with high rates of potassium chloride (0-0-60).

In Massachusetts, the interaction of K form (chloride or sulfate, 0-0-50) and rate with N rate was studied (DeMoranville, unpublished data). Plots were set up in a grid pattern so that rows received various K rates and forms while columns received high or moderate N rates. The results showed that K at 100 or 200 lb per acre gave higher yield than that in the zero K rows. After the first year, yield declined in the high N columns and fruit rot increased. Further, increasing K rates with either source did NOT overcome the deleterious effects of high N. Growth was not 'shut down' but neither was any damage observed with the chloride (Cl) form at these rates.

To further investigate the possibility of Cl toxicity in cranberry plants, a cooperative project was initiated by researchers at UMass, University of Wisconsin and Washington State University with funding from the Mass Highway Department. In a greenhouse study in sand culture, cranberries exposed to 250 ppm Cl in irrigation water showed leaf reddening with Cl provided as NaCl <u>or</u> KCl. At lower concentrations, runner production was stimulated and at 250 ppm as KCl, many plants died. Fig. 5 shows the Cl concentration in plant tissue after several months of exposure to contaminated irrigation. Not surprisingly, the Cl in the shoots rose as the concentration of Cl in the irrigation water was increased from 50 to 250 ppm (DeMoranville, unpublished data).

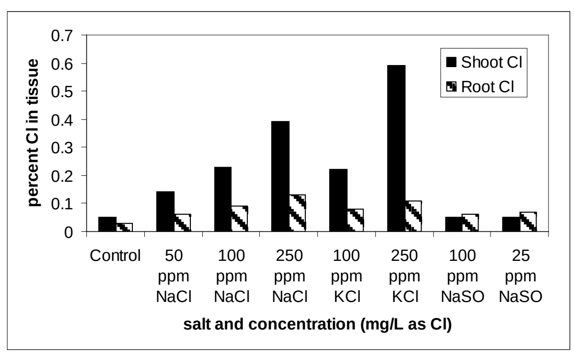

Fig. 5. Chloride concentration in cranberry plants exposed to irrigation water contaminated with salts. (DeMoranville, unpublished data).

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

FERTILIZER USE

This section covers how growers decide on fertilizer rates and timing, how fertilizer is applied, and the interaction of fertilizers and water quality.

Fertilizer use decisions. As noted above, most cranberry fertilizer rate decisions are based on N requirements. Aside from taking varietal differences into account, decisions regarding fertilizer N rate are based in part on length and density of uprights. Other factors that are considered include bog history (previous crops and response to fertilizer), results of soil and tissue tests, and weather conditions. Records of previous crops and response to fertilizer along with the results of soil and tissue tests are used as guidelines in fertilizer decisions.

Upright length and density. By mid-June, the minimum total growth on new cranberry uprights should be 2.25 inches for Early Black and Howes, and 2.5 inches for Ben Lear and Stevens. Flowering uprights should have 1.5 to 2 inches of leafy length above the flowers and fruit. The presence of adequate foliage (length) by mid-June is significantly correlated with yield later that season. Small, stunted uprights early in the season are associated with poor crops. The average upright density for a productive bog should be about 600 uprights/sq. ft. for Early Black and 400 uprights/sq. ft. for Howes, Ben Lear, and Stevens. Ideally, 200 or more of these uprights should be the flowering type. An adequate stand of vegetative uprights is also important, as about 80% of these will flower next year. Even and adequate vine cover is the key to good production: 200 flowering uprights/sq. ft., each producing an average of 1 berry, will give a crop of 200-300 bbl per acre.

A bog with thin vine cover, pale leaves, or stunted vines may not be getting enough N. However, vines that are too long and too dense are related to diversion of nutritional assets to vegetation (small berries), shading of fruit, poor fruit color, increased fruit rot, and inability of bees to reach pollination sites.

Soil and tissue tests. Soil and tissue tests are tools that a cranberry grower can use for several purposes. These include: 1) diagnosing deficiencies of mineral elements; 2) monitoring soil pH; and 3) aiding in the decision-making process for choosing fertilizer (tissue tests). However, several factors preclude the use of the test results alone as the basis for a cranberry fertilizer 'prescription':

- standard soil tests poorly predict the availability of nutrients and poorly correlate with yield in cranberry;
- as a perennial plant, cranberries store nutrients from the previous season(s) making it impossible to base fertilizer choices only on soil content and yield potential;
- there is virtually no variability in soil test N values from bog to bog;
- tissue test N concentration may vary depending on length of upright (N concentration in the tissue does not always correlate well with added N);
- nutrient availability changes with soil pH and soil pH is not uniform from bog to bog;
- common soil test methods for P do not give results that correlate well with cranberry yields due to very acid soils in cranberry production; standard P tests are of no value if soil iron is above 200 ppm.

With these warnings in mind, tissue and soil analyses can be beneficial as a long-term record of changes in a bog. Soil and tissue tests are particularly useful when compared to one another; a soil test alone is virtually useless in determining a fertilizer recommendation for cranberry. Tissue tests are more useful for setting target fertilizer ranges. Tissue testing for %N is used to determine nutrient status of cranberry plants. The standard value for all cultivars in August (recommended testing time) is 0.9-1.1%, with up to 1.3% acceptable for high-yielding hybrids. Earlier in the season, higher values (up to 1.5%) are normal. As growth dilutes the nitrogen in the plants, N declines to approximate 1%. Values below normal may indicate the need for added N fertilizer.

Nutrition Decision Making in Cranberry Production

As we have seen, many factors, including temperature, moisture, pH, and soil type can play a part in the availability of nutrients and the ability of the plant to acquire them. How then can one decide what to supply to cranberries in the form of fertilizer? The following tips are provided for cranberry growers:

1. Observe growth and flowering. Adjust fertilizer based on the appearance of the plants and the potential for cropping. Pay particular attention to upright length and growth above the fruit.

2. Healthy cranberry plants with adequate N are deep, bright green. Fading to yellow is an indication the N may be insufficient.

3. Test the soil to determine the organic matter content. This will supply information regarding the potential for mineralization. Soil pH information can be gathered at the same time. Soil testing every 3-5 years should be sufficient.

4. Adjust spring fertilizer applications based on soil temperature. Apply only after soil has warmed and decrease N applications if spring has been warm and dry.

5. Do not apply P to wet soils; P is being released under these conditions. Do not apply more than 20 lb P per acre each season.

6. Adjust N rate based on cultivar and crop potential. Cultivars that crop heavily generally require more N compared to native selections.

7. Finally, keep good records of your management and observations, look for patterns, and learn how each bed responds to the addition of fertilizer.

Fertilizer application timing. The timing of N and P applications is an important factor affecting the potential for fertilizer loss to the environment. The greater the time between application and plant uptake, the greater the chance for loss to ground or surface water. It is best to time fertilizer applications based on the stage of plant growth. Applications should be delayed when spring temperatures are cold. Cranberry plants respond to nutritional support during initial leaf expansion in the spring, during bloom, during fruit set, and during bud development for the following season. Fall application of N should be minimized.

Aside from water, the next most important constituents of the cranberry fruit are carbohydrates (acids and sugars) that the plants make in the green leaves and then transfer to the fruit. Plants that are starved for mineral nutrients in the spring will not make enough new green leaf surface to produce the carbohydrates necessary to support a large crop. Adding large amounts of fertilizer to stunted plants will not set a large crop of fruit. By that time, fertilizer is no longer the limiting factor if nutrition was inadequate earlier. Therefore, it is essential to apply fertilizer in the spring if needed based on plant analyses (from the previous summer), size of previous crop, and observations of early growth.

However, cranberry plants have little ability to take up nutrients when the soil is cold (>55ºF). Fertilizers applied too early in the spring may wash out of the root zone before the soil warms enough for uptake into the plants.

Nutrient Recycling. In perennial crops such a cranberry, nutrients can be stored in roots and mature stems. Further, floral buds are formed in the year prior to the crop. These factors make it likely that nutrients acquired in a given season may be more important in determining crop for the following season than for determining current season crop. Davenport and DeMoranville (unpublished) conducted a survey of 30 cranberry plantings in Massachusetts including the collection of grower records of N applications and yield. Regression and correlation analyses of surveyed variables showed that N applied in the year prior to the crop was an important determinant of yield, while N application in the crop year was of little significance.

When labeled N was applied to cranberries in Oregon (Hart et al. 1994) prior to fruit set, at least one half of the label was found in old stems and roots. Nutrients that are incorporated into the fruit are lost when the crop is harvested and removed from the system but the nutrients in the shoots and roots can be available for growth the following season. One study (Smith 1994) showed that one third of ^{15}N taken into the plant from soil applications moved into new growth and fruit in the year of application. The following year, 70% of the label was in mature tissue but 30% had been remobilized into that season's new leaves and fruit. This illustrates the ability of cranberry plants to both store nutrients and to remobilize them for growth and fruiting. For this reason, early spring applications of fertilizer are adjusted based on potential carryover (if the previous crop was small, for example).

Application methods. Fertilizer is applied to cranberry beds using ground rigs (spreaders and seeders), helicopters (aerial application), and the sprinkler system (fertigation). Fertilizer is applied in split doses if water-soluble materials are used. As previously mentioned, the dose for the total season is split over 3-4 applications. This lessens the potential for leaching of the material below the root zone. For a soil-applied fertilizer to be used by the plants, it must be taken up by the roots. Cranberries are shallow-rooted. This, combined with the limited ability of cranberry soils to hold nutrients, makes split applications essential. Overloading of soluble materials would be unsound economically as well as ecologically.

As an alternative to split applications of soluble materials, some growers use fish fertilizer (organic nitrogen) or inorganic slow-release materials. Fish fertilizer remains available over an extended period due to the fact that the material adheres to soil particles where the organic nitrogen can be slowly released and become available to the cranberry plants. Inorganic slow-release materials depend on their low solubility to prevent being washed down below the root zone. This is generally achieved by a slowly dissolving coating or a chemical structure that requires breakdown by soil bacteria (analogous to the chemical process by which the N in the organic matter becomes available to the plants).

Liquid or foliar fertilizers are also used when a quick response (generally to correct problems) is desired. These are low-analysis materials designed to be taken up quickly by the plants. When used at the recommended rates, they have little potential for movement into water supplies. Due to nonuniform application with irrigation systems, only low rates of fertilizer are applied by this method. Otherwise, the plant stand grows unevenly, leading to difficulties in harvesting and other management tasks.

Interaction with water management. Moisture and aeration in the soil can determine nutrient availability. Plants take up nutrients dissolved in the soil water. If soil is too dry, minerals cannot dissolve and move to the roots and uptake cannot take place. Conversely, if soil is waterlogged, the oxygen the plant needs for root respiration to drive active uptake will be limited.

The change in P availability during flooding cycles on cranberry soils is discussed above. Hydric status of the soil determines availability of iron and manganese. In flooded soils, availability of these elements is high enough to present a danger of toxicity in species not adapted to flooded conditions. In fact, the ability of cranberries to tolerate high iron and manganese is indicative of their status as wetland species. High tissue test manganese levels may indicate poor drainage.

Proper soil drainage improves fertilizer efficiency so that less fertilizer is required. Soil moisture should be monitored and at minimum checked twice a week. Soil should be moist but not saturated in the root zone.

Environmental considerations. Fertilizer N and P can be environmental pollutants. N is of particular concern in estuarine waters, while P is primarily associated with degradation of water quality in inland, freshwater systems. When excess P is provided in such systems, algal blooms (eutrophication) can result. As the algal population peaks and the algae die, oxygen in the water is depleted, often resulting in fish kills.

Downward leaching of nutrients is minimized by the layered structure of cranberry bog soil. Layers of sand are added to the beds every 2-5 years leading to alternating sandy and organic layers. The organic layers are comprised of decaying roots and leaves. Nutrient leaching is also minimized in peat based soils by trapping in the high organic matter content of the subsoil. Further, the low pH of bog soils limits the conversion of ammonium N (the form recommended for cranberry fertilization) to the more leachable nitrate form and P is bound to iron in acid conditions. While leaching is of minimal concern in cranberry fertilizer management, the potential for movement of N and P in surface water should be taken into account in management decisions.

Cranberries are grown in wetland soils, either natural wetlands converted to cranberry production or manufactured cranberry wetlands (Johnson 1985; Turenne 2002). While wetlands are generally perceived to improve water quality, primarily due to their ability to retain sediments, their capacity to retain nutrients may change over time and with continued loading may actually reverse so that they become nutrient exporters (Peverly 1982; Richardson 1985; Johnston 1991).

Fertilizer Best Management Practices for Cranberry

- Apply N only when the plant can use it (active growth and fruit production). Use ammonium N.
- Apply seasonal fertilizer in split applications. Adjust rates based on observations of growth and plant appearance.
- Reduce fertilizer applications in response to insect infestations that impact potential crop, frost damage, pruning or sanding, and following the use of late water.
- Use tissue testing as a tool to help determine required fertilizer rates. Use soil testing to monitor soil pH and soil organic matter.
- Avoid N applications if the soil is cold (<55ºF) and limit applications if soil temperature is 75ºF or greater.
- Avoid excessive N application to prevent excess vegetative growth and poor cropping but do not starve the plants of N early in the season as this will lead to poor growth and reduced ability to size and retain fruit.
- Limit P applications to no more than 20 lb per acre per season, use less if tissue tests are well above the critical level of 0.1%.
- Do not apply P to saturated soil.
- Monitor soil moisture – soil in the root zone should be moist but not saturated.
- Minimize water in drainage ditches during fertilizer applications.
- Limit flow from beds during the growing season – use tailwater recovery if possible.
- Hold harvest floods long enough for settling (~3 days) then discharge slowly to minimize particulate discharge. Complete discharge before Day 10 to avoid flushing of P from the soil as oxygen depletes.

