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MINERAL NUTRITION: WHAT ARE THE GUIDING PRINCIPLES?

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As early scientists developed the ability to analyze plants, they found that most of the plant was composed of water and organic compounds, and that in most plants the mineral fraction accounted for less than 10% of the dry mass. At that time, the presence of an element in the plant was accepted as proof that the element was essential to the plant. However, it was found that plants often take up and incorporate any element present in the growing medium, sometimes accumulating an element to toxic levels. By the turn of the century, water and sand cultures were being used to study the mineral needs of plants under controlled conditions. In 1939, Arnon and Stout published the criteria for essentiality of a nutrient element:

- The element must be present in the plant for normal growth and completion of the life cycle.
- The element is required specifically and cannot be replaced by another element.
- The element must be directly involved in growth or metabolism.

By the turn of the century the major or macronutrients necessary for plant growth had been identified. In addition to carbon (C), hydrogen (H), and oxygen (O), nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), and iron (Fe) had been shown to be essential. In the first half of the 1900s, the minor or micronutrients manganese (Mn), copper (Cu), zinc (Zn), molybdenum (Mo), boron (B), and chlorine (Cl) were identified. The terms macro- and micronutrients are used to distinguish elements needed in relatively large amounts from those required in only tiny amounts. In no way do these designations mean that any of these elements is less 'essential' than any other.

Once it was known that certain mineral elements were needed for plant growth, plant response to the addition of an element that had been lacking was thought to follow a certain pattern of diminishing returns. As one added the deficient element, plant response would be great and then as the deficiency was overcome, response to additional provision would be less and less as the growth rate approached its maximum. However, what we find is that the pattern is more likely to be one with an 'inversion point', where growth increases until the element is present in sufficient amounts but declines again when supply of the element becomes excessive (the toxic range). Put simply, if some is good, more is not necessarily better.

We can study the response of cranberry plants to the absence of each mineral element and what happens as we reintroduce it into the medium. But in a field situation, we are more interested in finding out what factor(s) is limiting growth and production. In addition to the mineral elements, other factors may be limiting to production or may interact with mineral nutrition. We can think of all the essential mineral and other factors as different length staves in a barrel. The shortest stave will determine how much the barrel can hold. If that stave is lengthened (the element is added), the barrel will hold more (plant growth and productivity will improve) until a new limiting factor or short stave is reached. In cranberry production, the limiting factor may not always be nutritional. Mineral elements interact with one another, with management, and with cultivar.

Interactions among the responses to the additions of mineral elements may be due to interaction in the soil or during uptake, or may be due to the limiting element rule. For example, if N was lacking, the plants might not respond to the addition of K but if N is added as well, then there might be a K rate response. Often management factors are limiting plant productivity and response to nutrient addition. For example, if a cranberry planting was suffering from upright dieback disease, adding fertilizer might not increase growth and yield. Conversely, in a nutrient poor bed, recovery from tipworm damage might be limited. Response to nutrition also varies by cultivar. An example from research in Oregon by Hart, Poole, and Strik is shown in the table below.

Yield (bbl/A) at various N rates, third year of treatment. Values followed by the same letter are statistically similar.

Cultivar	0 lb/A N	20 lb/A N	40 lb/A N	60 lb/A N
Crowley	85	110 b	152 a	141 a
Stevens	115	201 c	314 b	485 a

Yield response in 'Crowley' was maximized at 40 lb/A nitrogen while 'Stevens' yield continued to increase at the 60 lb/A rate.

Roles of the mineral elements.

The essential elements all have specific roles in plant structure and metabolism. We can group elements according to their functions in the plant:

1. Structural elements make up the physical body of the plants. In addition to C, H, and O that are components of all organic matter, mineral elements play structural roles.
    - N and S are components of structural and enzymatic proteins.
    - N and P are structural components of DNA.
    - P is part of the phospholipids that make up the cell membranes.
    - Mg forms the center of chlorophyll molecules.
    - Cu and Fe are part of the structure of important energy transferring proteins.
    - Ca strengthens cell walls.
2. Mineral elements are involved in enzyme functions.
    - K, Mg, and Mn are enzyme activators, acting as catalysts.
    - Fe, Cu, Zn, and Mo are part of the active structural part of enzyme cofactors, molecules attached to enzymes that facilitate reactions.
3. Mineral elements are critical in photosynthesis
    - Mn and Cl are involved in splitting water to release oxygen in light reactions.
    - Fe is involved in energy transfer and in chloroplast development.
    - Mg is part of the chlorophyll molecule.
    - K is involved in cross-membrane energy harvesting reactions.

In addition to these general roles, some elements play other specific roles in the plant:

1. Nitrogen

As a critical constituent of protein, nitrogen is a controlling element in plant nutrition. The production of chlorophyll, the predominant functional protein in plants, is regulated in part by the availability of N.

2. Phosphorus

Phosphorus plays many roles in plant metabolism. P is involved in energy transfer as part of the ATP molecule. P plays a regulatory role in starch synthesis, active transport of materials across membranes, root growth and function, and hormonal balance. This last is critical to floral induction.

3. Potassium

Potassium is the only major element with no structural role in the plant. K is involved in sugar transport in the phloem tissue (transport among plant organs). K also has a major role in preserving plant turgor (water relations) and in osmoregulation (regulating water movement across plant membranes). This last role accounts for the involvement of K in opening and closing of stomata and extension growth. K is also involved in cold tolerance of plants.

4. Calcium

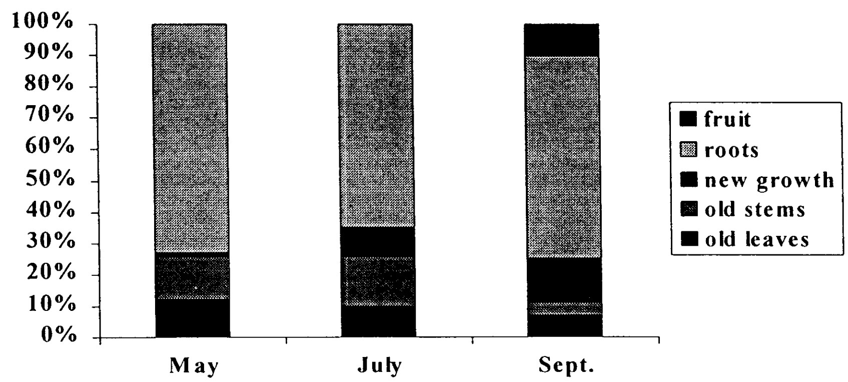
Calcium is involved in determining membrane structural integrity that determines the selectivity of membranes in taking in or excluding materials. This is the basis for the plant's ability to actively take up needed minerals and exclude those that might be harmful.

5. Boron

Boron is essential for pollen tube growth, if B is deficient, pollination may occur but fertilization and fruit set will not be successful. B is also involved in cell elongation and must be present in sufficient amounts for bud and flower retention on the plant.

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, fruit formation and filling, initiation of floral buds, 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. Patterns of biomass production in cranberries are shown in the figure below (DeMoranville, 1992).



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. Birrenkott and Stang (1990) showed that cranberry fruit on an upright are in competition for resources. Patten and Wang (1994) showed that when numbers of berries on an upright was high, buds produced tended to be small. 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.

Ways to evaluate plant nutrient status.

Tissue testing is used to determine the content of the various nutrients in the plant. This can be informative for crops such as cranberry where standard ranges have been established. Soil testing can also be useful in determining what is available for the plant to acquire from the soil. However, one of the best ways to determine nutritional status is to look at the plant. Stunting or off colors in the foliage may be symptoms of mineral deficiency.

Short or pale uprights in cranberry are often an indication that N is lacking. Because leaf greenness (chlorophyll content) is often related to N status, this parameter can be measured and calibrated to nitrogen status. Minolta markets the SPAD meter, a device that measures leaf greenness in dimensionless units (SPADs) that correlate with chlorophyll content. Tentative ranges for cranberry have been established based on the positive correlation between tissue %N and SPAD reading in an extensive cranberry survey. This allows the use of the SPAD meter to substitute for a mid-season tissue test. This may be useful as tissue test values are only stable and subject to useful interpretation late in the season and thus, mainly serve as a 'report card' for this seasons management and for planning for next season.

Where and how do plants get the nutrients they need?

For the most part, plants take their nutrients from the soil via the roots. This is an active process (requiring the expenditure of energy), allowing the plants to accumulate the nutrients they need. In this way, nutrient concentration in the plant may be greater than that in the soil. In many plants, this uptake is mediated by *mycorrhizae*, fungal organisms that live within the roots. Cranberry plants from associations with Ericaceous mycorrhizae that differ from the more common types in that they are more likely to mediate the uptake of nitrogen rather that phosphorus.

The ability of the plant to take the nutrients it needs from the soil depends on the status of the soil and on the status of the plant. Soil factors that are important include moisture, aeration, pH, temperature, and mineral content. In addition, minerals in the soil become available due to the action of soil microorganisms (mineralization). Important plant factors include root mass, root health, and energy (carbohydrate) supply in the roots for active transport.

Nitrogen is released from soil organic matter through the action of bacteria in a process known as mineralization. In a recent study funded by the MA Dept. of Food and Agriculture, DeMoranville and Davenport showed that nitrogen release in cranberry soils increased when soil temperature reached 75°F. In the same study, we found that soil pH was important in determining the form of the nitrogen after it was released by mineralization. The initial product of mineralization is ammonium, a form preferred by cranberry plants. At low pH, the N remained in this form because the bacteria that convert ammonium to nitrate are suppressed at low pH. This confirms the recent study by T. Roper and A. Krueger. Study results are compiled in the table below.

Effect of temperature on total N release.

Soil temperature	Total N (ppm)
55°F	77.77 b
60°F	65.60 b
65°F	61.55 b
70°F	77.94 b
75°F	183.34 a

Effect of pH on conversion to nitrate

Soil pH	Nitrate N (ppm)
High (6.0)	50.22 a
Medium (4.5)	6.45 b
Low (3.0)	8.51 b

Soil pH also has effects on the availability of nutrients in the soil and on the ability of most plants to take up those nutrients. This is due to the change in chemical state of the elements as the soil pH changes. As the chemical state changes, the interaction between the mineral and soil particles changes so that the element becomes more tightly of loosely held in the soil. In fact, at pH 4, all nutrients except the minor element metals are quite tightly bound in the soil (poorly available). Plants often exhibit a preference regarding which chemical form of an element is taken up as well. For example, at pH below 4, nitrate may be taken up preferentially compared to ammonium and K uptake may be depressed. This is due to the need for the roots to exchange acid (H^+) equivalents for the cations (K, ammonium). As soil pH drops, H^+ builds up in the soil and moving more out of the plant becomes more difficult as the gradient increases. Because cranberries evolved in acid soils, they are adapted to life in a nutrient poor environment. To a large extent, pH effects that would be negative for other plants are not a problem for cranberries. This may be an advantage in suppressing pH sensitive weeds.