Since managed cranberry wetlands are receiving fertilizer on a regular basis, there is a strong possibility that they may act as nutrient exporters. In laboratory studies, saturated wetland soils discharged N and P to nutrient-poor surface water and only acted as nutrient sinks when the water source had high concentrations of N and P (Phillips 2001).

A great deal of literature exists regarding the movement and release of nutrients, including N and P, in natural wetland systems, both estuarine and fresh water (Johnston 1991; Howes et al. 1996). A study in Massachusetts, which included careful mass balance calculations, documented N and P release from established cranberry beds to Buzzards Bay (Howes and Teal 1995). In that study, N losses were similar to those in surface water-dominated vegetated wetlands. P output was shown to be minimal with the exception of certain seasonal occurrences, associated with the release of flood waters.

Cranberry growers have a horticultural disincentive to apply excess N fertilizer. Too much N quickly promotes vegetative growth and this growth comes at the expense of fruit production (Davenport and Vorsa 1999). As mentioned above, the ammonium N used in cranberry fertilizers is less susceptible to leaching than nitrate N. The adoption of Best Management Practices can assure that N movement out of the bog is minimized. These include: minimizing water in drainage ditches during fertilizer applications, limiting flow from the bog during the growing season (including the use of tailwater recovery), applying N only at times of plant need (maximizing uptake to the plants), and limiting N use in the fall.

Cranberry soil chemistry, particularly the high iron and aluminum associated with acidic soils, leads to extensive binding of P as iron and aluminum phosphates in the soil (Davenport et al. 1997). However, it has been shown in rice (Shahandeh et al. 1994) that P can be released from such compounds when flooded soils become anaerobic. A similar phenomenon occurs in pond sediments during anaerobic events. In the absence of oxygen, iron and aluminum change chemical state and no longer strongly bind P. It is likely that the spikes of P associated with flood release found in the Howes and Teal study (Howes and Teal 1995) were related to change in aerobic state of the cranberry soils during the flooded intervals.

The capacity for P release from bog soils during flooding was studied further in the laboratory using soil cores collected from natural cranberry bogs and commercial beds that received P fertilizers (DeMoranville et al. 2008). In flooded natural bog soil, uptake of P was observed during aerobic conditions as P was bound to iron and aluminum in the soil. As the oxygen in the flood was depleted and the soil became anaerobic, P was released into the overlying water. The anaerobic P release likely resulted primarily from the dissolution of the iron and aluminum phosphates previously formed in aerobic conditions.

In contrast, commercial cranberry beds, under both low and high P fertilization rates, exhibited some P release immediately upon flooding regardless of the oxygen levels in the overlying water. Aerobic release was strongly related to fertilizer P rate (much more pronounced in the high P soils), while under both low and high P fertilization there was a large release of P as the soils became anaerobic.

All three soils showed the same timing of development of anaerobic conditions and associated P release (~10 days) independent of P fertilization. P release declined for all soils after about 20 days. However, the magnitude of anaerobic P release was dependent upon the level of P addition during the preceding growing season, with unfertilized soil releasing one tenth that of the low P fertilized soils. Soils receiving high P appeared to have almost twice the anaerobic P release than the low P soils but with much greater variability.

Data collected from a harvest flood at a field site in 2002 showed a similar pattern to that of the high P soils in the laboratory study, with an initial increase in P for 1-5 days followed by a large increase in P release to the flood beginning at 10-12 days (Fig. 6) and leveling out at ~20 days (DeMoranville 2006). The bog received 20 lb per acre P that season.

The data from these studies indicated that native cranberry wetland soils can act as sinks for P under aerobic conditions. Under commercial management with P fertilizer applications, cranberry soils no longer removed P from water and when fertilizer P applications exceeded 20 lb per acre, P moved from the bog soil into flood water even under aerobic conditions. As beds were held in flooded conditions the soil became anaerobic after ~10 days and P was released into the water regardless of bog management. However, the magnitude to P release from the soil was proportional to previous fertilizer P additions.

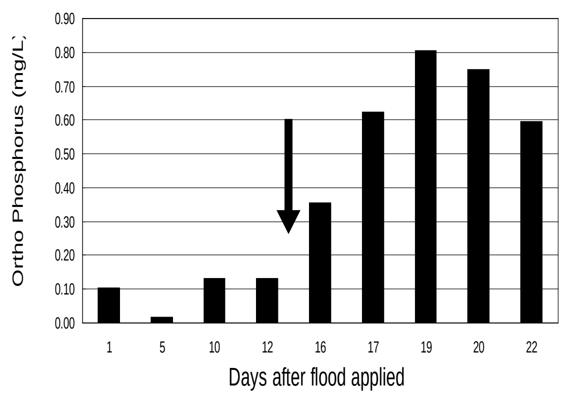

Fig. 6. Phosphate levels in cranberry bog harvest water. Water collected within the bog prior to discharge (arrow) and then at outlet flume (DeMoranville 2006).

At the field site referenced above, fertilizer P application was reduced beginning in 2003. Table 4 shows the change in applied P and the impact on the magnitude of P movement into flood water that resulted. This is further evidence that the potential for P release from the bog into flood waters can be reduced with reduction in applied P.

These results, along with the field research showing that cranberries with sufficient tissue P do not respond to P additions above 20 lb per acre, are the basis for additional fertilizer best management recommendations specific to P management. These include using no more than 20 lb/acre P per season and reducing below that rate if the bog discharges to a sensitive water body, and holding harvest floods only long enough to allow particle settling and then releasing prior to Day 10. Current research efforts are underway to determine if additional management practices can be developed to further reduce the P levels in flood discharges.

Table 4. Change in concentration of P in flood discharge water at a site where P reduction was implemented (DeMoranville et al. 2008).

Year	Fertilizer P applied (lb/acre)	P concentration in flood discharges (ppm)
2002	17.8	0.377
2003	14.3	0.424
2004	5.6	0.237
2005	16.5	0.097

Additional reading

T. Roper, J. Davenport, C. DeMoranville, S. Marchand, A. Poole, J. Hart, and K. Patten. 2004. Phosphorus for bearing cranberries in North America. Joint Publication of UMass Extension, University of Wisconsin Extension, Washington State University, and Oregon State University. 9 pp. http://www.hort.wisc.edu/cran/mgt_articles/articles_nutr_mgt/em8741.pdf

Davenport, J., C. DeMoranville, J. Hart, and T. Roper. 2000. Nitrogen for Bearing Cranberries in North America. Cranberry Nutrition Working Group. Joint Publication of UMASS, WSU, OSU, U- WI Madison and the Cranberry Nutrition Working Group, 16pp. http://www.hort.wisc.edu/cran/mgt_articles/articles_nutr_mgt/Phoshorus%20Publication%20.pdf

Pollination

Kenna MacKenzie

Pollination is an essential component of cranberry cultivation. Pollination is simply the transfer of pollen from a stamen (male floral structure) to a stigma, the tip of the pistil (female floral structure). Following pollen deposition, pollen germinates and produces pollen tubes that grow through the style to the ovaries and if all is well, fertilization occurs in the ovary. Pollination can occur within a flower or between flowers on either the same plant or different plants. Plants can be self compatible (fertilization occurs within the same genetic individual) or self incompatible (pollen must be transferred from a different genetic individual for fertilization to occur). Cranberry is self compatible.

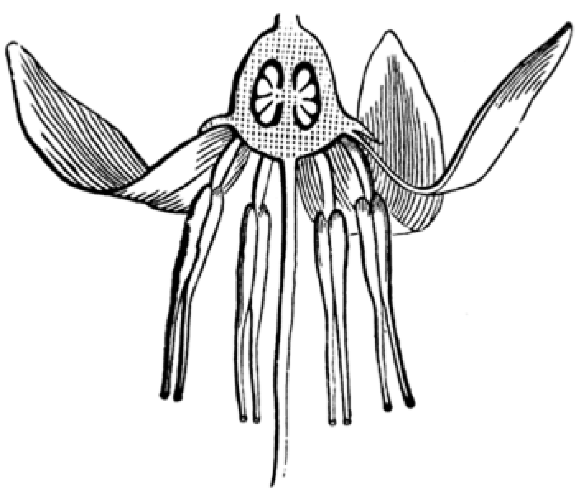

Fig. 1. Cross-sectional diagram of a cranberry flower, showing four large anthers (top portion of stamen that holds the pollen; male part), 3 of 5 petals, lower portion of the style (female part, stalk in center) connected to an inferior ovary with seeds. Flower is oriented downward to convey the appearance of the reproductive parts facing towards the ground, which is the typical position. Courtesy unknown.

Pollination can be abiotic through wind or water, or biotic in which an agent such as a bird, bat or insect transfers the pollen. These biotic pollinators visit flowers to collect resources such as pollen and nectar. Nectar is their carbohydrate source, while pollen is their protein. During these foraging visits, pollen transfer occurs. Bees are particularly good pollinators of flowering plants because they consistently forage for both pollen and nectar, visit many flowers during a foraging trip, and because they have a nest that they return to (called 'central-place' foragers).

Cranberry pollen is packaged in a group of four grains called a tetrad. It is large (for pollen), heavy and sticky, and thus, is not moved by wind. Instead, an agent, an insect pollinator, is required for pollen transfer to occur. Bees are the most important pollinators of cranberry.

CRANBERRY PLANTS AND YIELD

The cranberry plant consists of horizontal vines (runners) with vertical stems, commonly called uprights. These uprights may be either vegetative or reproductive. Generally, reproductive uprights will have four to five flowers and produce one to two berries. The newer hybrid cultivars, such as Stevens, tend to produce more flowers and berries than the older cultivars such as Early Black. Both flower and fruit numbers vary among cultivars, growing areas, site characteristics, and management strategies.

While pollination is a necessary step in crop production, it is not the only factor that influences yield. Plant health, climatic conditions, disease and insect problems and water availability also influence berry yield. Yield potential analysis has shown that the proportion of flowering uprights and fruit set are the two most important contributors to cranberry yield. Other components of lesser importance are the total number of uprights per area, the number of flowers per flowering upright and fruit size. Of these, pollination affects only fruit set and fruit size. So, to maximize production, management practices that result in good plant cover with lots of uprights, a high proportion of reproductive uprights and many flowers per upright are essential. Growers need to remember that while excellent yield is a result of excellent pollination, due to the many factors that influence yield, good pollen transfer may have occurred in fields with low yields. Thus, while pollination must be planned for, it is not a substitute for good crop management.

FRUIT SET AND FRUIT SIZE

Fruit set varies due to many factors including such things as plant health, weather and pollination intensity. Of course, the more pollinators present, the more flowers are likely to be visited and the more berries produced. However, on average just over one-third of the 20 million or more flowers on an acre of cranberries will set fruit. This level of set results in about 150 barrels per acre (1 barrel = 100 pounds) for varieties such as Early Black and Howes; 200-225 bbl/A for Stevens and Ben Lear. It is not unreasonable that these averages can be improved. Production levels of exceeding 300 barrels per acre and up to 50% set have been recorded.

Fruit size is also influenced by pollination level. If more pollen is deposited on the stigma, more seeds will result. And, the more seeds per berry, the larger it will be. Cranberry flowers require only a small amount of pollen to be deposited for fruit set to occur. Working with Stevens plants and Early Black pollen in greenhouse studies in New Jersey, scientists found that maximum fruit set and berry weight occurred when eight pollen tetrads were deposited on a stigma (Cane and Schiffhauer 2003); the deposition of additional tetrads did not increase fruit size. This means that single visits by most bee species including honey bees (that deposit seven tetrads on average) are sufficient to produce a marketable fruit. Pollen sources also can influence berry size with cross-pollinated berries larger than self-pollinated in laboratory studies (Cane and Schiffhauer 2003). However, in field situations, self-pollinated flowers produce large, marketable fruit. This means that solid cultivar plantings are economically viable.

THE CRANBERRY FLOWER AND POLLINATION

The cranberry flower has an interesting structure. As the bud opens, the white or slightly pink petals of the flower separate and reflex backward exposing the reproductive parts. There is a single pistil surrounded by a ring of eight stamens. Nectaries are located at the base of the flower between the reproductive parts. The reproductive parts of the flower mature at different times. For the first two days after the flower opens, the anthers release pollen and the female parts are not mature. The pistil continues to grow and the stigma become receptive after all the pollen is shed.

Fig. 2. Cranberry upright with open flower (on left) and flower buds (on right). Courtesy J. Mason.

Although individuals are theoretically self-fertile, cross-pollinations among individuals actually must occur. Once fertilization occurs, the petals are quickly lost. If a flower is not pollinated, the petals can stay attached for up to three weeks and may deepen to a rosy pink color. A prolonged rosy-colored field may indicate poor pollination.