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. Hydric status of the soil also determines availability of iron, manganese, and phosphorus that is bound to or released from iron compounds. In flooded soils, availability of these elements is high enough to present a danger of toxicity (especially of Fe and Mn) in species not adapted to flooded conditions. In fact, the ability of cranberries to tolerate high Fe and Mn is indicative of their status as wetland species. The change in P availability during flooding cycles on cranberry soils was shown in laboratory studies (Davenport et al., 1997). In peat and layered, sanded cranberry soils P is released from the soil during flooding. However, as the soil dries, P once again becomes bound on the soil. Moisture availability in the soil may also affect the ability of the plant to take up elements indirectly. If moisture is lacking, the movement of water up through the plant and out through the leaves (transpiration) will be limited and so will the uptake of elements that move in that water stream.

Plants have the ability to exert control over nutrient availability and uptake by releasing chemical compounds into the rhizosphere. Some compounds release needed elements from their attachment to the soil. Other compounds are released onto the root surface and bind elements that are present in excessive levels so that they are prevented from entering the roots. X-ray microanalysis of cranberry roots (Rosen et al., 1990) showed particles on the root surface containing Fe and Mn as well as P bound to the Fe. Both Fe and Mn are present at high levels in acid cranberry soils. While levels in the plants are higher than those in dryland species, they are not extreme, perhaps due to sequestering at the root surface.

Root anatomy may be affected by pH in the rhizosphere. Cranberries grown in solution culture had more branch roots at pH 6.5 than at 4.5 (Finn et al., 1990). This may have an effect on nutrient uptake.

In commercial production systems, some of the nutrition requirement is supplied in fertilizers added to the soil or applied to the foliage. Soil applied fertilizer dissolves in the soil water and is bound to the soil, fixed on the soil, or lost to leaching below the root zone. Bound and fixed fertilizer elements behave as native soil elements as discussed above. Foliar applied fertilizer generally cannot replace soil fertility. However, it can be useful during periods when soil uptake is limited and for elements that become tightly bound in the soil. Foliar uptake of nutrients is limited by the thickness of the leaf cuticle. In cranberry, the cuticle is less thick on the lower surface and some uptake can occur via that route. In addition, urea has been shown to be able to pass through the cuticle. Foliar uptake may also be limited by the amount of nutrient that can be delivered in the spray, washoff by rain, and length of the wet period after application. Uptake generally requires moisture on the leaf surface.

Seasonal nutrient carryover and 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 MA 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. Smith (1994) showed that one third of ^{15}N taken into the plant from soil application 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 seasons new leaves and fruit. This illustrates the ability of cranberry plants to both store nutrients and to remobilize them for growth and fruiting.

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 we decide what to supply to cranberries in the form of fertilizer?

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. SPAD meters may be used to predict if N is sufficient. However, practiced observation of leaf greenness is just as good.
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 three 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.
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.

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THE NEXT ERA OF LAND REMOTE SENSING FROM SPACE: IMPLICATIONS FOR CRANBERRY GROWERS

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Background

Several interrelated factors are influencing the form and significance of "the next era" of land-oriented satellite remote sensing systems, all of which have also impacted on agricultural management in the US. Among these are:

- continued transition toward an information-based society in general;
- recognition of the interdependence between environmental quality and sustainable economic development; and
- the continued maturation and application of kindred geospatial technologies such as geographic information systems (GIS) and the Global Positioning System (GPS).

As a consequence of the above, spatial technologies are playing an increasingly central role in land and natural resource management activities, the conduct of business and government, and the advancement of scientific knowledge about the earth as a system. As applied to agriculture, widespread application is presently practiced or is being considered in crop acreage estimates, crop disease detection, weed and insect infestation, and off-farm effects on surrounding lands (Robert 1997.)

With the coming of the next generation of satellites, and vast improvements in computational infrastructure at every level, remote sensing promises a new set of innovative tools for small and large farm operations alike. With those promises, however, come important caveats which must be considered by all prospective users. The purpose of this paper is to give an optimistic sense of the "next era", balanced with technical and economic trade-offs that all potential remote sensing data users, including those in agriculture, should consider before committing to remote sensing technologies.

Remote Sensing is a Technology That Is Large, Diverse, and Here to Stay

We are entering an era of tremendous growth in the development and application of geospatial technologies in general, and satellite remote sensing in particular. With the relaxation of military intelligence constraints in the civil marketplace, at least four US

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companies or consortia are either operating, or planning to operate, advanced capability imaging systems, as are international private sector and government consortia. Value added data and service providers, including those specifically designed for the agricultural industry, are becoming more numerous as the latent commercial demand for their products continue to be realized. The specifications of the four major U.S. high resolution commercial systems launched or planned for launch by the year 2000, summarized on Table 1, gives an indication of the magnitude of investment and technology development in this area.

Table 1. Preliminary Specifications for U.S. Commercial Satellite Remote Sensing Systems Planned for Launch by 2000

Source	*Satellite Name*	*Expected Launch*	*Spectral Bands*	*Wavelength (μm)*	*Resolution at Nadir (m)*	*Swath Width at Nadir (km)*	*Revisit Time (days)*
EarthWatch	**EarlyBird**	**launched**	G	.490-.600	15	15	2-5
		12-24-97	R	.615-.670	15	15	
			NIR	.790-.875	15	15	
			PAN	.445-.650	3	3	
	QuickBird	1998	B	.450-.520	3.28	22	1-4
			G	.520-.600	3.28	22	
			R	.630-.690	3.28	22	
			NIR	.760-.900	3.28	22	
			PAN	.450-.900	0.82	22	
ORBIMAGE	**OrbView-3**	1998	B	.450-.520	4	8	2-3
			G	.520-.600	4	8	
			R	.630-.690	4	8	
			NIR	.760-.900	4	8	
			PAN	.450-.900	1	8	
			PAN	.450-.900	2	8	
			HYPER*	.450 - 2.5, and 3.0-5.0	8	5	
Resource21	**Resource21**	2000	B	.450-.520	10	205	<1
			G	.520-.600	10	205	
			R	.630-.690	10	205	
			NIR	.775-.900	10	205	
			MIR	1.55-1.65	20	205	
			MIR	1.23-1.53	100	205	
Space Imaging/ EOSAT	**IKONOS**	1998	B	.450-.520	4	11	9-11**
			G	.520-.600	4	11	
			R	.630-.690	4	11	
			NIR	.760-.900	4	11	
			PAN	.450-.900	1	11	

*280 narrow band channels.
**Revisit time substantially less with tilt >10° .

Primary sources upon which this table is based include the current homepages for the various firms. The information contained above is preliminary and subject to substantial change.

Additionally, some 42 other satellites have been placed in operation since 1990 or are scheduled to be launched by 2004 (ASPRS 1996). Several include non-U.S. systems (e.g., SPOT and the Indian IRS system) with spatial resolution of 10 meters or less. Other optical systems follow in the footsteps of the Landsat system (e.g., wide swath widths, intermediate to low resolution, and relatively broad spectral coverage). A number of the satellites will feature hyperspectral capacity (numerous narrow bandwidths, further discussed below), and still others will feature radar sensor systems. An up-to-date summary and links to additional information on all of these satellite systems is maintained on the ERSC homepage (http://www.ersc.wisc.edu/ersc/resources.html).

Challenges and Considerations for Integrating Remote Sensing into Agricultural Management

The challenge for commercial remote sensing data providers, the agricultural community, university researchers, and others, is to consider what will be the technically and economically appropriate role for remote sensing in the near future. As with any tool available to the agricultural community, there needs to be careful consideration as to whether the investment in same will have the level of expected economic return. Some of the most important considerations, discussed below, include the following: **spatial resolution; swath width; spectral resolution; temporal considerations; data delivery considerations; and finally ultimate usefulness to agricultural management.**

Spatial Resolution - Although the present spatial resolution (e.g., SPOT 10 meter panchromatic) has been satisfactory for the evaluation of many past agricultural operations, precision farming may require a 1-5 meter spatial resolution. (Robert 1997). Of the satellites presented above, those proposed by EarthWatch, Orbital Sciences Corporation, and Space Imaging/EOSAT will feature panchromatic imagery available at 1-3 meters. A major consideration will be that of data volume. For example, at 1m resolution, a 40 acre field will encompass approximately 162,000 picture elements (pixels); a single acre comprises approximately 4050 pixels! This data volume may necessitate 10's of gigabytes of storage capacity for a medium sized farm operation.

Swath Width - With the exception of the Resource 21 sensor (swath width = 205 km), the swath width of these systems is relatively narrow (3-22 km). Many farming operations or cooperatives, with wide-spread operations across multiple townships or counties, may consider the extent of coverage a more important consideration than spatial resolution for some applications.

Spectral Resolution - The recent ORBIMAGE announcement that the OrbView-3 will carry a 280 band hyperspectral sensor offers a new range of challenges and opportunities. Combinations of these narrow bands may allow the development of anomaly detection systems that would detect even very early stages of plant stress or pest infestation. The trade-off again will be data volume (280 data observations per 8 meter pixel).

Temporal Considerations - The stated revisit time of all four satellite systems is less than a week[2]. Chris Johannsen of Purdue University notes that this is the most important

[2] Note the caveat for Space Imaging EOSAT and the revisit time of 9-11 days, with substantially less with a tilt of > 10°.

aspect of remote sensing for agricultural purposes as the frequency of the image coverage is paramount to fast and effective crop management response. Confounding the temporal consideration is the impact of weather (cloud cover) on the ability to obtain usable satellite data at the requisite frequency for agriculture. In anticipation of weather-related complications to satellite data collection, many satellite data providers and users are planning to complement their satellite data acquisition with airborne counterparts and substantial ground-based observations. *Determining the optimal mix of space, airborne, and ground-based observations in the context of a variety of agricultural applications in near-real time will be a great challenge.*

Data Delivery Considerations - A number of the satellite data providers stress their commitment to deliver "products" or "information", and not raw "data". Raw data is often minimally corrected for geometric and atmospheric distortions, and needs a certain level of processing to be useful to the end user. Data processing has a price, however, both in terms of final cost and time period between the collection of the data by the satellite and its delivery to the data customer.

Usefulness to Agricultural Management - Past attempts to integrate remote sensing techniques in agricultural management have largely failed due in part to the lack of infrastructure in farming regions to acquire, process, and interpret the data, and then make appropriate agronomic recommendations (Robert 1997). It is critical that farmers and farm cooperatives communicate the usefulness of such information to the data providers and crop consultants, as well as to university researchers and agricultural extension agents. Such information sharing will be critical to advance the state of the art.

Resources at UW-Madison and Beyond

A logical first step in considering geospatial information technologies for those involved in agriculture in Wisconsin is a review of some of the university, state and federal resources available on the internet (Table 2) . Many are interactive with sample images and applications, and most provide links to additional information.

Table 2. University, State, and Federal Resources for Remote Sensing

Name	Description	WWW Address
Environmental Remote Sensing Center	UW-Madison facility for interdisciplinary research on the application of remote sensing to environmental monitoring and resource management.	http://www.ersc.wisc.edu/ersc/ (Web site contains documents on research activities and programs, publications, staff, faculty and students profiles as well as links to other web resources devoted to remote sensing)
NASA Visiting Investigator Program	NASA-sponsored program designed to provide U.S. companies a low cost (no exchange of funds) opportunity to examine the application of current and future remote sensing technologies in their businesses	http://www.ersc.wisc.edu/ersc/Projects/VIP/vip.html (Description of the program and current and future VIP projects)
Wisconsin Initiative for Statewide Cooperation on Land Cover Analysis and Data (WISCLAND)	Statewide initiative designed to develop and sustain a long-term partnership among organizations to collect, analyze and distribute statewide land cover and natural resource information	http://www.ersc.wisc.edu/ersc/Projects/WISCLAND/wiscland.html (Project description and links to related resources)

Timely Satellite Data for Agricultural Management (TiSDat)	NASA-sponsored program to facilitate access to satellite data for potential users. Applications include: determining potato irrigation needs and cranberry frost prediction	http://bob.soils.wisc.edu/nasacan.html (Program description and resources)
USGS Global Land Information System (GLIS)	An interactive computer system developed by the U.S. geological Survey (USGS) to assist in finding data about the Earth's resources, including the archive of Landsat Thematic Mapper	http://edcwww.cr.usgs.gov/webglis/
EarthWatch Incorporated	Provider of satellite data, including high spatial resolution commercial imagery.	http://www.digitalglobe.com

Conclusions

Farmers and agribusinesses interested in remote sensing data will be forced to face numerous trade-offs in resolution, revisit period, swath width, and spectral range. Considerations are also numerous relative to the overall accessibility, reliability, timeliness, and mode of delivery of the data to users. Furthermore, the technical integrity of the data (spectral, spatial, and radiometric) and the range of image product options will also be important. All of the above furthermore need to be considered within the cost structure and contractual agreement for the data product.

The issues presented here are but a small portion of the overall international picture of private and governmental systems that are either available or are planned for launch soon. Organizations such as the American Society for Photogrammetry and Remote Sensing (ASPRS), the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Agency (NOAA), and the US Geological Service (USGS), as well as leading land-grant universities are on the forefront of research and applications in remote sensing as applied to agriculture and natural resources. Those interested in learning more about remote sensing in general and satellite remote sensing systems in particular are encouraged to consult the various texts or references available on the subject (e.g., Lillesand and Kiefer, 1994) and/or the numerous relevant publications available through ASPRS.

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The Effect of the Food Quality Protection Act on Cranberry Production

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What is the FQPA?

The Food Quality Protection Act of 1996 (FQPA) was signed into law by President Clinton on August 3, 1997 after passing through both houses of Congress without a dissenting vote. It amends the two major pesticide laws: The Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) and the Federal Food, Drug and Cosmetic Act (FFDCA).

Under FIFRA pesticides are labeled for use on specific crops following specific rate, timing and application guidelines (the label's the law) to prevent unreasonable negative human health and environmental effects. The FFDCA establishes tolerances (maximum permissibly legal residues) of pesticide residues in foods.

The FQPA includes rules that dramatically change how levels of pesticide residues in foods are set and includes special provisions to ensure a safe food supply for infants and children. In addition, the FQPA provides that pesticide exposure from sources other than foods, including structural pest control, lawn care and drinking water, must be considered when setting food pesticide tolerances.

The EPA, whose mandate is to protect public health and safeguard and improve the natural environment, must review all pesticides (approximately 9,300 tolerances) under the new FQPA guidelines by 2006. They will begin by reviewing the products of most concern including organophosphate and carbamate insecticides and probable carcinogens.

FQPA provisions in a nutshell

- Review on all pesticide tolerances must be completed by August 2006
    - 33 percent of all existing tolerances must be reviewed by August 1999
    - 66 percent of all existing tolerances must be reviewed by August 2002
- The riskiest pesticides must be assessed first
    - Organophosphate insecticides (39 chemicals; 1,800 tolerances)
    - Carbamate insecticides (12 pesticides; 670 tolerances)
    - Probable (B-2) carcinogens (688 tolerances)
- When reassessing tolerances EPA must consider:
    - the aggregate exposure from a pesticide
    - the cumulative effects from other pesticides with a common mode of activity
    - whether there is an increased susceptibility from exposure to the pesticide to infants and children
    - whether the pesticide produces an effect in humans similar to a naturally-occurring estrogen hormone
- EPA is mandated to provide pesticide-related pesticide information for supermarkets (supermarkets, however, are not required to display these)
- Establishment of a USDA-EPA Minor Use Office to deal specifically with the issues minor crops (e.g., cranberry) face through FQPA implementation
- EPA is encouraging the registration of EPA-determined "reduced-risk" pesticides

Cranberry growers will be effected by FQPA

FQPA has just begun to be implemented at this writing (1/98) and the net impact on the cranberry commodity is clouded by a great deal of *uncertainty*. However, the law clearly changes the rules about pesticide use in the US and those rules will, in our opinion, alter the pesticides growers have available to control pests.

The bottom line is that cranberry growers are heavily dependent on pesticides the EPA and the FQPA are most concerned about. These include the following products:

Pesticides on the FQPA "hit" list

Organophosphate and carbamate insecticides

Chlorpyriphos (Lorsban), acephate (Orthene), diazinon, carbaryl (Sevin), and azinphos-methyl (Guthion)

Probable carcinogens

Maneb, mancozeb and chlorothalonil (Bravo)

If organophosphate and carbamate insecticides are treated as "one pesticide" under the *common mode of activity* provision cranberry growers are at great risk of losing one or all of these key products. Based on what we have heard about the status of EPA's decision-making process, this is a real possibility.

It is clear that our most important pesticides are at great risk for loss of registration. Minor crops, such as cranberry, are more vulnerable than higher acreage crops (e.g., potatoes, citrus, apple, grapes, etc.) because chemical companies will protect registrations based on market profitability. Although an important niche market for some companies, cranberry does not compare to the acreages offered by other horticultural and agronomic crops.

CI and cranberry commodity progress towards solutions

In 1997, the majority of the Cranberry Institute's $170,000 research budget was spent on identification, evaluation and registration of alternative pesticides or biological control alternatives. Many of the chemical pesticides tested have unique modes of action and several are "reduced-risk" pesticides. Several products are showing very good promise in terms of efficacy and crop safety.

Approximately 30 different products were tested in 1997 by the following researchers (with full or part CI funding):

- *Insecticides*
  - Dr. Sridhar Polavarapu; Rutgers,
  - Dr. Lynell Tanigoshi and Dr. Steven Booth, WSU
  - Dr. Anne Averill, UMass
  - Dr. Don Weber, Oceanspray Cranberries, Inc.

Some of these pesticides will be labeled for commercial use in cranberry as early as 1999 while others are just beginning their 4 to 5 year journey. The Cranberry Institute may be sponsoring part of the IR-4 process (through 1998 research dollars) during 1998 to reduce the time it takes to get key products labeled.

In conclusion

The FQPA, which was passed unanimously by Congress in 1996, is likely to cause the cranberry commodity to lose several key pesticides as early as 1999. New pesticide evaluation, sponsored by CI and the commodity at large, is finding replacements for these older at-risk pesticides. There are currently 12 pesticides in the "IR-4 pipeline" that will be registered in one to 5 years. The commodity must continue to work with EPA, IR-4, and chemical companies to fashion a practical and economically viable bridge between the loss of current key pesticides (e.g., Lorsban, Guthion, etc.) and the registration of new generation reduced-risk pesticides. Biological controls, with implementation through IPM, will become an increasingly important tool in pest management.

- *Herbicides*
    * Dr. Herb Hopen, UW-Madison
    * Dr. Brad Majek, Rutgers
    * Susan Butkewich, Oceanspray Cranberries, Inc.
    * Dr. Kim Patten, WSU
    * Dr. Tom Bewick, UMass

- *Fungicides*
    * Dr. Jonathan Smith, Northland Cranberries, Inc.
    * Dr. Patty McManus, UW-Madison
    * Dr. Peter Bristow, WSU
    * Dr. Peter Oudemans, Rutgers'
    * Dr. Frank Caruso, UMass

- *Researchers investigating biological-based insect controls (with full or partial CI funding)*
    * Dr. Sheila Fitpatrick, Ag Canada (BHFW mating disruption)
    * Dr. Sridhar Polavarapu, Rutgers (Sparganothis mating disruption)
    * Dr. Steven Booth, WSU (Insect-pathogenic fungus *Metarhizium* on cranberry girdler)
    * Dr. Deborah Henderson, E.S. Cropconsult, Ltd., Vancouver, BC (*Trichogramma* parasitism on BHFW)
    * Drs. Ralph Berry & Jie Liu, OSU (Indigenous insect-pathogenic nematodes on cranberry girdler)

Organizations other than CI are also contributing money and or personnel towards the search for alternative methods of pest control, including biological controls and reduced-risk pesticides. These include, but are not limited to, the Wisconsin Cranberry Board, Oceanspray Cranberries, Inc., New Jersey Blueberry and Cranberry Research Council, Cape Cod Cranberry Growers Association, Massachusetts Cranberry Research Foundation, Oregon Cranberry Growers Association, Pacific Coast Cranberry Research Foundation, Washington State Cranberry Commission, Washington State Commission on Pesticide Registration and British Columbia Cranberry Growers Association.

New pesticide identification, evaluation and registration is the number one priority for CI research dollars in 1998.

<u>IR-4 cranberry projects going forward</u>

In addition to early-stage identification and evaluation of pesticides, the cranberry commodity has pesticides further along in the registration "pipeline" through the Office of IR-4. IR-4 is the vehicle for registration of pesticides on minor crops.