Stamen morphology is adapted to a particular kind of foraging by bee pollinators. Pollen is produced in the anther of the stamen (see Fig. 1). In cranberry, there is a basal anther sac with a long appendage ending in a terminal pore. This floral shape is adapted to a particular type of bee foraging behavior called 'vibratile pollination' (also called 'buzz pollination'). What is meant by this is that a visiting bee will vibrate her wing muscles while holding onto the flower. These vibrations are transferred to the flower and starts pollen moving in the anther sac and results in the release of a stream of pollen onto the bee.

While bumble bees and many of our other native bee species carry out this type of foraging, honey bees do not. However, honey bees do collect cranberry pollen using a different foraging method. Honey bees manipulate the anther sacs with their forelegs, effectively releasing pollen. Bumble bees regularly forage for both pollen and nectar at the same time, while many honey bees will concentrate on nectar collection. This is because honey bee colonies have a great need of nectar to produce enough honey to survive the winter in comparison with other bees that need only enough nectar to feed their young and themselves while they are active. Because of these foraging differences and the often small number of honey bees collecting pollen, cranberry has been often called a poor pollen plant for bees. This is not true. Cranberry actually has abundant pollen, it is just that specialized foraging behavior is required to collect pollen from these flowers.

For honey bees in particular, nectar production is an important attractant to cranberry flowers. Although cranberry produces only a small amount of nectar per flower, because of the great number of flowers on a bed, cranberry can provide a rich nectar source. Cultivars vary in their nectar production. In New Jersey, Stevens produced 25-35% more nectar per flower than Ben Lear and Early Black. This suggests a genetic basis to nectar production that could be used in breeding programs.

CRANBERRY POLLINATORS

Many different insects (e.g., flies, wasps, bees) visit cranberry flowers to collect nectar. However, only bees are consistent pollinators of this plant. Pollination effectiveness is related to the foraging behavior of the visiting pollinator. An effective pollinator is one that consistently forages for cranberry pollen in a manner that ensures pollen transfer occurs. For, example, berries produced from flowers visited by pollen foraging bees (including honey bees and bumble bees) are larger with more seeds than those produced from flowers visited by nectar foraging bees. Bees are also known to 'steal' nectar by foraging from the back of the flower. While bumble bees almost always forage 'legitimately' for nectar and almost always collect pollen, honey bees often 'steal' nectar and are inconsistent pollen collectors. Bumble bees also tend to carry purer pollen loads than do honey bees. Thus, bumble bees deposit more cranberry pollen on a stigma than do honey bees. This is likely true for other of our native bee pollinators.

Native Bees. Many native bee species visit cranberry in areas where cranberry grows naturally. In Massachusetts, 36 species were collected foraging on cranberry. Most of these species were found in very low numbers, particularly on commercial plantings (MacKenzie 1994). Bumble bees were the most common native bee with eight species identified. The species reared commercially, *Bombus impatiens*, was the most numerous. Bees in the families, Halictidae (sweat bees), Megachilidae (leafcutter and mason bees), Andrenidae (digger bees), and Anthophoridae (carpenter bees) are known to forage on cranberry. In addition, some *Vaccinium* specialists, *Melitta* nr. *americana* (Melittidae) in Massachusetts and *Megachile addenda* in New Jersey are also found.

Bumble bees are robust, hairy bees with black, white and yellow and/or orange markings. These colors serve as warning signals indicating distastefulness and the possession of a defense mechanism, the sting, which protects them from predators. It should be noted that all female bumble bees have smooth stingers and can sting repeatedly. Some species are quite defensive of their colony, while others are fairly mild. Bumble bee populations on cranberry beds in many different growing areas including British Columbia, Massachusetts, the north coast of Quebec and Nova Scotia appear to be quite healthy. However, there are reports from other areas such as Wisconsin and the major growing areas in Quebec that native bee populations are rather sparse.

If there is a healthy native bee population foraging on a commercial cranberry planting, the grower will have fewer concerns about pollination needs and require fewer managed bees. Thus, methods of conserving, and perhaps even enhancing, native bumble bees and other native bee populations are being explored.

Encouraging Native Bees. In order to have a healthy bee population for cranberry pollination, everything they require must be found near the bogs. Bees require food and sites for nests and sometimes for mating. Forage must be available for the entire lifespan of the bee. In the case of some of the solitary bees, this can be as short as three to four weeks (the length of their adult life). For the social bumble bees, forage must be available from early spring (when the queens are present) to late fall. In addition, the further an individual has to fly to find food before and after the crop, the fewer offspring will be produced. Nest sites are usually in the ground for both solitary and bumble bees. It may be possible to provide nests for some bees. Nest boxes (wooden boxes about the size of a shoe box with an overlapping lid, a small entrance hole and a filling of insulation material such as upholster's cotton or bulk wood) have been tried for bumble bees with very poor success rates in Massachusetts (MacKenzie, unpublished data). Trap nests (small wooden blocks with drilled holes) are used for mason bees (*Osmia* species) in other crops. This may help in cranberry where *Osmia* are rarely seen. The use of pesticides during bloom should be avoided whenever possible because native bees may be adversely affected.

Research in lowbush blueberry has found fields with the greatest habitat diversity (e.g., forests, meadows, wetland) consistently have the most abundant and diverse bee populations that are also the most stable (S. Javorek, pers. comm.). Stability is an excellent feature because bee populations are more reliable and the large year to year variation seen in fields with low habitat diversity is avoided. Having a sequence of floral sources around plantings is the leading way to maximize residential populations of bees. Early spring flowering plants are important because bees including bumble bee queens will establish nests where there are ample food sources. For bumble bees, summer resources are important for the production of reproductives (queens and drones). A succession of flowering plants must be present for bee populations to thrive. In the spring, flowering shrubs and trees such as willows and wild plums provide pollen for the initiation of colonies. Wildflowers provide resources over the summer and fall. Planting of suitable perennials (e.g., heather, rhododendron) near beds or supplemental bed pasture in the field margins (e.g., borage, catmint, anise hyssop) should enhance bee populations. Undisturbed lands that provide nests sites and forage are also a good idea.

Managed Bees. It is obvious, however, that given the number of flowers on a cranberry bed, growers cannot rely solely on native bee populations for their pollination needs during bloom. Four types of managed bees, honey bees, bumble bees, alfalfa leafcutting bees, and mason bees, are commercially available. Honey bees and bumble bees are both social species that live in colonies with a reproductive queen, sterile workers and males (called drones) at certain times of the year. Alfalfa leafcutting bees and mason bees are solitary bees; each female is a reproductive that looks after her own young.

Honey bees are the most important managed pollinator worldwide because they are readily available and their management is well known. Honey bees are kept in hives and are used for both honey production and pollination. Bumble bees, also kept in hives, are now reared commercially for the pollination of greenhouse tomatoes and are being used for a number of field crops including cranberry. Alfalfa leafcutting bees are used on a massive scale in Western Canada and the United States for the pollination of forage crops for seed production. In nature, they nest in cavities above ground. This means it has been possible to develop artificial nests that are kept in shelters to protect them from poor weather conditions. Mason bees, also cavity nesters, are used on a smaller scale for fruit tree pollination. While the majority of cranberry growers use honey bees for their pollination needs, bumble bees and alfalfa leafcutting bees are being used on limited acreages.

Honey Bees. The European honey bee (*Apis mellifera*), the only honey bee species in North America, is valued for the honey it produces and for the pollination services it provides. A colony consists of a single queen, thousands of workers, brood (eggs and larvae) except for in the winter, and drones in the summer and early fall. Larvae are fed a mixture of glandular secretions, pollen and nectar by workers. A queen is produced when young female larvae are fed only these glandular secretions, often called 'royal jelly', in greater amounts than what is fed to worker larvae. New queens are usually produced in the spring or early summer, and will live up to five years. The drones mate with these queens and then die. Unmated drones die in the late summer or early fall. Once mated, a queen lays eggs and also produces chemicals called pheromones that mediate the activities within the hive. The workers carry out all the duties required by the colony including hive tasks and foraging. In addition to nectar and pollen, honey bees also collect propolis (plant resins) that are used to seal up holes in the hive and water, which is used to cool the colony.

Honey bees have a caste system in which the youngest workers perform in-hive tasks such as cleaning and feeding young, while older workers guard the colony and forage. A colony sometimes is made up of more than 80,000 individuals, although 30,000 to 40,000 is more common. Colony size will vary throughout the year with higher populations present during the summer and lowest populations of around 20,000 bees during the winter. Honey bees reproduce by swarming, essentially splitting their colony. This will happen when the hive gets too crowded. New queens are produced first. Then, the old queen and many workers leave the colony to find a new home, while a new queen and the remaining worker population stay in the old colony. Honey bees are well known for their defensive behavior when the colony is threatened. They will chase and sting vertebrate predators. It should be noted that worker honey bees have barbed stingers that remain in the skin of their victim pumping venom into them. While queen honey bees have smooth stingers and can sting repeatedly, they really only use them on other bees.

Bumble Bees. Like honey bees, bumble bees are social insects. During mid-summer a colony will consist of a queen, sterile female workers and males (drones). However, bumble bees also have a solitary phase. At the end of the summer, reproductives (both male and female) are produced by a colony. After mating, the new queen finds a suitable spot, usually in the ground, and spends the winter there. The new mated queens are the only bumble bees to winter as the rest of the colony (drones and workers) die in the fall at the onset of cold weather. In the spring, the queen emerges, searches for and locates a nest site. She establishes her nest and begins rearing young while foraging. Once the first brood emerges, the new workers will take over the foraging and most nest activities, while the queen's tasks now are mainly egg laying. Bumble bees nest primarily in the ground and require insulating materials in their nest to keep the young warm. Thus, they will use sites such as abandoned mouse burrows, empty bird nests and man-made sites such as discarded mattresses, manure piles and walls of old buildings. Bumble bees store only enough food reserves to keep the colony going for a few days, and can be found foraging at lower temperatures and in poorer conditions than both honey bees and alfalfa leafcutting bees.

Bumble bees are reared mainly for the pollination of greenhouse crops. Bee producers also sell colonies for use on field crops. Managed bumble bee colonies have potential in cranberry production, since these bees are not aggressive. However, hives can be expensive.

Alfalfa Leafcutting Bees (ALB). ALBs naturally nest in cracks and crevices aboveground. Thus, it was possible to construct artificial nests for them. These bees are used on a massive scale in forage seed production in Western Canada and the United States, and have well developed management and equipment. Some advantages of ALBs is that they have limited flight and foraging ranges so they tend to stay where they are put, are not aggressive, and all females forage for both pollen and nectar. However, they do require warmer temperatures and bright days to work to their potential. They are currently being used successfully to pollinate lowbush blueberry (*Vaccinium angustifolium*) particularly in New Brunswick and Quebec. While research (Stubbs et al. 1999) has shown that they have potential on cranberry and are being used successfully by some growers located near lowbush blueberry growing areas, there are drawbacks to their use (MacKenzie and Schiffhauer, unpublished data). In particular, while management is relatively easy, they do winter as mature larvae and need to be incubated in the spring to produce adults at the time of crop bloom. They also have a number of pests that must be successfully managed, and strategies need to be adapted to the crop of interest. It is best if knowledgeable beekeepers are involved; this is somewhat difficult due to the distance of most cranberry growing areas from the majority of ALB usage.

Beekeeping. Beekeepers maintain colonies throughout the year and expand their operations by starting new colonies in the spring or summer. Colonies are started by splitting existing colonies, or from a package (bees and queen) or a nucleus (bees and queen in a small hive). It usually takes a full year to achieve a sufficient size to be considered a producing colony. Colony growth occurs if the bees have enough space to store honey and pollen and to raise brood. As the colony grows, the beekeeper needs to supply extra space by adding boxes (supers) to the colony. While bees can be used for both honey production and pollination services, it is becoming more and more common for beekeepers to concentrate on one major role.

As pollination has become more important to many crops, beekeepers have specialized in providing this service, often taking their bees to multiple crops for pollination each year. The pollination season usually begins in mid-spring and continues into early summer. Pollination colonies are smaller than those used for producing honey to allow for ease of movement between crops and due to disruption in colony function and buildup with each move. It is known that the field force in small colonies is proportionally smaller than in large colonies. A healthy average colony may allocate 50-60% of its workers to foraging compared to 35-40% in a small colony. What this means is a colony of 40,000 bees will have more foragers than two colonies of 20,000 each. Thus, it is important that the hives to be used for pollination remain healthy with enough bees to pollinate the crop.

Standard Strength for Pollination Hives. A colony used for pollination should have the following characteristics:

1. a population in excess of 30,000 worker bees,
2. at least six frames (honey comb) with brood,
3. several frames of honey, and
4. be housed in two deep hive bodies.

Of the methods beekeepers use to build up colonies, strong wintered colonies are more likely to meet this standard. Colonies started in the spring from either packages or nuclei may not be strong enough at pollination times, especially if used previously for pollinating earlier crops. In addition, hives that are established and acclimated to an area seem to outperform colonies imported just before the pollination season. Cranberry growers should specify what they expect the colony strength to be and if beekeepers cannot meet that requirement, provisions should be made for extra colonies. Good communication between growers and beekeepers is essential. To ensure that everyone understands their role, pollination contracts are a good idea.