These projects include:

- four herbicide projects (for control of dodder, grasses, sedges, asters, wild bean, beggarticks)
- five insecticide projects (grubs, fireworms, cutworms, fruitworms, tipworm, mites, other leps)
- three fungicide projects (phytophthera, cottonball, fruit rots)

CRANBERRY PEST MANAGEMENT IN THE FUTURE

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The Food Quality Protection Act of 1996 (FQPA) is likely to have a profound impact on cranberry pest management. The organophosphate and carbamate insecticides will be amongst the first groups of pesticides to come under rigorous review. The great majority of synthetic insecticides used on cranberry belong to these two chemical groups (Table 1), and their usage patterns will undoubtedly change once FQPA becomes fully implemented, supposedly by 2006. The changes may be substantial, to the point that some products in common use today may not be available at all in the future; usage patterns will certainly change.

Table 1. Insecticide groups commonly used in cranberry insect control (trade names).

Organophosphate Group	Carbamate Group
Diazinon	Sevin
Guthion	
Lorsban	
Orthene	

Partly because of FQPA, we may be entering the period of greatest change in insect control on horticultural crops since the golden age of broad spectrum synthetic organic insecticides starting in the late 1940s. But FQPA is not the only factor responsible for the changes on the horizon. Consider the following.

Consumer interests drive marketing. Today's consumers are more vocal and certainly concerned about the safety of the food they eat as well as the impacts of farming (and other human activities) on our resources and the natural environment. Although consumers probably often make decisions with poor information or no information, the fact still remains that they will be more likely to consume products that are perceived to be produced as safely as possible.

Many studies recommend safer practices. Various national studies have pointed to the need for safer and more sustainable pest management practices. These are studies conducted by objective scientific groups that evaluate real data.

Farmers and farm groups seek alternatives. Many major farming groups supported the legislation that resulted in the Food Quality Protection Act because they see it as an overall benefit to our agricultural economy. In my role as an extension entomologist, I get numerous questions from individual farmers each year about how to reduce reliance on using broad spectrum pesticides. The reasons are usually threefold: (1) protection of the health of the farm family and workers, (2) the strong environmental ethic held by many farmers, and (3) the increasing demand by consumers for safer foods.

Agrichemical industry recognizes need for new types of products. The agrichemical industry is definitely switching directions in the development of new pesticide products. In the past, insecticides were broad spectrum. In modern pest management, the use of pesticides is much more highly targeted to specific problems known to occur through pest scouting. Therefore more selective materials can be used; more selective materials are easier on the beneficials important in biological control of many pests. Therefore, many newer products will fit much better into IPM programs. Many of the new products belong to new groups of pesticides, so called "new chemistry." Having an increased number of chemical groups will also be important in the future in delaying the onset of pesticide resistance.

Increased development of non-pesticidal methods. Both federal granting agencies and private industry are putting more resources into developing alternatives to toxic pesticides. Mating disruption and biological controls are two examples of non-pesticidal practices that will have an increasing role in cranberry pest management in the near future.

New Directions in Cranberry Pest Management

In addition to changes in pesticides, other approaches to cranberry pest management are likely to be more widely adopted in the future.

Insecticides.

Insecticides of the future will be quite different than those of today. How far away is the future? Some of these products are very close to registration, and we should be seeing at least a couple new products for use on cranberry before the end of the 1990s. Many of the new products will have the following general characteristics.

Selectivity. Products will be effective against narrower groups of target organisms and often not harmful to beneficials.

Human risk. Many newer products are much safer to higher organisms, including people. No product will be completely without risk, but some of the newer products come amazingly close to that level of safety. Table 2 compares the relative mammalian toxicity of currently registered cranberry insecticides to two products that will likely be registered for use on cranberry within the next couple of years.

Table 2. Approximate mammalian toxicity expressed as oral LD_{50} values (milligrams of toxicant per kilogram of body weight) (the higher the value, the less toxic the material).	
Product	Oral LD_{50}
Diazinon	66
Guthion	13
Lorsban	380
Orthene	900
Sevin	300
New product A	>5000
New product B	>5000

Environmental safety. Again, because of their greater selectivity, many newer products will be safer to aquatic organisms, fish, birds, and mammals.

IPM compatability. Because of safety towards beneficial insects, some of the newer compounds will be easier to integrate into IPM programs. These will increase the survivorship of naturally occuring beneficials, providing an even higher level of natural pest control.

New chemistry. As stated above, new chemistry provides many advantages, such as greater selectivity and increased opportunities to delay the development of resistance. Whereas the majority of current cranberry insecticides are in only one chemical group, the organophosphates, newer products under review belong to close to 10 distinct chemical groups with different types of pesticidal activity. However, it remains to be seen how many of these actually end up registered for use against cranberry pests.

Mating disruption.

Mating disruption involves the use of synthetic insect pheromones to mask the scent of the female moth, thus keeping the males from finding and mating with the females. Females are unable to lay eggs. Where it works, this is an effective form of pest control because it completely blocks the damaging larval stage. Research on mating disruption of blackheaded fireworm is nearing completion, and the results are promising. Although it may not be a complete cure, especially for very high populations of BHFW, it appears that this technique will have a very important role in cranberry IPM. Because BHFW is one of our major cranberry pests, it often dictates the direction of pest management. If we could replace much of the usage of broad spectrum insecticides by more target-specific approaches such as mating disruption, a significant benefit would be the preservation of naturally-occurring biological control organisms. For more information on mating disruption, see the three articles on this subject in the 1997 *Wisconsin Cranberry School Proceedings*.

Biological controls.

Biological control is defined as the use of living organisms for killing pests. These organisms can be those that occur naturally in cranberry beds, or those that can be purchased from companies who mass produce these beneficial organisms. For more background information on biological control, see my article in the 1992 *Wisconsin Cranberry School Proceedings*. Since that article was written, there has been much research on biological control of cranberry pests. Some of the more promising approaches to biological control are summarized here.

Insect parasitic nematodes. Research in the Pacific Northwest has found a new species of insect pathogenic nematode that performs well under cool conditions. *Heterorhabditis marelatus* has been shown to have up to six weeks of residual activity in cranberry soils and provide up to 95% control of cranberry girdler, which is outstanding. Research is currently underway to develop mass production techniques.

Some growers in Wisconsin are currently using nematodes that are already commercially available for cranberry girdler control. These include the species *Heterorhabditis bacteriophora* and *Steinernema carpocapsae*. Research also continues around the country to find nematodes effective against our species of white grubs, but as of yet there is nothing promising to report.

Microbial pesticides. Microbial pesticides based upon the bacterium *Bacillus thuringiensis* continue to be improved. Whether or not there will ever be a product that is excellent against blackheaded fireworm remains to be seen. Current products are marginally effective against BHFW, and these materials have to be precisely applied to maximize benefits. However, the products are highly effective against spanworms when applied when the larvae are young. If spanworms are the sole target pest, the use of a Bt product would help conserve beneficial natural enemies.

A new microbial insecticide based upon the fungus *Beauveria bassiana* is now registered for use on cranberry. However, there are few data at this point to determine its effectiveness against various target pests. With a grant from the Cranberry Institute, we are investigating the possible use of this product against the larvae of cranberry tipworm.

In addition to microbial insecticides, plant pathogens have also been developed as weed control agents. These are frequently called mycoherbicides. Research at the University of Wisconsin and elsewhere has shown that a type of *Alternaria* fungus is very effective for dodder control when applied as a pesticidal spray. This product appears to be close to commercial availability.

Parasitic insects. Many types of tiny stingless parasitic wasps are important natural enemies of many agricultural pests. For example, our research has shown that a complex of four wasp species attacks cranberry tipworm. Although parasitism rates are not high, these wasps do contribute to the substantial amount of natural mortality of tipworm larvae.

Trichogramma wasps are very tiny parasites of insect eggs. The wasp larva lives inside the egg of its host insect and kills it before it hatches. Several species of *Trichogramma* are commercially available and widely used on a variety of crops. Some of these have been evaluated several times in cranberry, specifically for control of cranberry fruitworm, unfortunately without satisfactory results. However, researchers in the Pacific Northwest have discovered a species that naturally attacks the eggs of blackheaded fireworm. In field release studies, *Trichogramma sibericum* shows good promise in helping to control BHFW. Research is currently underway to improve mass production technology. Once this parasite becomes more readily available, we plan to test it here in Wisconsin against BHFW, cranberry fruitworm, and sparganothis.

Host plant resistance.

Thus far, relatively little work has gone into developing cranberry cultivars that are resistant to insect or disease pressures. Research in Dr. McCown's lab on inserting Bt genes into cranberry for control of Lepidoptera has been moderately successful, but there are still some substantial constraints to implementation. Relatively little work has gone into conventional breeding programs for improved plant resistance. However, we are aware that some cranberry plants tend to be less susceptible to certain insects and diseases than others. Perhaps in the future we may see the development of resistant plants, either through conventional breeding or by genetic engineering.

Transitions in Cranberry Pest Management: How Will the Industry Cope?

There appear to be many changes in pest management on the horizon. Some will be forced on us by regulatory issues. Some will be provided to us as new tools developed by university, governmental, and private research. How will the cranberry industry cope with upcoming changes? Very well, I think. The cranberry industry has some unique strengths to draw on during changing times.

Widespread adoption of IPM. The cranberry industry is recognized as a national leader in the adoption of IPM practices. Very few other commodities are so heavily scouted by trained IPM personnel. And growers are already using a diversity of tactics for pest management, including cultural controls such as sanding and biological controls.

Research support. The cranberry industry has an outstanding history of supporting pest management research. Although it is impossible to do all research in all states, research and extension people network very well, allowing advances in one state to be implemented in another. Continued support of research will be critical to develop, evaluate and implement new methodologies.

Adoption of new technologies. Many cranberry growers are progressive farmers very willing to evaluate new technologies as they become available. This allows the industry to continue to stay in a leadership role in the adoption of evolving IPM practices.

Making The Transition

My best advice for making the transition is for the industry to continue to do what it has already been doing well. IPM monitoring practices must be continued so that appropriate pest management decisions can be made on what is actually happening in the beds. Stay informed of new developments. As new products and pest management practices become available, growers should evaluate how these work on their own farms. In that way you will have experience with newer materials if older products are lost.

NITROGEN FERTILIZATION

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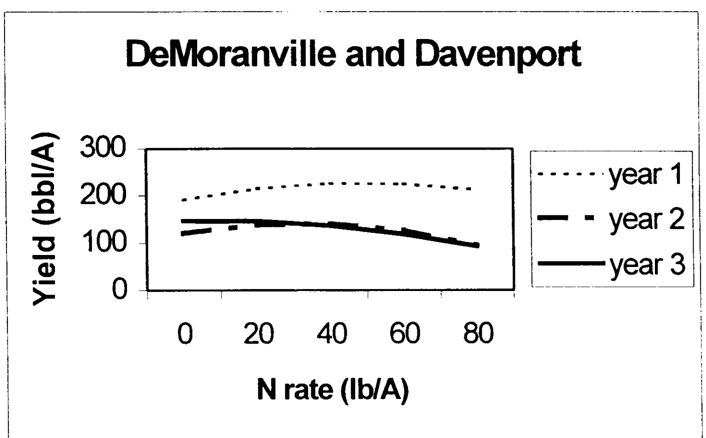
Nitrogen is the most important fertilizer element in cranberry production determining vegetative growth and productivity. Your choice of N rates and timing can make the difference between adequate growth and high yields and excessive growth with poor cropping. Choice of N form can be important in maximizing the efficiency of fertilizer use and in protecting environmental quality. These factors will be discussed and factors affecting N fertilizer use will be explored.