FIELD USE OF MANAGED BEES

Honey bees will forage whenever the weather conditions are suitable and can fly one to two miles to find flowers. They are well known to prefer other forage to cranberry and growers often express concerns about the usefulness of the colonies they have rented. For example, if there is a flowering field of clover near by, honey bees from colonies whose purpose is to pollinate cranberry will likely be found foraging on the clover. Thus, it is important that cranberry fields have sufficient open bloom before honey bee colonies are placed on the fields. In cranberry, it is suggested that 20-25% of the bloom should be open. The proportion of workers that forage for cranberry pollen varies considerably among areas and between years. It would be beneficial to develop methods that increase pollen foraging because pollen foragers are more effective pollinators. Most of the bloom on a cranberry bed can be set in about four days of good flight activity. How quickly this is achieved varies and it is recommended that bees remain on beds for at least one week of good weather; this may take up to three weeks of real time.

Commercially produced bumble bee colonies do have potential in cranberry production. While, these colonies have only 100 to 200 foragers and are somewhat expensive, they are being used successfully for cranberry pollination especially in areas near residential areas because bumble bees are less aggressive than honey bees. These bees can be brought to fields at very early bloom (<10%). They should be placed at the field edge in a protected spot and not placed directly on the soil. They should be shaded from direct sun and protected from the elements. A tarp or tent cover works well. As bumble bees orient to their nests using features of the landscape, placing the colonies near a prominent feature such as a large tree may increase success.

Alfalfa leafcutting bees are being used commercially for pollination of lowbush blueberry in Canada. In areas where cranberry is near to these fields, they are also being used for cranberry pollination. Research (MacKenzie and Schiffhauer, unpublished data) with alfalfa leafcutting bees shows that they have some potential, but, more work is needed before they can be recommended as a large scale viable alternative pollinator on cranberry.

How many bees are enough? Bees should be brought onto the cranberry beds during early bloom and removed as soon as possible after flowering is finished. When to bring bees into fields varies with the type of bees. For honey bees, more than 15% of the flowers should be open before colonies are moved to the crop. Some recommendations are for 20-25% flowering. This differs due to the amount of alternate bloom in an area. If the field to be pollinated is surrounded by cranberry and/or forest with no alternate bloom, then honey bees can be brought in earlier than if there is other forage surrounding the beds. Bumble bee colonies can be brought in during early bloom, as can alfalfa leafcutting bees.

Recommendations for stocking rates for bees are as follows:

Bee	Stocking Rate per Acre
Honey bees	1-2 colonies in most growing areas, with up to 5 colonies recommended during poor weather conditions 2-4 colonies in Oregon
Bumble bees	1-4 colonies, probably requires more
Alfalfa leafcutting bees	20,000 bees

Growers should set up excellent relationships with beekeepers to ensure their pollination needs are met. Contracts are a recommended practice because the expectations of both the grower and the beekeeper are specified. It is important that space on or near the cranberry beds is available for bee placement during the pollination season.

MANAGEMENT PRACTICES

A number of management practices can influence fruit production and pollination success. Careful use of fertilizers and other cultivation practices are important to optimize the number of reproductive uprights and flowers in order to maximum crop yield. While there are no specific data to document the influence of dry conditions, it has been speculated that periods of dry weather may disturb nectar flow. Irrigation may prolong nectar production during such times.

Irrigation scheduling during bloom should be carefully planned as watering and wet beds could limit bee foraging. Thus, timing irrigation during periods when bees are least likely to be active such as late evening or early morning is a good practice. A good integrated pest management program should be followed to ensure that controls are applied only when necessary. Judicious use of pesticides, especially insecticides, is important. Applications should be made either before or after bloom if at all possible. In addition, when there is a choice, products that are least hazardous to bees should be used. Dust formulations should be avoided. Applications made in late evening after bees have finished foraging or early morning before bees have started foraging are recommended. Irrigation has been used as a method to ‘wash’ down chemical applications. In certain circumstances, it may be necessary to cover or even move bees to prevent pesticide poisoning.

Sign Posting and Description of Zone II Regulations

Jeff LaFleur and Brian Wick

SIGN POSTING

Both state and federal agencies regulate the posting of pesticide application warning signs. The requirement depends on the product being used and the location of the application. In all cases, the label of the product contains the wording that will trigger sign posting.

Restricted Use Pesticides carrying the label "Danger" that are applied within 50 feet of a public way *(road, trail, walkway or any other land over which the public is likely to pass)* require posting of an EPA Worker Protection Standards sign with the words: DANGER PESTICIDES, KEEP OUT.

- Post signs every 200 feet along the area facing the public way and at every principle entrance facing the public way.
- Post signs between 2 and 24 hours prior to the application.
- Remove signs no sooner than 48 hours after the application and no sooner than the expiration of any Restricted Entry Interval (REI) stated on the label instructions.
- Remove signs no later than 48 hours after the expiration of the REI stated on the label instructions under the heading "Agricultural Use Requirements".

Aerial Applications of all Pesticides within 500 feet of a protected area *(residential, business, public way, school, park, playground etc.)* require posting of an EPA Worker Protection Standards sign with the words: DANGER PESTICIDES, KEEP OUT.

- Post signs at conspicuous points no less than 200 feet away from one another at every principle entrance fronting a public road.
- Post signs between 2 and 24 hours prior to application.
- Remove signs no sooner than 48 hours after the application and no sooner than the expiration of any REI stated on the label instructions.
- Signs should be removed no later than 48 hours after the expiration of the REI stated on the label instructions under the heading "Agricultural Use Requirements".

Federal Restricted Use Pesticides within 300 feet of a sensitive area *(residential, business, hospital, or public area)* require posting of a federal chemigation sign that states: STOP, KEEP OUT, PESTICIDES IN IRRIGATION WATER.

- Post signs at all usual points of entry. If there are no usual points of entry, post at corners of treated area.
- Signs must be posted no sooner than 24 hours before the scheduled application.
- Signs must be removed within 3 days after the end of the application and any REI and before entry of agricultural-workers is permitted.

More information on Sign Posting is available on the Cape Cod Cranberry Growers' Association web site (www.cranberries.org).

PROTECTION OF GROUNDWATER SOURCES OF PUBLIC DRINKING WATER (ZONE II)

The Groundwater Protection Regulations from the Massachusetts Department of Agricultural Resources (MDAR) are intended to prevent contamination of public drinking water supply wells through regulating the application of pesticide products on the Groundwater Protection List within primary recharge areas. A primary recharge area is either an Interim Wellhead Protection Area (IWPA) or a Zone II. Primary Recharge Areas are updated yearly by the state. The pesticide groundwater protection regulations ONLY apply to public drinking water wells that pump greater than 100,000 gallons of water per day.

MDAR publishes a Groundwater Protection List of those pesticides subject to the regulations. The Groundwater Protection List refers to a list of pesticide active ingredients that could potentially impact groundwater due to their chemical characteristics and toxicological profile. As a result, a product containing any of these active ingredients is regulated if, and only if, it is to be used within the primary recharge area of a public well.

Any applicator who is in a Primary Recharge Area and is planning to apply a pesticide on the Groundwater Protection List must use an alternative pesticide that is not on the Groundwater Protection List for the particular pest they are seeking to control. If an alternative pesticide is not available, then the applicator must either follow an MDAR approved Integrated Pest Management Plan or file a Pesticide Management Plan with MDAR in addition to practicing IPM.

Primary Recharge Area maps are updated yearly and are available online at both the Massachusetts Geographic Information System (www.mass.gov/mgis) and MDAR web sites (www.mass.gov/agr). More information on Primary Recharge Area regulations is available on the Cape Cod Cranberry Growers' Association web site (www.cranberries.org).

Pesticide Registration, Licenses, Application, and Storage

Hilary A. Sandler

PESTICIDE REGISTRATION

All pesticides used in cranberry production must go through rigorous field and laboratory tests, which are ultimately evaluated and regulated by the U.S. Environmental Protection Agency (EPA). The actual number of pesticides available for use in cranberries varies from year to year as some chemicals are phased out and new compounds are approved for use. The path to registering a compound is long and expensive. It may take 10 to 20 years to go from discovery of a new compound to registration of a commercialized product. This process can cost millions of dollars.

Minor Crop Registration. Many pesticides used in cranberry production are registered with the assistance of a specialty crop (minor use) pesticide registration program known as the IR-4 Project. This program is specifically designed to supply specialty crops with pest management tools by developing research data to support new EPA tolerances and labeled product uses (http://ir4.rutgers.edu/index.html). IR-4 is administered through the USDA-ARS National IR-4 Director and the U.S. is divided into four regions. The eastern regional headquarters, affiliated with Rutgers, The State University of New Jersey are located in Princeton, NJ.

To start the process, representatives of the cranberry industry work together with cranberry scientists to identify the most promising compounds. Once identified, the industry solicits financial support from IR-4 and/or the registrant (the company that manufactures the chemical) to conduct the field trials and process fruit samples for pesticide residues. All procedures must conform to Good Laboratory Practices (GLP), which mandates meticulous record keeping. IR-4 designs the residue field trials; these are typically conducted at several sites across the country. IR-4 coordinates the collection of field and laboratory residue data from research scientists and prepares the package of relevant registration information as required by EPA. If successful, the compound will be approved for use by EPA and issued a full label registration (also known as a Section 3 label).

Specific and Crisis Exemptions. As per Section 18 of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), pesticides may also become available for use for specific time periods under specific circumstances against a specific pest(s) via a permit request process (www.epa.gov/opprd001/section18). Four types of Section 18 permits may be granted, but the cranberry industry has usually requested Specific Exemptions and has rarely requested a Crisis Exemption. These permits are requested when a compound is in the registration process but has not yet been approved for full label use by the EPA (i.e., it is still technically unregistered). The other criterion needed to justify a petition for an emergency use permit is that pesticides that once provided control for a particular pest are no longer available. Loss of availability may be due to resistance of the pest to the compound or loss of product(s) through de-registration. These permits are usually written by a University scientist, who submits the package to Massachusetts Department of Agricultural Resources (MDAR). This state agency will then make the formal request to EPA.

For Specific and Crisis Exemptions, significant economic loss by the industry without the use of the requested compound must be clearly demonstrated. A petition for a Specific Exemption can take several months from submission to approval. When applying for a Crisis Exemption, the situation must be dire and the timeline in which EPA must respond to the request is substantially shortened as compared to a Specific Exemption. In either case, the exemption is granted for a limited time period (usually several months). Repeat requests for the same compound and the same pest must be submitted on an annual basis and approved each time. For more information on the Section 18 process, please go to EPA's web site as noted above.

Special Local Needs. Under the authority of Section 24(c) of FIFRA, states may register an additional use of a federally registered pesticide product, or a new end-use product to meet special local needs. EPA reviews these registrations, and may disapprove the state registration if, among other things, the use is not covered by necessary tolerances, or the use has been previously denied, disapproved, suspended or canceled, or voluntarily canceled subsequent to a notice concerning health or environmental concerns (http://www.epa.gov/opprd001/24c). States have been granted the authority by FIFRA to issue special local needs registrations under certain conditions while EPA is responsible for overseeing the general program.

This procedure is usually fairly straight-forward. It requires submission of an application and payment of a fee by the registrant and the submission of an application explaining the new use and justification of need by a University scientist. Even as simple as this procedure is, it may take 1 to 2 years from initiation to approval of to a 24(c) registration. These do not need to be renewed and are in effect as long as the compound remains registered by EPA.

FIFRA 2(ee). Occasionally, situations arise where a small change in the label language of a registered product would satisfy a pest management need. FIFRA Section 2 (ee) permits "use of any registered pesticide in a manner inconsistent with its labeling". Such situations might include recommending use of a pesticide for a target pest not currently listed on the label or applying a pesticide at a dose lower than specified on the label (unless the label specifically prohibits any rate deviation). A knowledgeable expert (typically a University Extension professional or faculty member) can make such a recommendation. All other use patterns and directions specified as on the pesticide label must be followed. Any written recommendations should acknowledge the invocation of the FIFRA 2(ee).

PESTICIDE LICENSES FOR APPLICATORS

Massachusetts pesticide law requires that all persons who apply pesticides in public areas and private places used for human occupation and habitation, must be in possession of a valid license or certification issued by the Massachusetts Department of Agricultural Resources (MDAR). In accordance with the Massachusetts Pesticide Control Act and the current pesticide regulations, MDAR conducts written examinations to measure competency to use, sell, and apply pesticides in Massachusetts. For the most up-to-date information, go to the MDAR Pesticide Bureau web site, http://www.mass.gov/agr/pesticides.

Four types of licenses are offered by MDAR. Most cranberry growers who apply pesticides to their own beds have Private Applicator Certification. Private certification is for applicators who use or supervise the use of restricted-use or state-limited pesticides for the purpose of producing any agricultural commodity on property owned or rented by the grower or their employer. This assumes no compensation is granted other than the trading of personal services between producers of agricultural commodities on the land of another person. A Commercial Applicator License permits individuals to use general use pesticides, or any restricted-use pesticide under the direct supervision of a certified applicator, for hire or compensation for any purpose or on any property other than that defined for the private applicator certification. The third category is Commercial Applicator Certification. This certification is for someone who uses or supervises the use of any pesticide that is classified for restricted use for hire or compensation for any purpose or on any property not covered in the definition for the private certification. The fourth license type covers those wishing to sell restricted-use or state-limited pesticides; they must obtain a Dealer License.

APPLICATION OF CHEMICALS

Pesticides can be applied to Massachusetts cranberry beds in several ways: chemigation (application through the sprinkler system), ground application, wiper application, and aerial application.