Nitrogen rates.

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 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 *or* 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' when the highest rate in the study was 60 lb/A (Hart et al., 1994). However, in a study with rates up to 80 lb/A, yield decline in 'Stevens' was seen at high rates (figure below).



While high rates of N were 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. High N rates were also associated with decline in fruit quality as shown in the tables on the next page.

Results over all locations after 3 years of treatment (Davenport, 1996).

N rate (lb/A)	Yield (bbl/A)	Field rot (%)	30D rot (%)	60D rot (%)
0	114	3.8	5.4	8.2
20	148	5.5	6.7	9.7
40	130	7.7	10.2	14.2

Stevens in BC after 2 years(Davenport, unpublished).

N rate (lb/A)	Yield (bbl)	% rot	TAcy	%N	%K
0	214	4.05	23.2	0.88	0.61
25	222	4.74	20.3	0.99	0.61
50	247	5.64	16	1.09	0.66
75	67	8.42	8	1.26	0.77

At high N rates, field and storage rot increased and TAcy declined. It was interesting to note that as tissue N with increasing N rate, tissue K also increased. Similar effects on tissue K as well as a decline in tissue Ca were reported by Davenport and Provost (1994). Decline in Ca may be related to poor fruit quality.

Optimum N rates from studies in North America can be summarized:

Location	**Cultivar**	**Investigator**	**Optimum N rate (lb/A)**
All	All	Davenport	20
WI	Stevens	Davenport	40
MA	Early Black	DeMoranville	30
BC	Stevens	Davenport	50
MA	Stevens	DeMor./Davenp.	40-60
OR	Crowley	Hart et al.	40
OR	Stevens	Hart et al.	60

Nitrogen timing.

Optimum timing for N applications to cranberry has been studied in Oregon (Hart et al., 1994) and across North America (Davenport, 1994). Oregon studies with ^{15}N showed that uptake was most efficient early in the season. If N was applied after fruit set, less was taken up and most of that was stored in the roots. While early applications were more likely to move into new vegetation and fruit, high rates early in the season were associated with excessive vegetative growth. As a result of this research, a moderate N rate split into 4-5 applications was recommended for Oregon, with early applications limited unless tissue tests from the previous season showed N deficiency.

Davenport separated timing results by growing region since results varied by location. The timing recommendations from her research are shown in the table below.

State	Cultivar	Bud break	Bloom	Fruit set	Bud set	Pre-harv.
MA	Early Bl.	X	X	X	X	
NJ	Early Bl.		X	X	X	
WA	McFarlin	X	X	X	X	
WI	Stevens	X	X	X	X	X

Timing recommendations for other cultivars could not be made due to conflicting outcomes over the duration of the study.

Nitrogen forms.

Most crop plants assimilate N as nitrate (NO_3). However once taken up, the plants must then convert NO_3 to the metabolically useful ammonium (NH_4) form using the enzyme nitrate reductase. Evidence suggests that cranberry preferentially uses the ammonium form of nitrogen over the nitrate form. This phenomenon was first reported from the University of Wisconsin (Greidanus et al., 1972). In that study, cranberries grown with NH_4 grew well and accumulated N in their shoot tissue, while those grown on NO_3 showed little response. Further, no nitrate reductase activity was found in the cranberry leaves. However, a later study (Dirr, 1974) demonstrated nitrate reductase activity in cranberry roots.

In solution culture cranberries grew best in the presence of NH_4 but also showed adequate growth with a combination of the two N forms (Rosen et al., 1990). This result was confirmed by Smith (1994) in field and greenhouse experiments.

Cranberries evolved on acid soils. It has been shown for other crops and confirmed for cranberry soils that N remains in the NH_4 form in acid soils due to inhibition of the bacteria that mediate the transformation to NO_3. Cranberries may have lost the nitrate reductase enzyme during evolution since it was not critical to survival in an environment where much of the N was in the NH_4 form. Since NO_3 leaches readily in sandy soils and the cranberry can thrive with just NH_4, it is good management practice to avoid applying this NO_3 to cranberry beds.

Nitrogen availability.

Native nitrogen is released from cranberry soils due to mineralization - biological breakdown of organic nitrogen into ammonium. Mineralization was studied by Davenport and DeMoranville (unpublished). The amount of N released by this process depends on two major factors: 1) amount of organic matter present, and 2) soil temperature.

As organic matter increases in cranberry soil, release of ammonium increases. Increasing ammonium release followed the series: sand (pH 4.5) $<$ layered $<$ organic. However, in highly decomposed muck soil, the ammonium was rapidly converted to the less useful nitrate. Interestingly, clay content in the soil had a negative relationship with mineralization. While cranberry soils are normally low in clay, clay content should be taken into account when selecting a site for a new planting and when selecting material for sanding.

Mineralization rates were similar at temperatures from 55°F to 70°F. The rate increased dramatically when soil temperature rose to 75°F. Accumulated mineralized N also became available at low soil temperatures (50°F) as the soil drained to normal seasonal moisture levels (removal of winter floods).

Mineralized nitrogen (ammonium) is converted to nitrate by specific soil bacteria. This is an *undesirable* reaction on a cranberry bog. Populations of nitrifying bacteria and thus, the rate of this nitrification reaction, were influenced by two major factors: 1) soil type, and 2) soil pH.

Nitrification rate (nitrate release) was extremely high in muck soils. Nitrate release decreased by soil type as follows: muck > peat > layered > sand (average bog pH). Nitrification was lower in normal to acid cranberry sands (pH 4.5 or 3.0) than in high (6.5) pH sands. This confirms the results of Roper and Krueger.

Monitoring cranberry nitrogen status.

DeMoranville and Davenport surveyed N use, yield, plant growth, nitrogen content in the tissue, and leaf greenness to determine the least laborious and costly way to evaluate cranberry plant nitrogen nutrient status during the growing season. Testing for nitrogen content in the plants by chemical analysis is costly and the results are generally not available for days or weeks. In addition, nitrogen in the tissue is stable and susceptible to interpretation only late in the growing season. Many cranberry growers rely on a visual examination of upright length and color (greenness - indicative of the amount of chlorophyll present) as the basis of fertilizer decisions. Upright length can also be an objective criterion for decision-making if standardized. However, not all people perceive color in the same way, making color evaluation problematic. SPAD chlorophyll meters evaluated chlorophyll based on light transmittance, thus making the process objective.

Length of new growth in June was a good indicator of cranberry plant nutrient status. Stunted uprights are likely to be poor in nitrogen. SPAD readings could be used to estimate nitrogen status of cranberry plants throughout the summer. Readings could be made on old or new leaves during June and July but should be made on new leaves only in August.

Recommendations for cranberry growers.

Temperature:

- 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.
- At soil temperatures from 55°F to 70°F, release of N from soil organic matter is only moderate. Fertilizer applications should be beneficial.
- During spells of hot weather, when soil temperatures exceed 70°F and air temperatures exceed 85°F, soil N release increases and crop development slows, so planned fertilizer N applications should be reduced, delayed, or eliminated.

Soil type and pH:

- Sandy bogs 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 cranberry-useable ammonium to less-desirable nitrate increases. Soil pH on cranberry bogs 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.

Nitrogen rates:

- 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/A should be used with caution as they may lead to vine overgrowth and reduction in fruit quality.

Monitoring vine nutrient status during the season:

- Length of new growth can be used to indicate nutrient status of cranberry plants up until early bloom. From hook stage through early bloom, ideal lengths are as follows:
  Early Black - 50 to 60 mm   Howes - 45 to 55 mm
  Stevens - 60 to 70 mm   Ben Lear - 55 to 65 mm
- SPAD Chlorophyll Meters may also be used to monitor leaf nitrogen status. Old or new leaves may be monitored in June or July, while *only* new leaves should be monitored in August. Meter reading vary by cultivar and year. Standard values are shown below.

	Roughneck to Hook		Bloom to Set		Pre-Harvest
	old	new	old	new	new
Early Black	40	25	35	35	35
Howes	45	30	40	40	40
Stevens	40	30	35	35	40
Ben Lear	40	25	35	35	40

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TOXICITY OF MINOR ELEMENTS

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Cranberry growers are increasingly concerned about mineral nutrition of cranberry vines. Significant yield increases have been associated with fertilizer application. However, once the nutritional requirements of the plant are met, applied mineral elements can continue to accumulate in the soil and plant tissues. Once these levels reach some undetermined point, toxicity to the plant may occur. The levels at which specific nutrients become toxic to cranberry should be equally important to cranberry growers as at what point nutrients become limiting (deficient). Growers will need to keep soil and tissue levels between these two points to maximize yields. Nutrients that are required in small doses may also become toxic in large doses.

Plant nutrition advisors are recommending applications of large amounts of some elements. The long-term impact of these recommendations are unknown. We began a research project to understand the effect of large quantities of minor elements on cranberry growth. Some of the results are reported here. This is not a final report since the research is ongoing.

Approach:
The research was conducted at the University of Wisconsin-Madison, Arlington Research Center. 'Stevens' cuttings were rooted and grown hydroponically in dilute Hoagland's solution per our standard practice. Solution pH was adjusted three times per week. Once the plants were growing well, concentrations of a single minor or micro-element was increased to a series of elevated concentrations. All other nutrients were held constant at normal levels. Plants were watched for visual symptoms. Once symptoms of impaired growth or appearance were observed, plants were harvested, dried and analyzed for mineral content to determine the tissue concentration where symptoms appeared. Following this initial screening, the experiments were repeated in aeroponics (fresh nutrient solutions are intermittently sprayed onto the roots) but at concentrations closer to the concentration that produced symptoms to produce a narrower bracket where damage may be observed.

Plants grew well in the greenhouse environment. We did not have severe insect or disease problems. We were able to observe different symptoms depending on the element we provided in excessive amounts. Visual symptoms are not distinctive and are not reliable indicators of mineral nutrient toxicity. Common symptoms are leaf necrosis and leaf drop.