Chemigation. Chemigation, or application of chemicals through a solid-set irrigation system, is the most common method of pesticide delivery in Massachusetts (See Chemigation chapter). Insecticides, fungicides, herbicides, and fertilizers may be applied through the irrigation system. Growers often use a specialized piece of equipment, a chemigation injection unit, to mix the pesticide with water in the irrigation system. Injection systems must provide backflow prevention through the inclusion of various check valves. Pesticides cannot be introduced into a system through the suction side of the pump. Growers are encouraged to contact chemigation specialists prior to purchasing injection equipment.

The application rate of a chemical applied by chemigation is dictated by the label and is typically applied in 300-500 gallons of water per acre. The effectiveness of many pesticides, especially the newer chemistries, may be affected by the amount of time needed for water to move from the first head to last head in the irrigation system (wash-off time). Wash-off time has the greatest impact on the performance of the chemical injected into the system. If the wash-off time is long, material applied early in the delivery may wash off the cranberry leaves by the time the chemical reaches the last heads, thus reducing the effectiveness of the chemical. Growers should always read the label of any product prior to use to familiarize themselves with any specific instructions for that material.

The layout of a system, age of the components in the system (e.g., nozzles, gaskets, lines) as well as the type and height of the sprinkler heads, can affect the performance of an irrigation system (Sandler 1998a). Growers routinely clean and inspect their systems for signs of leaks and excessive wear. Many factors can affect the coefficient of uniformity (CU) of an irrigation system, which ultimately impacts the delivery of water, pesticides, and fertilizers onto the production area. Growers should always try to maximize the CU for their systems. Design experts should be consulted to determine system requirements, especially when installing new systems in recently constructed or renovated sites.

Ground Application. Growers may employ several types of ground applicators to apply preemergence and postemergence herbicides and granular fertilizers. Most growers use motor-powered herbicide rigs (e.g., Gephardt) to apply granular preemergence herbicides in the spring. During the growing season, growers may need to apply fertilizers or spot-treat weeds with herbicides. Typical ground applications may involve the use of various hand-held devices to apply postemergence herbicide solutions (as wipes or sprays), machines that use a large roller to apply (as a wipe) postemergence herbicides, or hand-crank rotary spreaders for the application of granular fertilizers. More recently, growers are incorporating the use of boom sprayers as another type of ground application equipment. Photographs of equipment used in pesticide applications may be found in the Weed Management section.

Aerial Application. Aerial applications of pesticides are made by specially equipped helicopters. Even though helicopters are most often used to perform other normal agricultural practices (e.g., removal of harvested fruit or ditch debris), certain pesticides and fertilizers may be applied by air. A typical aerial pesticide application uses approximately 5-25 gallons of water per acre. Aerial application is more expensive than other methods of application. Growers decide whether to use aerial application based on efficacy of the product, cost of the application, proximity to abutters, and available labor and time. Most aerial applications are granular fertilizers.

Acres Treated. The number of acres treated with any particular pesticide can vary greatly from year to year. These values are heavily dependent on pest pressures and available products in a given year (Sylvia and Guerin 2008). For Massachusetts, chemigation is the industry norm for pesticide application. In 2003 and 2005, 81% and 78% of all treated acres received pesticides via chemigation, respectively. For the same years, approximately 6% and 4% of all treated acres received pesticides by ground application (mostly herbicides). For both years, 6% of all treated acres received herbicide applications by hand or machine wipers (J. DeVerna, Ocean Spray Cranberries, Inc., pers. comm.).

Aerial spraying of pesticides continues to play a relatively minor role, especially compared to chemigation. In 2005, 12% of all pesticide applications made in Massachusetts were applied by air (down from 15% in 1995). Compared to 1995 data noted in the previous edition of this publication (Sandler 1997), the percentage of acres treated with aerial fungicide applications have remained stable at 17%. The percentage of aerial herbicide and insecticide applications have decreased from 32% to 11% and from 14% to 10%, respectively (J. DeVerna, Ocean Spray Cranberries, Inc., pers. comm.).

PESTICIDE STORAGE

Growers may purchase quantities of pesticides in the spring in anticipation of their use during the growing season. These pesticides should be stored in well-ventilated and secured storage facilities (DeMoranville and Sandler 2000a). It is recommended to avoid carry-over of extra pesticides. Growers should always try to buy only what they will need for the current season. Containers should be labeled with date of purchase and the date the container was opened. Pesticides should be sorted by type within the facility and stored in their original container.

Dry pesticides (granulars, powders) should be stored in a cool, dry place. Generally, no other precautions are needed with these materials. Liquid or emulsified product may have restricted temperature ranges at which they should be stored. In general, liquid or emulsified materials should not be stored at temperatures below 45°F nor at temperatures that consistently exceed 100°F.

Material Safety Data Sheets (MSDS) should be read for current disposal information. Empty containers should be kept in a safe place until disposal. Empty bags and triple-rinsed liquid containers can be placed in sanitary landfills or incinerated, or if permitted by local authorities, by local burning. Empty liquid containers should be triple-rinsed and offered for recycling or reconditioning, if available.

More information on pesticide storage (as well as mixing and loading) may be found at: http://www.mass.gov/agr/pesticides/waste/index.htm.

Disposal of Pesticides. When a pesticide is being phased out, announcements are made by EPA to notify Extension personnel and growers that the period of legal application of a particular compound is expiring. This typically occurs because the food tolerance for a compound is being revoked. Any material, remaining in the hands of growers (i.e., that is not used or given back to a distributor) will be considered hazardous waste once the tolerance is revoked. Unused pesticides must then be disposed of as hazardous waste, and growers must absorb all related costs.

Cape Cod (Barnstable County) Cooperative Extension has offered collection of household and agricultural hazardous waste at minimal or no cost to the grower. Check their web site for current program status and any other relevant information:
http://www.capecodextension.org/home.php.

Breakdown and Movement of Pesticides

Hilary A. Sandler

The movement of a pesticide in the soil is influenced by the properties of the soil and the properties of the chemical (Biggar and Seiber 1987; Brady and Weil 1996). Once added to the soil, a pesticide is degraded by biological, physical, and chemical processes that influence its behavior in the soil environment (Goring and Hanmaker 1972; Maier-Bode and Hartel 1981; Deubert 1990). The following discussion outlines the principle factors that affect the movement and breakdown of chemicals applied to the soil.

PROPERTIES OF THE SOIL

Soil Texture and Bog Structure. The relative amounts of sand, silt, and clay in a soil are collectively known as soil texture. Sand is a very prominent component of most cranberry soils, sometimes accounting for as much as 98% of the soil mineral matter. Many cranberry growers in Massachusetts use the cultural practice of sanding every 2-5 years. Sanding stimulates vine growth by encouraging shoot production and improving soil aeration. The occasional application of a 0.5 to 2.0 inch layer of sand over the layer of leaves that have naturally fallen off the vines creates a unique soil situation called stratification. These events and activities, which are repeated over time, result in layers of organic matter interspersed with layers of sand in the upper profile of cranberry bog soil.

Commercial beds built on the contours of iron ore bogs will have a stratified soil profile in the uppermost layers (the thickness will vary depending on the age of the bog), typically followed by a substratum of peat. This substratum may be 10-30 feet thick. Pesticides are largely retained in the upper layers of the organic component of the stratified bog soil, though some may be retained in the peat substratum. Additionally, a natural restrictive layer may occur beneath the peat layer of the bog. The presence of this restrictive layer would further separate chemicals applied to the cranberry bog from the groundwater.

Current best management practices (BMP) recommend that beds constructed on upland soils utilize a perched water table above the natural water table. Below the perched water table is an organic-confining layer followed by a water-confining layer (an impermeable layer that mimics the natural restrictive layer found underneath many traditional bogs). These layers are constructed to enable the grower to hold floodwaters for harvest and pest management activities and to minimize leaching. The natural water table lies beneath all of these layers.

The clay fraction can be very important in influencing the behavior of chemicals in some soils. However, typical cranberry soils contain less than 1.0% clay, an amount that does not significantly improve the adsorption capacity of a bog soil. The clay fraction is thus considered to play a very minor role affecting the breakdown and movement of pesticides in Massachusetts cranberry beds.

Organic Matter. Organic matter content is the most influential factor affecting the fate of a soil-applied pesticide. Even though it may only comprise 1-2% of the soil composition (as in Massachusetts beds), the importance of organic matter must be emphasized. Its large surface area adsorbs cations and organic compounds in the soil solution. Soils high in organic matter have a low potential for pesticide leaching. Research indicates that compounds applied to cranberry beds are retained in the top 0-4 inches of soil.

The flow of water through the cranberry root zone is slowed by the presence of organic matter. Chemicals can then have time to react with the organic matter. In addition, nutrients can be retained in the root zone long enough to be taken up by the plant. Organic matter also acts as a nutrient reservoir, and supports microorganisms that are associated with the breakdown of plant material and chemicals that are introduced to the environment.

Soil Moisture. The natural setting of a cranberry bog ensures that soil water is not physically far away from the vines. However, in the cranberry system, a high soil moisture content does not guarantee that water is accessible to the roots. Water that contributes to the soil moisture content may be held tenaciously by the peat fraction and is unavailable for plant uptake. The movement of water downward is impeded by the mat of fine, fibrous roots produced by the cranberry vines, and by layers of organic matter. Stratification encourages the horizontal movement of water within cranberry beds.

The movement of water and chemicals through the soil may not be the same; the pesticide may be slowed due to its adsorption to organic matter. Research indicated that pesticides are primarily retained in the top two inches of bog soil (K. Deubert, personal communication). Since the degradative activities of soil microorganisms are also dependent upon the availability of water, pesticides tend to break down more rapidly in moist soils.

Contrary to a common misconception, cranberries are not grown in a constantly flooded state. Cranberries need a consistent source of water to grow properly, but the root system cannot grow in saturated soil. Well-maintained beds will have the ability to provide adequate water on a regular basis coupled with good soil drainage. Good soil drainage is important for providing a favorable environment for pesticide degradation.

PROPERTIES OF THE PESTICIDE

Soil Adsorption. K_{OC} is a measure of soil adsorption, the tendency for pesticides to become attached to organic particles. High K_{OC} values indicate that a pesticide is strongly adsorbed to the soil surface and therefore is not easily moved, unless soil erosion occurs. Chemicals with low K_{OC} values have a greater tendency to be moved with water, thus may be moved away from the area of application either by run-off or leaching. The degree of adsorption is dependent upon the chemical structure and concentration of the pesticide in the soil water and on the organic matter content.

Solubility. The maximum amount of a substance that can be dissolved in water at a given temperature is a measure of its solubility. Generally, compounds that have low solubility tend to remain on the soil surface and not leach through the soil profile. Compounds with high solubilities are more likely to be moved with water through the soil. However, there are exceptions to the principle of highly soluble compounds being more apt to move through the soil, as other environmental factors can decrease the probability of leaching and always need to be considered.

Persistence. Used only as a relative indicator of persistence, the half-life of a compound refers to the time required for a chemical to degrade to one-half of its original concentration. In general, the longer the half-life, the greater the potential for pesticide movement within the environment. The compound may resist degradation long enough to be moved into the groundwater or carried from the application site by run-off. Half-life values are greatly dependent upon other parameters such as soil moisture, temperature, oxygen status, soil pH, concentration of the chemical, application method, presence of microbial populations, etc. Half-life values for any compound can be variable and should be used only as a general guideline and/or in conjunction with other known chemical properties. In general, modern chemicals have significantly shorter half-lives than pesticides that were used 30 years ago.

Odor. Some pesticides or their carriers have strong odors that some people may find offensive. The odor may be a warning agent added to the pesticide to signal that a chemical has been recently applied or it may be an aromatic organic solvent specifically added to facilitate dissolution of the pesticide.

Application of a strong-smelling pesticide when the humidity is high and the air is very still may increase the likelihood of neighbors detecting a strong odor. This does not mean that the pesticide has drifted off the bog. It is a misconception to assume that if one smells a pesticide odor that the chemical has drifted off of the bog.

Many pesticide odors are formulated fragrances and not part of the active ingredients. Because they are fragrances, odors will carry much farther than the actual droplet portions of a pesticide spray. However, the odors will be more likely to carry in the humid air. This principle is similar to the odor often associated with the ocean's low tide. Often during a humid day in the summer, one can smell the odor of mud and salt from the exposed earth long before the ocean is seen.

PROCESSES AFFECTING DEGRADATION AND MOVEMENT

The primary processes involved in degradation or movement of a pesticide applied to the soil are documented in the figure. The significance of these processes in determining the persistence or breakdown of any chemical is dependent upon many interrelated factors (e.g., soil and pesticide properties). Despite the development of complex mathematical models, predicting the exact behavior of a chemical in the dynamic soil ecosystem is still very difficult.

Pesticide Adsorption and Desorption. The tendency for chemicals to adhere to the soil surface is a continuous, reversible process. The more organic matter that is present, the more adsorption may occur. Adsorption is inversely related to soil moisture content, water movement, and solubility.

As the soil moisture content increases and the amount of material dissolved in water increases, adsorption decreases. The effect of temperature can be variable, but temperature is directly related to solubility. Therefore, as the temperature rises, the adsorption of the compound tends to decrease. The compound would tend to move with water through the soil profile.

Leaching. The process by which materials are washed through the soil by the movement of water is known as leaching. Plants with dense root systems, such as cranberries, tend to lower the leaching potential of pesticides due to increased soil aeration and larger microbial populations that tend to be associated with the root zone. Generally, the amount leached is directly related to its solubility. The higher the solubility, the less likely the compound will be adsorbed to the soil, and the greater its potential to be leached. The intensity and frequency of rainfall, as well as any use of the irrigation system, affects the amount of the chemical that is leached as well as the depth to which a material is leached.

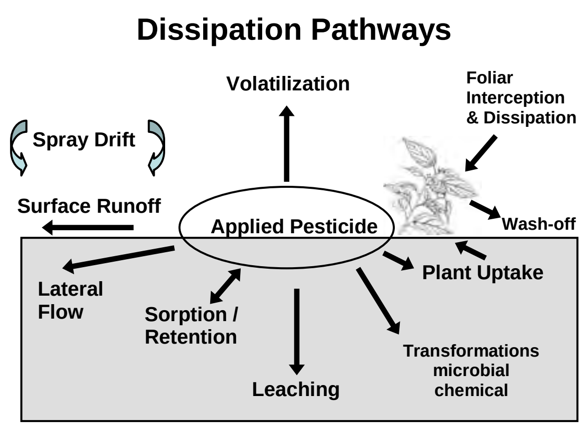

Fig. 1. Illustration of the many processes associated with the breakdown of a pesticide. http://www.epa.gov/oppefed1/ecorisk_ders/toera_analysis_exp.htm. Plant drawing courtesy http://aquat1.ifas.ufl.edu/drawlist.html.

Plant Uptake. The uptake and movement of a chemical into a plant is affected by the age of the plant, climatic factors, pesticide formulation, and mode of application. Uptake occurs to both target and non-target plants. The persistence of any chemical in the plant is directly related to the rate of the metabolism of the plant.

Evaporation. According to its tendency to vaporize, a compound will evaporate when in contact with air or moisture. The rate of evaporation is directly related to the soil moisture content and temperature. However, when more organic matter is present, the potential for adsorption of the compound is increased and the potential for evaporation is decreased.

Microbial Decomposition. Degradation by microorganisms depends on many factors including the chemical structure and concentration of the pesticide, temperature, soil organic matter content, pH, available water, and nutrients. Most microorganisms are found in the root zone; if a material is moved quickly past the roots, degradation by microbial activity is significantly reduced. Often, pesticide degradation is an incidental event for many microorganisms, i.e., the chemical is not used as an energy or nutrient source by the organism.

Chemical Degradation. Hydrolysis, the breakdown of a compound by water, is an important pathway of chemical degradation. The rate of these reactions is temperature and pH-dependent. Many pesticides react with water to produce compounds that are usually less toxic than the parent compounds.

Photodecomposition. The energy of sunlight may break down organic compounds, causing them to lose their effectiveness. Pesticides applied to plant surfaces are more subject to photodecomposition than those that are incorporated or injected into the soil. This factor is generally of minor importance relative to other factors that affect pesticide degradation and movement.

CONCLUSION

Due to the influence of organic matter in cranberry soils and the dense root systems of the cranberry vines, the potential for movement of pesticides to groundwater is low. Penetration into lower soil layers is inhibited due to the retention of organic chemical in the top 0-4 inches of the soil. Stratification provides a reservoir of adsorption sites that are found in the uppermost portions of cranberry soil profiles. These alternating layers of sand and organic matter facilitate the horizontal movement of water; downward flow is impeded. The organic matter content serves as a substrate for microbial population that actively degrades pesticides.

Concentrated in the upper 2-4 inches of the soil, the dense fibrous root system of the cranberry vines slows the downward movement of water and serves as an additional deterrent to leaching. Furthermore, cranberry vines may be separated from the groundwater by the presence of a restrictive layer under the peat (as in Massachusetts beds) and stagnant bog water. Currently, it is recommended to hold water within the bog system for variable time periods to allow for degradation (see Cranberry Chart Book for specific times). Thus, the potential for groundwater and surface contamination is reduced further in these situations.

When pesticides are used properly and judiciously, the cranberry agroecosystem contains a suitable contingent of biological and chemical properties that buffer the potential movement of compounds into water and land resources.

Normal Agricultural Practices for Maintenance or Improvement of Cranberry Bogs

Cape Cod Cranberry Growers' Association

The practices set forth below are based on a number of important agricultural and environmental principles. These activities have evolved over the years as growers find more efficient ways to accomplish certain jobs. In many cases, the activities are predicated by research results published from major agricultural and academic institutions. Improvements and amendments will be made as research and technology dictate.

Under certain circumstances, some of the activities may require a permit from local, state, or federal agencies. Regulations that may be triggered by agricultural activities are listed at the end of this chapter. Growers should contact the CCCGA or the appropriate authority (see "Directory of Agencies") if they are unsure if a particular activity falls under the jurisdiction of one or more of these regulations.

BRUSH CUTTING AND TREE CLEARING

Removal of brush and trees around the perimeter of the bog is necessary for the following reasons: 1) promotes air movement that helps reduce frost risk. Air movement on the bog also minimizes potential for fungal infection; 2) removes plants that may serve as hosts for certain insects (this decreases the risk of infestations on the bog and may reduce pesticide usage); 3) minimizes weed incursion and helps cut down on herbicide usage; and 4) encourages sunlight to reach the vine canopy. Although the area to be kept clear depends upon the slope, type of vegetation present, and the direction of the sun, this area is generally at least 50 feet but can extend up to 100 feet, for land not in a bordering vegetative wetland (BVW). For land in a BVW, tree removal is not allowed within 25 feet of a water body that is not managed as part of the farm. Removal of trees and vegetation within this zone is allowed to control alternate hosts (as long as no more than 50% of the canopy is removed) or to maintain existing dikes.

BURNING

Growers cut brush adjacent to the bogs to improve sunlight and air circulation for their bogs. An efficient method of disposing of the light brush is to burn it on-site. Agricultural burning is done primarily during the winter months under damp or snowy conditions to minimize damage to surrounding woodlands.

CLEANING AND DREDGING RESERVOIRS AND WATER STORAGE SYSTEMS

Reservoirs and water storage systems lose holding capacity because of vegetation growth and siltation, reducing the availability of water for frost protection, irrigation, and harvest (Franklin 1948). These reservoirs and other storage systems must be cleaned and dredged from time to time to maintain water availability. Usually only a small area of the reservoir is dredged (~6-10 feet) and volume needed is based on one week's pumping. Shallow water supplies need to be cleaned and deepened for a number of reasons, including but not limited to: 1) to insure movement of water to pumps or water control structures; 2) to control vegetation growth that clogs pump suction; and 3) to insure water availability in cold weather when ice forms.

CLEARING LAND IN PREPARATION FOR SAND PITS

Periodic sanding of cranberry vines is a very important part of cranberry cultivation. To accomplish this, cranberry growers must either purchase sand or use natural sand deposits located on their property. These sand deposits, usually located in the hills surrounding the bogs, require that the trees and brush be cleared and the top soil removed to allow removal of sand deposits by the grower. Screening of the sand is frequently required.

CONSTRUCTION AND MAINTENANCE OF BUILDINGS

Structures that house and protect equipment used for harvest, sanding, and other production related operations are built near bogs to provide easy and efficient access. General maintenance of the structures includes painting, replacement of damaged wood or foundation, roofing, siding, etc.

CONSTRUCTION AND MAINTENANCE OF PUMP HOUSES

Pump houses are built to protect irrigation and pumping equipment from weather and possible vandalism. The pump house is built next to the water source for efficient access. General upkeep would include painting, re-roofing, new siding, and replacement of decayed timbers.

DITCH CLEANING

Ditches facilitate flooding and draining of the bog, and keep the water table close to the root zone during the growing season (Deubert and Caruso 1989). These ditches must be kept free-flowing. Ditch cleaning is necessary to keep water moving and to cut down the amount of fungicides necessary (Bergman 1954; Demoranville 1980). It also helps to manage certain weeds that grow in excessively wet conditions, thus reducing the amount of herbicides used. Excessive flooding at blossom time will devastate a cranberry crop; thus, free-running ditches are necessary. Removal of excess ditch material may be done by truck or helicopter.

FERTILIZER AND PESTICIDE APPLICATION

Fertilizers are applied to cranberry bogs to replace nutrients necessary for growth. Fertilizing the bogs begins in the spring and continues until fall. Time and rate of application varies with each individual bog. However, growers strive to maximize plant uptake. Fertilizers can be applied aerially with the use of helicopters, or on the ground through irrigation systems, rotary spreaders, or motorized vehicles (Chandler 1961; DeMoranville et al. 1996b; Sylvia and Guerin 2008).

Application of pesticides is a necessary component of cranberry agriculture to prevent damage to the cranberry plant by various pests. During the season, each grower scouts the cranberry bogs for pests (e.g., insects, weeds, and disease). If the pest population reaches a predetermined economic threshold, the grower decides which management strategy is needed to bring the population below the threshold (Sylvia and Guerin 2008). Chemicals are applied to the cranberry bog using chemigation systems, helicopters, and portable spray units.

Herbicides are applied in the spring as broadcast applications to prevent weed emergence and as postemergence sprays or wipes during the summer to control weeds growing above the vine level (DeMoranville et al. 1996b; Sylvia and Guerin 2008).

FLOODING AND FLOOD RELEASE

Cranberry growers flood their beds primarily for three reasons: 1) water harvesting in September-November; 2) protection from winter injury during December-March; and 3) enhancement of fruit quality by holding a flood from mid-April to mid-May late water).

In addition to the above, a small number of growers without irrigation systems utilize flooding for frost protection. Some growers will employ the practice of flooding the bog to apply sand by means of a specialized barge during late fall-late spring. Flooding can also be used as a cultural practice to reduce insect damage. For some insects, it is the only known control.

When flooding the bogs, growers take advantage of portable pumps and/or stationary lift pumps.

GATE AND FENCE CONSTRUCTION

Gates are normally built to control access to a bog to minimize vandalism and theft. Construction and maintenance of gates is ongoing throughout the year.

GENERAL MAINTENANCE OF PUMPS AND EQUIPMENT

The irrigation pump is the grower's lifeline between success and failure. This pump must provide water to protect the vines and berries during spring and fall frost time, respectively, and during the summer heat. Many chemicals and fertilizers are applied through the sprinkler system, powered by either an internal combustion or electric motor. These motors must be able to start on a moment's notice and run without fail for 10-12 hours. Proper maintenance of these units is essential. Growers test and maintain the pumps on a regular basis.

Equipment is used for almost every phase of production, including but not limited to: 1) harvesting, 2) sanding, and 3) ditch cleaning. This equipment is constructed and maintained in buildings adjacent to bogs.

HARVESTING

Cranberry harvest takes place once a year from mid-September through early November. Two methods of harvest are employed. One method is dry harvesting, which involves using machines to rake the berries off the vines into boxes or bags. Berries are removed from the bog either by bog vehicles or helicopters. The other method, wet harvesting, involves flooding the bog with up to one foot of water and mechanically removing the berries from the vines. Berries are corralled and removed from the bog by pumps or conveyors. Nearly 90% of the crop is wet-harvested (DeMoranville et al. 1996b).

IRRIGATION SYSTEMS

Low-volume sprinkler systems are essential for applying water for frost protection and irrigation, as well as for applying pesticides and fertilizers in modern cranberry cultivation. It is common for the main and lateral lines to be buried.

When the new bogs are constructed, before vines are set out, a sprinkler system is set in place. Many systems that were buried in the bogs during the 1960's and 1970's are now being replaced or upgraded as new technology develops. Older systems were generally undersized and need to be replaced with larger pipes. The proper spacing and sizing of the modern systems provides uniform distribution of irrigation water, which leads to a more conservative use of water.

These modern systems are usually made of black poly pipe plowed into the ground or trenched in by backhoes as in the case of main supply line. For most of the year, only the sprinkler heads are seen but following harvest, these heads are removed. They are again put into place in early spring (DeMoranville et al. 1996b). Currently, many growers are also installing pop-up heads instead of traditional impact sprinkler heads. Pop-up heads do not need to be removed each year since they sit flush with the ground and distribute a more uniform spray of water, thereby increasing efficiencies.

MAINTAINING DIKES AND FLUMES

Since most cranberry bog dikes were built by hand and are not wide or strong enough to accommodate large vehicles, it became necessary to repair and widen them. In addition, animals continuously bore holes in dikes causing structural damage (Franklin 1948). A combination of wind action, when the bogs are flooded, and heavy rains, deteriorate the dikes, making graveling and re-sloping necessary. Properly maintained dikes provide storm water protection.

Water control flumes were mostly made of wood or concrete and time and weather have taken their toll to the point where replacement with new metal ones is necessary. In some cases, the old flumes were small and it is necessary to enlarge them to improve water management efficiency. Faulty, leaking flumes result in lost water, making flume replacement a water conservation practice.

MOWING

Upland areas adjacent to cranberry beds are periodically mowed during the growing season to prevent weed seeds from moving onto the bog and to minimize the risk of fire. Underbrush is also cut and removed at different times throughout the year.