Boron
In solution culture the Boron concentration in shoots increased linearly with increasing solution concentration. Once the solution concentration exceeded the normal amount supplied in solution (0.125 ppm) shoot tissue concentrations were high enough to be considered excessive (Fig. 1). Root tissue concentration stayed relatively stable to slightly increasing with increasing solution concentration. Tissue dry weights of both shoots and roots did not change with increasing Boron concentration in solution (Fig. 2). This suggests that Boron does not cause significant reductions in growth even at extremely high tissue concentrations. Our data clearly show that Boron accumulates in shoot tissues and not in roots.

We chose 4 ppm boron to go into aeroponics which we thought would give about 225 ppm in the tissue or roughly 3 times the levels currently considered excessive. For the first 6 weeks in aeroponics both the control and +B plants grew well indicated by similar fresh and dry weight measurements (Fig. 3). By about week 4 or 5 we began to notice necrosis of leaves on the +B treatments and by weeks 7 and 8 leaf drop contributed to a decrease in fresh and dry weight. Tissue B concentration was stable in the control plants at about 80 ppm, but climbed in the +B plants to exceed 450 ppm (Fig. 4). Preliminarily, we propose that tissue B in excess of about 300 ppm indicates that symptoms will be imminent.

Copper

Copper concentrations in roots increased almost linearly with increasing solution concentrations (Fig. 5). Surprisingly, copper concentration in the shoots did not change with increasing solution concentrations. After a few weeks in elevated copper solutions cranberry roots were darkly discolored suggesting that copper was accumulating in the roots. Elevated copper concentrations did reduce shoot growth at elevated solution concentrations even though copper concentrations in the shoots were not elevated (Fig. 6). Excessive copper will be difficult to diagnose since we would not expect to find high copper levels in shoots that would normally be sampled for tissue testing, yet excessive copper will reduce plant growth.

We chose 4 ppm copper for aeroponics. For the first four weeks both control and +Cu plants grew well. For weeks five through seven there was a noticeable reduction in both fresh and dry weights of the treated plants (Fig. 7). Tissue Cu concentration declined during the experiment from about 8 ppm to about 5 ppm, suggesting too little Cu in the control solution (Fig. 8). Copper in the tops increased from about 14 ppm to 30 ppm. Cu concentration in the roots was even more pronounced, rising from 300 ppm at the outset to over 1400 ppm by week 7. No proposal is made for toxic Cu leaf tissue levels as the greatest injury appears to occur in the roots and we have no reliable technique for sampling roots in the field at present.

Sulfur

As sulfur concentration in the solutions increased both root and shoot sulfur concentrations increased (Fig. 9). By the time these samples were harvested even the normal solution produced very high tissue sulfur levels. All of the elevated sulfur solutions produced excessive tissue sulfur levels. Excessive tissue sulfur levels reduced the dry weight of shoots, but not of roots (Fig. 10). Excessive tissue sulfur should be easy to detect with normal tissue testing.

We chose 750 ppm S for our aeroponics solution. The growth of the tops was similar for the control or +S plants for the first 5 weeks (Fig. 11). At that point the rate of fresh or dry weight increase declined for the +S plants (Fig. 12). Sulfur concentration stayed stable at about 0.3% of dry weight for the control plants, but rose from 0.4 to almost 1% dry weight for the +S plants. Preliminarily, we propose that tissue sulfur concentrations in excess of about 0.65% should be considered toxic.

Conclusions

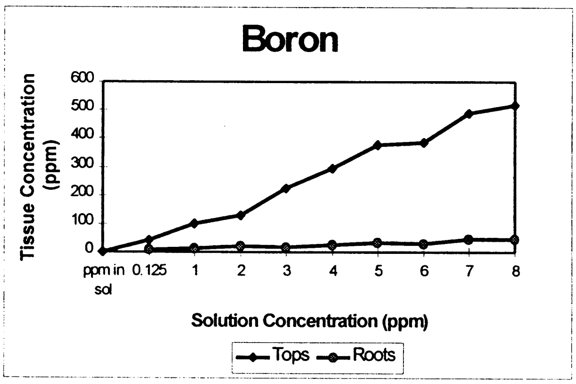
The results of this research so far indicate that when "soil" levels of micro or minor elements is very high excessive levels can be found in tissues. In some cases these elevated levels are associated with decreased shoot growth. Boron and sulfur excesses will be easy to detect with tissue tests. Copper accumulates in the roots and will be difficult to detect with normal tissue tests.

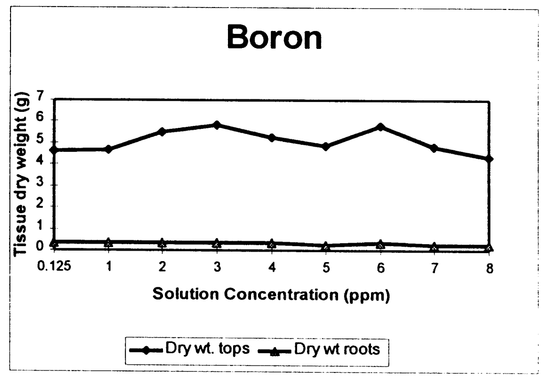
Tissue values considered to be excessive for Boron is 300 ppm and for sulfur tissue concentrations in excess of 0.65% should be considered excessive. Based on cranberry tissue tests submitted to the UW-Extension Soil and Plant Analysis Lab, we have not seen tissue concentrations even approaching the levels we have found to be excessive in this research. While growers need to be aware of the risks of providing excessive amounts of nutrients, to date we have not seen samples submitted by growers with grossly excessive levels of nutrients.

We are continuing this work and are presently studying Iron, Zinc, Manganese and Magnesium.

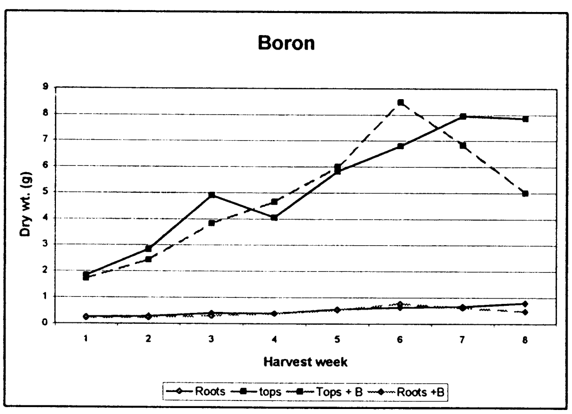
This research was supported by the Wisconsin Cranberry Board, Inc. Armand Krueger did the technical work on this research.

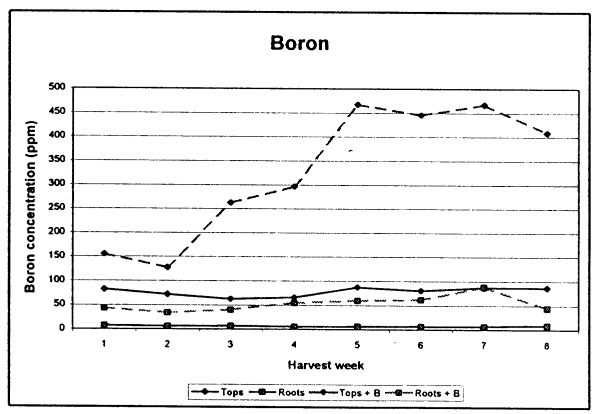
Figures 1 and 2. Effect of elevated Boron in solution culture.



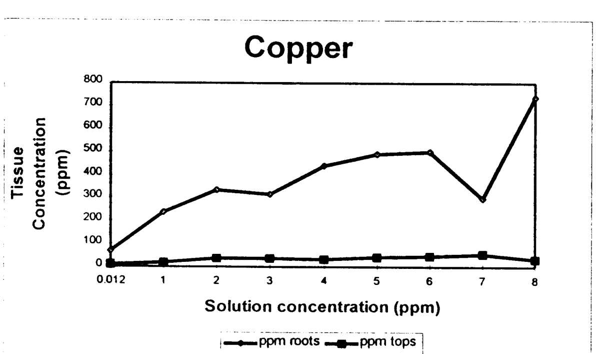


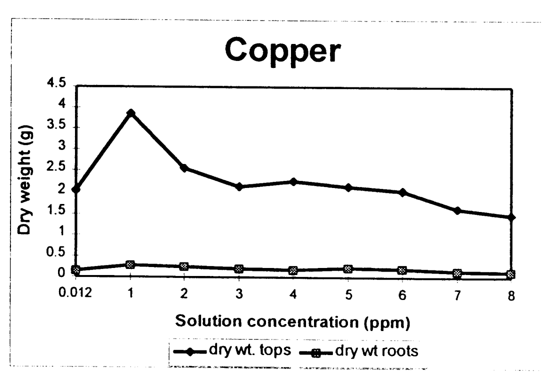
Figures 3 and 4. Effect of elevated Boron in mist culture (aeroponics).



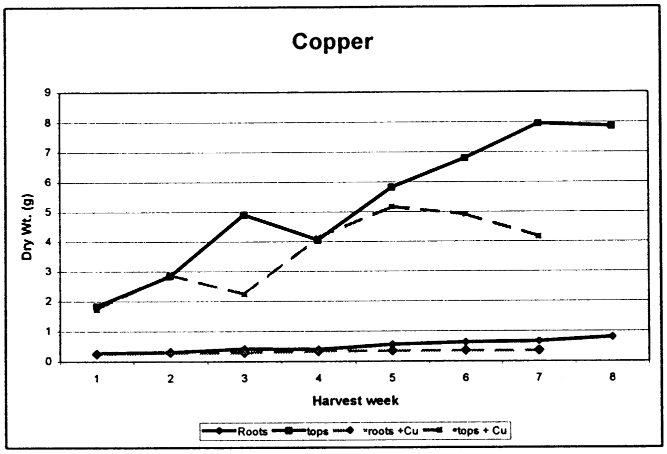


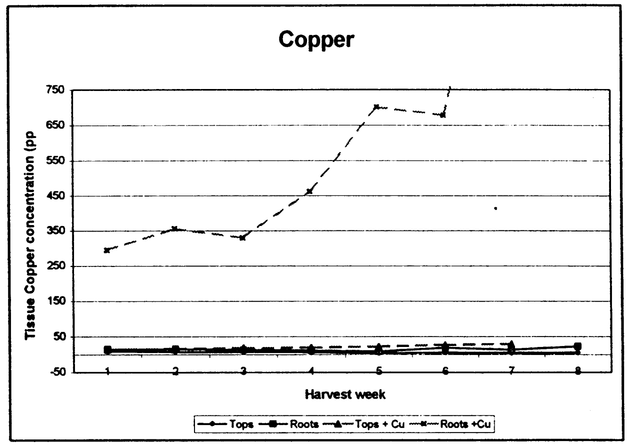
Figures 5 and 6. Effect of elevated Copper in solution culture.



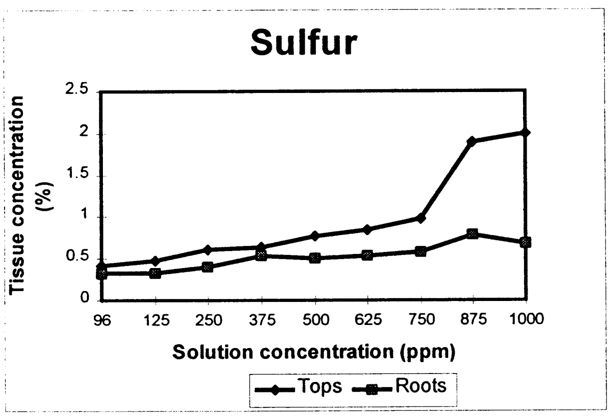


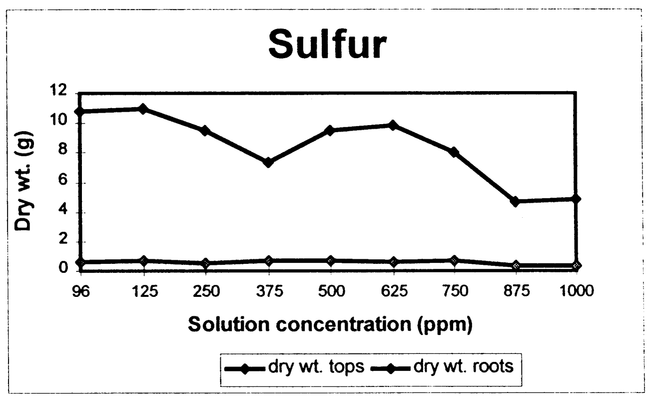
Figures 7 and 8. Effect of elevated Copper in mist culture (aeroponics).



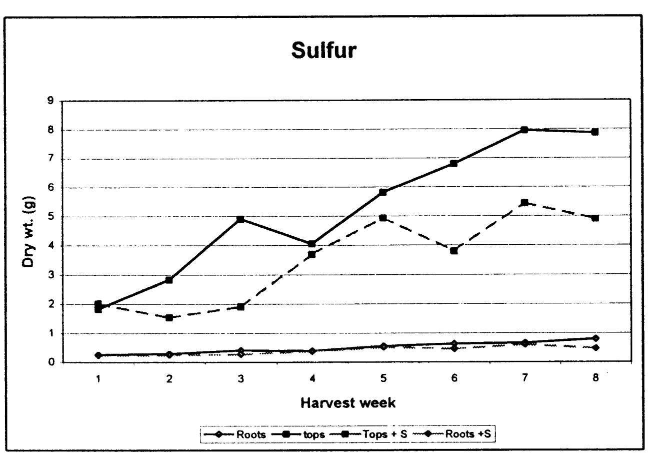


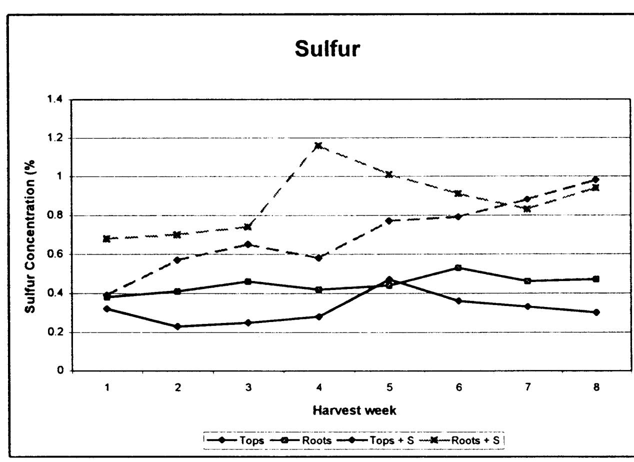
Figures 9 and 10. Effect of elevated Sulfur in solution culture





Figures 11 and 12. Effect of elevated Copper in mist culture (aeroponics).





PHOSPHORUS, POTASSIUM, AND MINOR ELEMENT FERTILIZATION

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The order of topics in the title reflects the relative amounts of knowledge that we have regarding P , K, and minor element fertilization. Extensive studies of P use in cranberry production have been conducted in WI (Greidanus and Dana, 1972) and in Massachusetts (Davenport et al., 1997; DeMoranville and Davenport, 1997). Some research on K fertilizers has been published (DeMoranville and Davenport, 1994) and studies are in progress in MA, WI, and OR. Due to the acid medium in which cranberries grow, minor elements tend to be readily available to the plants. Some research has been done with minor element foliar supplements but the results have been mixed and often vary from year to year on the same bed. Minor element toxicity is of interest due to the extreme availability of metallic minor elements in cranberry soil. Roper and Krueger are investigating nutrient toxicity symptoms in cranberry.

Phosphorus – soil chemistry.

Cranberry soils are high in iron and have low pH. This chemistry leads to conditions where phosphorus (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 are often found growing on soils with high P test values. Most cranberry growers add inorganic P to the soil in N-P-K fertilizer or as triple superphosphate (TSP). When applied to the soil, the P in these materials dissolves in the soil water and quickly becomes bound to iron - only a small percentage of the P remains dissolved in the soil water. Only a portion of that bound P is later released and available for uptake by the plants.

Phosphorus uptake and release in cranberry soils of varying organic matter content was investigated under flooded, dry, and transitional conditions (Davenport et al., 1997). Sand 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 sand soils was not dependent 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, 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 indicated high P availability under conditions where P was shown to remain bound in our soil studies. We found that if soil iron is high, a test for extractable Fe may be more meaningful than the P soil test for predicting P releasing potential of the soil during the growing season.

To summarize:

In sand 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.

In layered 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 (very low P additions may be bound to the soil and released poorly).

In organic (peat) soils, P was 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.

Phosphorus forms, rates, and timing.

Despite cranberry bog soils testing high for P, most cranberry growers continue to use P fertilizer each season. In some annual crops, a yield response to P has been found even in high P test soils, particularly if other production factors are maximized or if soil and climate factors impose plant stress early in the season. Cranberry bogs meet both of those conditions: high yields are common and soils are often cold and waterlogged early in the season. P forms, rates, and timing were studied in a three year field trial at six locations in MA (DeMoranville and Davenport, 1997).

Five P forms and a control receiving no P were compared in field plots (Table 1). The treatments were TSP (0-46-0), phosphoric acid (reagent grade 85%, foliar P), phosphate rock (PR; 0-32-0), half each PR and foliar P, and half each PR and TSP. PR was applied at bud break; TSP and foliar P were split-applied at roughneck, bloom, fruit set, and bud set stages. At the end of three years, yield was similar for all P treatments within each location. Plots receiving no P (control) had significantly lower yield than any of those receiving P (Table 1). Foliar applied phosphoric acid was associated with higher field rot compared to TSP or no P. Among the P treatments, plots treated with foliar P had the highest tissue P levels; those receiving PR the lowest.

Nine P forms and a control receiving no P were compared in field plots (Table 2). PR, Osmocote, and bone meal were applied at bud break; foliar P was split-applied at bloom and fruit set; chicken manure was split-applied at bud break and fruit set; fish was split-applied at bud break, hook stage, fruit set, and bud set; 10-20-10 and 14-14-14 were split-applied at roughneck, bloom, fruit set and bud set stages. Cranberry production in this set of plots seemed to be more dependent on P form than on P rate (Table 2). Yield was lowest in plots receiving no P but yield in the other treatments did not correspond to the three P rate groups. This is illustrated by the individual comparison of 10-20-10 (17.5 lb P/A) with 14-14-14 (8.5 lb P/A) - no difference in yield, although tissue P is higher in the 10-20-10 treatment. The lowest yields in plots receiving P were in those where P was applied in organic fertilizers (fish, chicken manure, and bone meal). Highest yield was in plots receiving PR alone or with added foliar P (but not statistically greater than that in 10-20-10 plots). Slow-release P was no more effective than soluble materials (Osmocote vs. 14-14-14) in promoting productivity but was less effective in raising tissue P content.

Four TSP rates and five split-application timings were compared in field plots (Table 3). The P rates and timing plots received only N and K in the first year and were then treated with the appropriate P rate and timing each year for the following three years. Timing of P application had no effect on cranberry yield, yield components, or soil test P (Table 3). There was no interaction between timing and rate but there were significant rate differences. Plots receiving P at any rate (20, 40, or 60 lb/A) had greater yield and tissue P content than those receiving 0 lb P/A. However, yield among the three P rates was similar - no further gain was achieved by increasing P above the 20 lb/A rate. An individual comparison of 0 lb/A vs. the other P rates was highly significant but there was no linear increase in yield with increasing P rate. However, tissue and soil P did increase with increasing P rate. Plots receiving no P had the fewest flowers per area of bog.

At the six experiment locations, the average soil test P was between 40 and 50 ppm Bray-1 P which is greater than the 20-30 ppm recommended by Wisconsin researchers Greidanus and Dana (1972) for maximum vegetative growth of cranberry plants. However, the sites all had cranberry tissue P levels at or below the 0.10% critical level (DeMoranville, 1997). Compared to adding no P fertilizer, cranberries at all locations responded to P rates ranging from 8.5 to 60 lb P/A with increased yield (Tables 1-3). While yield increased with the addition of P compared to adding none, the amount added seemed to have little effect. Regression analysis of the data from the rate study showed no significant relationship between P rate and cranberry yield. Only the comparison of the 0 lb P/A rate to the other rates showed a significant difference. However, increased P rate was associated with increased tissue P (Table 3), confirming the Wisconsin data. Comparison of 8.5 lb P/A to 17.5 lb P/A rates (Table 2, 14-14-14 and 10-20-10 treatments) showed no significant difference in yield, although the higher P rate was associated with higher tissue P values. Cranberries growing on high P soils did respond to the addition of P but there was no advantage to using high rates, the response was a good with low to moderate rates of P - approximately 20 lb/A. Response to added P was the same regardless of application timing (Table 3).

Application of P to cranberry bogs with Bray-1 P of 40-50 ppm raised soil P to 70-80 ppm and increased yield. However, tissue P remained below the published critical level (DeMoranville, 1997 and Greidanus and Dana, 1972). It is possible that the available P in these soils was less than that indicated by the Bray-1 test due to the presence of citrate/dithionate extractable Fe at interfering levels of greater than 200 ppm (Davenport et al., 1997). It was observed that the two locations where yields were lowest over all treatments were also those with the highest soil P (>100 and >80 ppm).