POLLINATION

Cranberries are normally in bloom from mid-June to mid-July. To aid in the pollination process, hives of bees are brought to the bogs during this period. One – two hives of bees are generally believed to be necessary to pollinate one acre of bog. These bees may be brought to the bog on trucks during evening or night hours since that is the time when all bees are in the hive. Once the cranberries are pollinated, bees may be removed to pollinate other crops. Generally, bees are present on cranberry bogs for approximately one month. Many growers who own and rent hives keep them on the property year-round.

POND CONSTRUCTION

Construction of water-holding facilities for irrigation and water management is a common practice. Existing small ponds may be expanded or ponds can be excavated in suitable areas adjacent to the bog.

PRUNING VINES

Pruning vines removes the woody portion of the cranberry plant. Woody portions produce few uprights. Pruning the undesirable parts enables the plant to put more resources into the flowering uprights, thus increasing production (Franklin 1948). Pruning also eliminates the heavy vine growth that promotes the development of fruit rot (DeMoranville et al. 1996b). Pruning may be done simultaneously during dry harvest with machines that prune as they pick. It may also be done after harvest, or in the spring before the vines break dormancy.

REGULATING WATER FLOW

Many growers utilize water from lakes and ponds and control the dams and flumes that allow water to be released. Most growers hold deeded water rights. Fluctuations in water levels may occur during flooding and flood release associated with harvesting, winter protection, and late water floods (Franklin 1948; Gilmore 1986).

ROAD MAINTENANCE

Bog road maintenance is a year-round activity consisting of grading and filling in pot holes, correcting washouts, mowing back brush along roadsides, and pruning of tree branches.

SANDING

Every few years, one-half to one inch of sand is applied to cranberry bogs as an essential part of good bog management. Sand can be applied directly to the vines in the spring or fall, applied directly on the ice during the winter, or by barge in unfrozen flood waters during the fall, winter, or early spring. Most growers use specialized sanders that many have built themselves (Norton 1982). Sanding is a cultural practice that stimulates new vine growth, suppresses insects, improves drainage of surface water, and helps to hasten the breakdown of the trash layer making more nutrients available (Franklin 1948; DeMoranville et al. 1996b).

SQUARING OFF BOGS

Many bogs in southeastern Massachusetts were constructed in the early 1900's by hand labor. Modern equipment of today, including excavators and bulldozers, allows growers to straighten crooked edges and odd-shaped pieces. Straightening edges make tasks such as harvesting and mowing much more efficient and facilitates better irrigation coverage.

STRIPPING AND REPLANTING

A bog is stripped and replanted for the following reasons: 1) the bog is out of grade, requiring excessive quantities of water to flood; 2) the variety is low yielding and/or prone to rot; or 3) weeds such as dewberries, poison ivy, or bushes have overtaken the vines.

TAILWATER RECOVERY AND BYPASS CANALS

Tailwater recovery is one of the most important management practices used by cranberry growers. Basically, it is a recycling of discharge water, thus conserving needed supplies and minimizing the risk of chemicals leaving the bog. As a water conservation measure, tailwater recovery is an economically sound way of maintaining an adequate water supply (SCS Engineering Staff 1985). Tailwater recovery also helps to control flooding by providing temporary storage in periods of excessive rainfall.

Bypass canals are normally used as a temporary diversion when a moving stream bisects a bog area. The canal diverts the stream to the perimeter of the bog area and out of the area where pesticides might be applied.

TRAPPING

Muskrats and other burrowing animals pose serious threat to cranberry bogs and the water management systems. These animals tunnel into beds, causing the muck soil to collapse and rendering the bed unusable. They also damage dikes and flumes, which can cause major washouts that damage property and endanger human lives. Only if all "non-lethal techniques" have been used to control an animal without any success and the animal poses an imminent threat, "resulting in a reduction in the production of an agricultural crop caused by flooding or compromised structural stability of commercial agricultural lands" (M.G.L. Chapter 131 Section 80A(i)(3)), can a grower apply to their local Board of Health for an emergency trapping permit. This permit is good for 10 days but may be extended through a joint filing between the grower and town to the state Department of Public Health for up to an additional 30 days. The emergency permit is for a conibear, box or cage-type trap.

UPGRADING DRAINAGE SYSTEM

Changes in drainage can sometimes be implemented in order to reduce disease in the cranberry bogs. Maintaining existing ditches and building new lateral ditches helps to improve drainage. Adding crushed stones or installing drainage tiles may be used to improve drainage if ditches have been eliminated.

Normal agricultural activities may fall under the jurisdiction of one or more of the following:

Clean Water Act (Federal - Section 404; wetlands activities)

Dam Safety (M.G.L. c253 302 CMR 10.00)

Massachusetts Environmental Policy Act (M.G.L. c30 301 CMR 11.00)

Open Burning Laws (310 CMR 7.07 and 527 CMR 10.22)

Pesticide Control Act (M.G.L. c132B 333 CMR 1.00-13.00)

Public Waterfront Act (M.G.L. c91 310 CMR 9.00)

Water Management Act (M.G.L. c21G 310 CMR 36.00)

Water Quality Certification
(Federal - Section 401; State jurisdiction: M.G.L. c21 314 CMR 4.00)

Wetlands Protection Act (M.G.L. c131 310 CMR 10.04)

Zoning Act (M.G.L. c40A)

Growers should contact the CCCGA or the appropriate authority if they are unsure if an activity falls under one or more of these regulations. Further details on many of the above regulations are available as Grower Advisories on the CCCGA web site at http://www.cranberries.org/growers/advisories.html.

Conservation Planning for Cranberry Farming

Linda Rinta

A Conservation Plan is a tool to help growers manage their lands profitably while protecting the natural resources on and around the farm. It is used to schedule improvements, document conservation practices, and provide access to USDA cost share programs.

Plans are written with the assistance of a USDA trained farm planner or a qualified technical service provider certified by USDA. However, the management decisions recorded in the plan are made by the landowner.

Typically a conservation plan contains the following components:

1. Maps showing the property's location, soil information, proximity to area resource concerns and regulated zones.

2. Practice assessments identifying conditions on the farm needing conservation treatment.

3. Record of decisions indicating a combination of conservation practices that are planned and a schedule of improvements.

In addition, the following documentation of the planning process may also be included:

4. Job sheets explaining how to implement the practices.

5. Conservation plan map to scale showing where practices will be installed.

6. Environmental evaluations and cultural resource considerations addressing the ecological and cultural resource impacts.

7. Cooperator assistance notes indicating the type of assistance provided.

8. Other information including engineering designs, Best Management Practices (BMPs) and Grower Advisories pertinent to the property.

More than the document itself, the process of developing a farm plan is an exercise in reviewing one's farming practices against a standard for resource protection and industry accepted Best Management Practices (BMPs).

Planning occurs through a series of site visits and landowner interviews and discussions. Planners follow a 9-step decision-making process universally employed by USDA throughout the country. These steps include: gathering locational data, identify goals and objectives, evaluate natural and cultural resources, investigate and evaluate various solutions and alternatives, develop and implement a schedule of practices, and ultimately re-evaluate and adjust as needed.

Planning is a dynamic and systematic way of constantly re-evaluating and improving one's farming practices.

USE OF FARM PLANS AS COMPLIANCE DOCUMENTS

Sometimes a Farm Plan is requested as a demonstration of compliance for a number of regulated and non-regulated activities. These may include water supply protection, water conservation, fisheries and wildlife concerns, gravel removal permitting and wetlands projects. In most cases, it is the participation in the planning process that is required.

There are only four situations in which a grower *must* provide a Town Conservation Commission a portion of their approved farm plan. These all involve improvement practices that will impact wetlands. These situations are: 1) Construction, reconstruction, or expansion of a pond or reservoir; 2) Reconstruction of an existing dike; 3) Construction of tailwater recovery; and 4) Construction of a bypass canal. See the Cape Cod Cranberry Growers' Association (CCCGA) Grower Advisory on the Agriculture Regulations of the Wetlands Protection Act for more information (http://www.cranberries.org/growers/advisories.html).

SPECIAL NOTE: *Some proposed new projects involve regulatory review and/or permits. The planning process does NOT exempt those activities from local, state and federal review.*

Wetlands Functions of Cranberry Beds

Garrett G. Hollands

ARE COMMERCIAL CRANBERRY BEDS WETLANDS?

This basic question must first be answered before a discussion of how cranberry beds function as wetlands can be conducted. In 1990, the St. Paul District of the U.S. Army Corps of Engineers issued a draft entitled, "Analysis Regarding Section 404 Review of Commercial Cranberry Operations". The draft analysis was the result of long debate between the cranberry industry, the Wisconsin Department of Natural Resources, Region 5 of the USEPA, and the U.S. Army Corps of Engineers concerning expansion of cranberry beds into natural wetlands. This first analysis reached the conclusion that commercial cranberry beds were not wetlands per the Federal definition of wetlands defined in either 1987 or 1989 Federal delineation manuals.

The draft analysis was reviewed in detail by the cranberry industry, and a scientific report was issued that countered many conclusions of the draft analysis. After considerable debate and public meetings, the Corps of Engineers found that <u>commercial cranberry beds are indeed Federal wetlands</u> because they meet the necessary field test as prescribed in the Federal Wetland Delineation Manual. Also, commercial cranberry beds were determined to be "water dependent", that is, they must occur in "waters of the USA" in order to be economically viable. The Corps issued a Regulatory Guidance Letter (RGL) 92-2 to clarify this issue.

This series of events led to the issuance of Nationwide Permit 34 (not ratified in Massachusetts), which allows for limited expansion of cranberry beds into natural wetlands as an activity believed not to result in significant environmental damage to wetlands (since the conversion) to commercial beds does not change the area to uplands. The area remains a wetland with modified wetland hydrology, hydric soils, and wetland vegetation. These areas have not been converted to uplands and when abandoned, quickly revert to natural wetland vegetation communities. Even cranberry beds created from upland are Federal wetlands. Therefore, if an area, no matter how altered, is a wetland and when abandoned continues to be a wetland, it must function as a wetland.

STATUTORY FUNCTIONS OF COMMERCIAL CRANBERRY BEDS

The Massachusetts Wetlands Protection Act (MGL Chapter 131, section 40) regulates activities that alter the function of wetlands. These functions or statutory interests are flood control, storm damage prevention, prevention of pollution, public or private water supply, ground water supply, land containing shellfish, fisheries, and wildlife habitat.

The Regulations (310 CMR 10.00) expand upon the Act. Wetlands are defined in the Act to include vegetative communities consisting of "bogs", "coastal wetlands", "swamps", "wet meadows", and "marshes". Cranberry bogs meet the definition of "bog" in the Act. Neither the Act nor its Regulations differentiate in any manner between natural and man-made wetlands. It is extremely difficult to define "natural" vs. "man-made" wetlands. Dr. John Lukins of the Rhode Island School of Design, in conjunction with Interdisciplinary Environmental Planning, Inc. (IEP) in the late 1970's, attempted to define artificial vs. natural wetlands. He found that in many regions, the majority of wetlands have either been inadvertently created by man, or so highly impacted by man that they no longer could be considered "natural" wetlands. My personal inventory of wetlands over the past 22 years, which has included thousands of square miles of Massachusetts wetlands, has shown that there are no wetlands in Massachusetts that have not been altered by man. "Altered" means man has raised or lowered water levels, constricted stream flows and outlets, increased stream flow, changed the vegetative community, etc.

Wetlands are dynamic features of the landscape. What you see today most probably is not what was there 100 years ago, and will not be the same 100 years into the future. The primary cause of these dynamics is man's land use practices. In a rapidly growing region such as southern New England, urbanization of the uplands, even when wetlands are avoided, results in major impacts to the wetlands.

Thus, if only "natural" wetlands were regulated, few of our valuable wetlands would fall under that definition. Some special interest groups might take advantage of the term, "artificial" wetlands, resulting in the destruction of much of the Commonwealth's wetlands.

The regulations (310 CMR 10.00) presume that **all** wetlands have one or more of the eight statutory interests. The Regulations define wetlands as: Wetland resource Areas; Land Under Water Ways or Water Bodies, Banks, Bordering Vegetated Wetlands, and Land Subject to Flooding. Most cranberry bogs contain all of these wetland resource areas. The Regulation in 310 CMR 10.54 through 10.57 define these Resource Areas and the functions that they are presumed to have. Only those wetlands that are not significant for any of the eight functions are not subject to the performance standards, nor worthy of protection. The person desiring to destroy wetland resource areas must prove with credible evidence that the wetlands in question have no function, that is, are not significant for any of the eight values. This is a formidable task.

The regulations in 310 CMR 10.04 Definitions states that Significant means "plays a role". A resource area is significant to an interest identified in the Act when it plays a role in the provision or protection, as appropriate, of that interest. The Regulations do not say "play a small role"; the regulations say "plays a role". This means any role, no matter how small. None of the wetlands assessment methods presently available that rate wetlands as having low, medium, or high values can be used here, as even a "low" value adds up to be a collective large value. To prove that a wetland has any one of the eight interests, all one has to do is to prove that the wetland has the necessary "parts" or elements to give rise to that value. The basic general parts of a wetland are plants, soils, hydrology, and topography. One can view a wetland similar to an automobile. All automobiles, when they contain the necessary working parts, provide transportation, which is their primary function. Some do so with basic and cheap parts, others do so with great expense and luxury, but they all provide the function of transportation. The increased complexity of an auto only adds to its ability to provide other functions as well as transportation.

The use of wetland parts to define function and significance is relatively simple. Let's take a typical cranberry bog as an example. Although a typical cranberry bog is difficult to define as they occur in a great variety of hydrologic settings, for illustrative purposes, the following description is used:

> The bog was created from a wood swamp. The bog is a groundwater discharge wetland, having an inflowing stream, bog ditches, and an outlet stream. The bog is surrounded by dikes and the outlet is structured to include flash boards. The cranberry plants grow as a thick monoculture on sandy soils overlying organic wetlands soils.

Applying the Regulations, we find that the bog contains Land Under a Waterway (stream), Banks (ditch banks), Bordering Vegetated Wetland (cranberry bog) and Bordering Land Subject to Flooding (100-year flood plain). This bog is presumed to be significant for all statutory values except Land Containing Shellfish. If we test these presumptions with the following examples, we find the following:

Flood Control. The topography and the outlet structure create a volume of water that is stored in the wetland up to the 100-year flood stage. The bog is part of a stream system, receiving and storing inflowing waters, and metering its release downstream through the outlet. It has flood control value since it has the necessary parts and a volume can be computed. If the bog is shown on a FIRM flood plain map as A or V zone, there is no doubt it has flood control value. In the Final Decision of the David Mann Case (DEQE wetland File 57-147), the DEQE (Department of Environmental Quality and Engineering) found that the Mann bogs did contain a flood storage of an average elevation of 2.3 inches for the 100-year flood. This volume of water was required to be compensated for by the Department of Public Works (DPW) proposed detention basin.

Prevention of Pollution. The wetland contains wetland plants and soils capable of removing nutrients, heavy metals and other contaminants from inflowing water. The inflowing water is periodically spread over the plants and soils allowing interaction of water, plants, and soil to remove contaminants. Thus, since the parts occur and are allowed to interact (function), significance is proven.

Again, in the Mann case, the DEQE found since wetlands plants and soils occurred in the bogs, they were significant for prevention of pollution. The DEQE position in the Superseding Order of Conditions was that the bogs were not significant since they did not "respond to natural conditions" as do "naturally occurring" wetlands, and that pesticides and fertilizers were placed into the bog. The Final Order disagreed with this position. The following is quoted from Pages 22 and 23 of the Final Order:

> "I reach this conclusion for two related reasons. First, I note that there is no evidence suggesting that the pollution attenuation capacity of the taken bogs has in any sense been 'used up' by the role that it may have played in taking up agricultural chemicals. Second, while Mr. Hartley has remarked in this testimony that he was not aware of the Department ever requiring replication of a cranberry bog, it is also true that it has not been the Department's policy, under either the Old or the New regulations, to conclude that compensatory measures were not required because a wetland that was being destroyed was already degraded or polluted. While it would be possible to rank wetlands and treat those of 'medium' pollution prevention value as subject to less restriction than those of 'high' value, that is not the regulatory framework which has been adopted in Massachusetts. Rather, the New regulations, codifying prior Departmental policy, have made it clear that the functions performed by Bordering Vegetated Wetlands are subject to protection unless they are wholly without significance to the interest of the Act.
>
> I therefore conclude that wetlands replication must be required in this case because of the destruction of a wetland with pollution-prevention capacity. Since I have not found that any of the unique characteristics of cranberry bogs make a particular contribution to pollution prevention, and since I have concluded that the protectable recharge and flood control function of the taken bogs are adequately accounted for by other means, I find no basis for requiring that the replicated wetland be in the form of a cranberry bog.
>
> Accordingly, the Final Order of Conditions accompanying this decision requires the establishment of a nine-acre area of shallow marsh to replace the bog area being destroyed."

Other Statutory Interests. Specific bogs may exist that qualify as being significant for the other interests: Public and Private Water Supply, Storm Damage Prevention, Fisheries, and Wildlife Habitat. One only needs to gather the data to show that the wetland has the necessary parts and that these parts occur in such a manner to function for a given interest. The Mann Case shows in the example of "Prevention of Pollution" that any function, any role, no matter how small, is protectable.

In summary, cranberry bogs have functions that are significant to the statutory interest of the Act. Any alteration of a bog that does not meet 310 CMR 10.54-57 is not permitted unless **<u>all</u>** of the presumptions of significance can be overturned (likely to be impossible). In light of the Mann

Case, it is probable that all cranberry bogs are significant for "Prevention of Pollution" value. Thus, destruction of existing bogs requires replication in the form of new wetlands of equal size to the area destroyed.

This article is reprinted in its entirety from, *Massachusetts Cranberry Production-An Information Guide*. *1993. Clark, W.F. and H.A. Sandler, eds. Univ. of Mass. Ext. Publ., pp. 30-32.*

Editor's note: ENSR was formerly known as Interdisciplinary Environmental Planning (IEP), Inc., of Sandwich, MA 02563.

Wildlife Utilization on Commercial Cranberry Wetlands Systems

Steven Ellsworth and Donald Schall

Commercial cranberry bogs were created in moist lowlands and scrub/forested wetlands for over 150 years. These natural wetland systems were utilized by cranberry growers because of readily available water sources, low pH and high iron soils with a base of peat. These are the basic requirements for various cranberry cultivation practices. In the case of some of the earliest beds, the presence of natural wild cranberry vines in the vegetative community encouraged their conversion to commercial cranberry bogs. After 1986, any new cranberry bed establishment needs to be conducted in upland soils, replicating a traditional wetland cranberry bog environment as much as possible.

Despite the long history of cranberry cultivation and the number of acres under cultivation, the ecology of commercial cranberry wetland systems, and in particular, their value to wildlife is only recently being inventoried and studied. A baseline ecological assessment of three commercial cranberry wetland systems in eastern Massachusetts was conducted by Interdisciplinary Environmental Planning (IEP), Inc., in the late Spring of 1990 with the primary focus being the wildlife habitat value and wildlife utilization.

Our studies of wildlife utilization of cranberry wetland systems in eastern Massachusetts incorporated several wildlife sampling methods such as transect bird surveys, mist net bird surveys, small mammal trappings, and fish and macroinvertebrate surveys to collect information on the species composition of the wildlife communities that utilized these systems. The field inspections also generated many interesting field observations.

The field surveys documented a diversity of wildlife on cranberry wetland systems that compared favorably to that reported in the literature for certain types of natural wetland systems (Massachusetts Wildlife Survey 1997). Overall, species diversity was closely tied to the number and variety of habitats found within the cranberry wetland system. During the field investigations, 11 species of mammals, 65 species of birds, 6 species of reptiles, 6 species of amphibians, and 11 species of fish were recorded. Species common to New England were well represented, but several of the region's wildlife species listed as "threatened" or "endangered" by the Commonwealth were also observed.

Fig. 1. Osprey building a nest atop a pole erected next to a cranberry bog. Photo courtesy J. Mason.

From an agricultural viewpoint, cranberry beds are monocultures of the large-fruited cranberry (*Vaccinium macrocarpon* Ait). As such, the diversity of plants life forms (e.g., herbs, shrubs, trees), which provide vertical structural diversity in a plant community, is limited on cranberry beds. Increased structural diversity correlates closely with higher wildlife diversity and utilization. Mammalian species found to utilize active cranberry beds in the study areas include white-tailed deer, red fox, and meadow voles. Trapping data documented inhabitation of the cranberry beds by meadow voles. However, trapping success was greater in adjacent disturbed areas and adjacent wetlands. Active beds were also utilized by waterfowl (ducks and geese) and raptors (hawks and owls). Shorebirds and herons fed along the banks of the irrigation ditches, while swallows and flycatchers hunted for insects above the vines.

Although the cranberry beds themselves appear to be utilized by a relatively low number of species, adjacent managed habitats such as reservoirs, drainage channels, irrigation ditches, low brush communities, and disturbed areas provide breeding areas, cover habitats, and feeding sites for many additional species. The water supply systems and land use management practices are an integral part of the operation of a cranberry bog, and they contribute to the overall diversity of the wetland system.

Construction and maintenance of cranberry wetland systems creates some excellent wildlife habitats such as reservoirs, ponds, and transition zones between adjacent uplands and undisturbed wetlands. The reservoirs often provide habitat for the more aquatic avian species such as double-breasted cormorant, great blue heron, green-backed heron, black-crowned night heron, mute swan, Canada goose, mallard, black duck, wood chuck, osprey, and belted kingfisher, where none previously existed. Permanent water bodies are utilized by various mammals, such as white-tailed deer, raccoons, and muskrats, as well as providing excellent habitat for turtles, frogs, and fish. The reservoir edge was particularly attractive as habitat for a number of avian species. Some of the more commonly observed species in this reservoir edge habitat were Eastern kingbird, gray catbird, yellow warbler, common yellowthroat, red-winged blackbird, and common grackle.

Herbaceous and scrub/shrub areas adjacent to the cranberry beds, in general, had high productivity (abundance). Cottontail rabbit, woodchuck, white-footed mouse, and meadow vole are mammal species that commonly used these habitats. White-tailed deer and red fox also used them. Red-shouldered and red-tailed hawks were seen foraging over these areas on a number of occasions. Bobwhite quail were also frequently observed. Among the more common song birds observed in these habitats were gray catbird, Northern mockingbird, brown thrasher, blue-winged and prairie warblers, Northern cardinals, rufous-sided towhees, and song sparrows. Snapping turtles and painted turtles, which must leave aquatic habitats to deposit their eggs in open, sandy areas were observed depositing eggs in sandy road banks and sand piles in the study areas. Open sand banks, which are maintained as part of the cranberry operation, create habitat for nesting turtles.

The diversity and abundance of wildlife species utilizing both wetland and upland habitats in the study areas were, in all probability, increased by their proximity to the reservoirs, cranberry beds, and disturbed areas of the cranberry operations. This <u>edge effect</u> contributed to ecological diversity. The value of habitats, particularly forested habitats, was improved for most wildlife species when they were adjacent to open areas.

Although wildlife diversity is relatively low in the cranberry beds, diversity within the overall system is high, when compensation from the other habitats is taken into consideration. The study was conducted during a brief 16-day period in May-June, 1990. If a longer study were conducted, the number of species that actually used these wetland systems over the course of an entire year would be increased significantly.

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Editor's note: The first paragraph was edited to note the difference between traditional wetlands bogs and new production planted in upland soils. ENSR was formerly known as Interdisciplinary Environmental Planning (IEP), Inc., of Sandwich, MA 02563.

Directory of Agencies

CAPE COD CRANBERRY GROWERS' ASSOCIATION www.cranberries.org	**(508) 759-1041**
CRANBERRY MARKETING COMMITTEE www.uscranberries.com	**(508) 291-1510**
CRANBERRY INSTITUTE www.cranberryinstitute.org	**(508) 759-6855**
EXECUTIVE OFFICE OF ENERGY AND ENVIRONMENTAL AFFAIRS	
Environmental issues	**(617) 626-1554**
Coastal zone management www.mass.gov/czm	**(617) 626-1200**
Conservation and Recreation www.mass.gov/dcr	**(617) 626-1250**
MA DEPARTMENT OF ENVIRONMENTAL PROTECTION (DEP) www.mass.gov/dep	**(508) 946-2700** **(617) 292-5500**
Questions concerning the Water Management Act	**(508) 946-2816**
Reporting pesticide spills	**(888) 304-1133**
Questions on hazardous material management or waste disposal	**(508) 946-2817**
Questions regarding wetlands laws in Massachusetts	**(617) 292-5695** **(508) 946-2800**
MA DEPARTMENT OF AGRICULTURAL RESOURCES (MDAR) www.mass.gov/agr/ **FAX:**	**(617) 626-1700** **(617) 626-1850**
Pesticide licenses and certification	**(617) 626-1776**
Water quality	**(617) 626-1773**
NATIONAL PESTICIDE TELECOMMUNICATIONS NETWORK www.npic.orst.edu *(Questions concerning health effects of pesticides)*	**(800) 858-7378**
RESOURCE CONSERVATION AND DEVELOPMENT *(Community assistance, land water and energy conservation)* www.pilgrimrcd.org	**(508) 295-1317**
SOUTHEASTERN MASSACHUSETTS AGRICULTURAL PARTNERSHIP (SEMAP) *(Marketing, farm transfer assistance)* www.umassd.edu/semap; www.semaponline.org	**(508) 295-2212 x50**

SOIL AND WATER CONSERVATION DISTRICTS
(Conservation farm planning, conservation plantings)

Barnstable County (Cape Cod Conservation District)	www.capecodcd.org	**(508) 771-8757**
Bristol County	www.bristolcd.org	**(508) 669-6621**
Plymouth County	www.plymouth.ma.nacdnet.org	**(508) 295-5495**
Norfolk County	www.walpole.ma.us/enorfolkcountycon.htm	**(508) 668-0995**

UMASS CRANBERRY STATION **(508) 295-2212**
www.umass.edu/cranberry

UMASS EXTENSION PESTICIDE EDUCATION OFFICE **(413) 545-1044**
www.umass.edu/pested
(Questions concerning safety and pesticide training)

U.S. ARMY CORPS OF ENGINEERS, New England District **(800) 362-4367**
www.nae.usace.army.mil
(Questions concerning wetlands permits)

USDA NATURAL RESOURCES CONSERVATION SERVICE
(Technical assistance; conservation plans and designs)

Barnstable County	www.ma.nrcs.usda.gov	**(508) 771-6476**
Plymouth County	www.ma.nrcs.usda.gov	**(508) 295-5151**

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