To summarize:

- Based on this research, P applications of 20 lb/A are recommended for producing cranberry bogs. Higher P rates or foliar P treatments may increase tissue P levels but there is no evidence that yields will improve beyond those with the moderate P rate.
- Foliar P was associated with increased field rot.
- Extreme P loading of the soil may be associated with lower yield.
- P should be split-applied (three or four applications) if a soluble material such as TSP is used to minimize fixation and /or leaching loss. Slow-release or PR may be applied in a single application early in the season. Uptake/ release studies have indicated that P applications should be delayed until soil is at seasonal moisture field capacity - roughneck stage or later.

Potassium.

In the early 1990s, DeMoranville and Davenport (1992) conducted field trials in which K was applied to cranberry in soil or foliar forms at timings designed to increase K during fruiting. Since concentration of K in fruit is significantly higher than in foliage of cranberry, we thought that K might be a limiting factor during fruit set. We found no yield response to our K additions.

We initiated a series of field experiments in 1995 to study several questions related to the use of potassium (K) and phosphorus (P) fertilizers.

Question #1 - do high chloride fertilizers have a negative effect on cranberries? After one year of treatment, chloride containing K fertilizers had no adverse effect on yield. However, at the Stevens site, yield was reduced in the treatment receiving $CaCl_2$. High N rates (50-60 lb/A), the other factor studied, were associated with reduced yields and increased rot.

Question #2 - Do P and K fertilizers have a role in the establishment of new cranberry plantings? *We* found that the use of 50 lb P/A at the time of planting increased the percent of coverage by cranberry plants at the end of the first season. The bogs also received 100 lb/A 31-0-0 (IBDU) at the time of planting. After two years of growth, all P treatments had equal vine cover. K applications seemed to have no effect on vining-in. We now recommend 50 lb P/A (100 lb/A triple super phosphate) during vine establishment (at or around the time of planting).

Question #3 - How does a fertilizer schedule including foliar P and K compare to using just 12-24-12? While the differences were not statistically different, yield and weight per berry were greater in the plots receiving an all granular 12-24-12 program at all 4 locations. Conversely, at all locations, field and storage rot was less in the plots receiving the granular/foliar combined program (foliar P+K in the spring, 12-24-12 at bloom, 21-0-0 at fruit set, and foliar P in August). In 1995, two of the locations had higher yields with the granular/foliar combined program (one location significantly greater). This leaves the picture unclear. There may be some benefit in adding foliar P and K applications to a granular fertilizer program at some locations in some years but it is by no means a sure bet.

Question #4 - Does the timing of K application affect the result? K applications, regardless of timing, appeared to have little effect on production after one year of treatment. However, plots receiving no K for the whole season had the highest yield in the second year compared to some of the K treated plots. Timing of K application appeared not to be important in either year of the study. We attempted to study timing of K application and fruit sizing using the Ocean Spray aeroponics system. The experiment was terminated due to high mortality in the study plant material.

Minor element fertilization.

Individual minor element supplements. Joan Davenport conducted three seasons of field studies in WI in which she applied individual minor elements at either hook stage or at early scattered bloom. The elements used were Cu, Zn, Mg, Ca, and B. Results varied from year to year. In the first tow years, some increases in yield were seen. However, in the third year, no treatment was effective. Further, no treatment gave consistent results over time. In two years Ca supplement was associated with yield increase, but the effective timing varied. In addition Ca was sometimes associated with an increase in fruit rot. Mg, B, and Cu had conflicting relationships with yield and quality over the life of the study. Only Zn applied at either timing showed no negative impacts during the study. However, positive impact was only seen in 2 of 3 years. The overall conclusion drawn from these data was that minor element supplements, unless applied to correct specific deficiencies, give at best, mixed results and are unlikely to provide much benefit for the cost involved.

Boron. Boron is essential for flowering and fruiting in higher plants, being involved in the growth of pollen tubes and in the induction of floral buds. We have shown that the addition of a supplement containing calcium and boron during the flowering period led to increased fruit set, presumably due to the effect on pollen tube growth (DeMoranville and Deubert, 1987). There have been reports of increased flowering following fall applications of boron to fruit trees and lowbush blueberry, presumably an effect on bud formation. Calcium-boron sprays during the summer (after bloom) had no effect on cropping that year or the following year. In fact, bloom sprays of CaB appear to be most effective on beds where yield potential is low. High yielding beds are unlikely to benefit from this combination.

Recently, we attempted fall sprays of B alone. Based on reports for other crops, such sprays may increase flower bud production (and crops), particularly on bogs which have shown a low tissue test B. Foliar boron was applied at 3 rates in the fall or spring. We started this project in the fall of 1994, in an attempt to replicate the flower bud stimulation seen in tree fruit crops with fall B (and sometimes spring B) supplements. While boron sprays lead to no statistically significant increase in cranberry production, it appears that there may be some effect on the numbers of berries produced. A 10.5% liquid boron applied to bogs with low tissue boron at 4 pt/A just prior to bud break (early May) was associated with at least 20% increase in number of berries produced at 3 of 5 sites in 1996. When all data from 1995 were combined, that same treatment was associated with more than 10% increase in yield (not statistically significant). *The bottom line:* There may be some benefit of applying boron sprays prior to bud break on bogs with low (30 ppm or less) tissue boron. Our "best" treatment consisted of 4 pt/A of a 10.5% boron liquid applied just prior to bud break in the spring. Use of B supplement sprays remains under investigation.

Minor element 'cocktails'. Foliar nutrient mixtures have been investigated by many researchers around the country. However, no consistent reproducible result has been found. I have made some of these attempts, looking at Zn-B-K, Zn-K-P, CaB, and various N-P-K foliars singly and in combination. The only yield improvements came from CaB or N-P-K additions. The value of additional supply of the major elements is obvious. However, minor element addition for yield improvement remains dubious at best.

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Table 1 - Comparison of soluble, insoluble, and foliar P forms applied to field-grown cranberries. Data collected after three successive years of treatments. All materials were applied each season at the rate of 17.5 lb P/A. Data from six locations combined; treatment comparisons were similar at each location. Within a column, values followed by the same letter are not statistically different.

Treatment	Yield (bbl/A)	Field rot (%)	Soil P (ppm)	Shoot P (%)
Triple super phosphate (TSP)	176 a	4.1 b	77	0.088 ab
Phosphoric acid (foliar P)	163 a	6.7 a	70	0.097 a
Phosphate rock (PR)	177 a	4.3 ab	71	0.078 b
PR + foliar P	176 a	5.7 ab	71	0.084 ab
PR + TSP	183 a	4.8 ab	82	0.088 ab
No P (control)	124 b	4.1 b	--	--
Initial content			44	0.110
Significance of differences	***	*	*ns*	*

Table 2 - Comparison of inorganic, slow-release, and organic P forms applied to field-grown cranberries. Data collected after three successive years of treatments. Data from six locations combined; treatment comparisons were similar at each location. Within a column, values followed by the same letter are not statistically different.

Treatment	Phosphorus rate (lb/A) per season	Yield (bbl/A)	Soil P (ppm)	Shoot P (%)
Inorganic 10-20-10	17.5	174 ab	69	0.098 a
Fish (2-4-2 liquid)	17.5	137 bc	55	0.083 ab
Phosphate rock (PR)	17.5	194 a	68	0.078 b
Osmocote (slow release)	8.5	174 ab	71	0.071 b
Inorganic (14-14-14)	8.5	164 ab	66	0.084 ab
Chicken manure (3-4-3)	11.6	146 bc	67	0.085 ab
Bone meal (4-12-0)	11.6	160 abc	70	0.081 ab
PR + foliar P	11.6	190 a	70	0.078 b
Osmocote + foliar P	11.6	163 ab	68	0.083 ab
No P	0	124 c	--	--
Initial content			39	0.104
Significance of differences		**	*ns*	**
Individual comparisons				
No P vs. all other treatments		***	--	--
10-20-10 vs. 14-14-14 (rate comparison)		ns	ns	**
Organic vs. 10-20-10		**	ns	**
Osmocote vs. 14-14-14		ns	ns	*
PR vs. PR + foliar P		ns	ns	ns
PR vs. 10-20-10		ns	ns	***

Table 3 - Comparison of four rates and five timings of phosphorus applied to field-grown cranberries. Data collected after three successive years of treatments. Phosphorus was applied as TSP. Data from six locations combined; treatment comparisons were similar at each location. Rate timing interaction was not significant. Within a column, values followed by the same letter are not statistically different.

Treatment	Yield (bbl/A)	Flowers (per ft^2)	Soil P (ppm)	Shoot P (%)
Rates				
0 lb/A	137 b	430 b	54 b	0.123 c
20 lb/A	170 a	476 ab	57 b	0.136 b
40 lb/A	157 a	440 ab	64 a	0.148 a
60 lb/A	165 a	493 a	67 a	0.152 a
Significance of differences	*	*	**	***
Timings				
RN, BL, ST, BD[Z]	161	460	64	
RN, ST, BD	162	451	64	
RN, BL, BD	161	498	62	
RN, BL, ST	169	477	63	
BL, ST, BD	166	462	60	
Significance of differences	*ns*	*ns*	*ns*	

[Z]RN = roughneck (1.5 cm growth), BL = bloom, ST = fruit set, BD = bud set

1 NUTRITION QUESTIONS AND ANSWERS

Jonathan D. Smith Ph.D.

Northland Cranberries, Inc.

2 How often do I need to fertilize a new planting?

- Need constant supply of nutrients
- Very little nutrient reserve in the stems
- When nutrients are gone, growth stops
- Soil type will influence the frequency
  - Very well drained..... More frequently
  - Moderate drainage.... Less frequently

3 What timing and rates should I use on my new plantings?

- Seasonal nitrogen rates from 100 - 180 lb/ac
- Timing:
  - Fertilize every three to four days
  - One appl. complete granular fertilizer
  - One appl. of a nitrogen only fertilizer
- Rates:
  - 5 to 8 lbs. nitrogen per week (on average)
  - Tissue concentrations from 1.8 to 2.6% N

4 How can I get the quickest start from my new plantings?

- Use vines with a high %N in their tissue
  - Look at previous August tissue report
- Low nitrogen vines emerge slowly
- Vines with a previous heavy crop load are slow
- Choose vines with low reproductive bud #'s

5 Should we apply a blended fertilizer before planting?

- Prior to planting is not necessary
- Fertilize vines as soon as they are planted
  - Fertigation works well
- Vines will take up nutrients through the stem and accelerate rooting
- Fertilizer will not burn the new roots (thus no need to wait 7 to 14 days).

6 What about adding phosphorus before planting?

- I recommend applications of preplant phosphorus

- Must first determine if a lot is needed
  - Use a soil test
- Must be incorporated into the top 4"
- Logistics of phosphorus application is the primary problem

7 ❑ Why bother with preplant phosphorus? Does it help?

- Phosphorus is a key element in the utlization of energy in the plant.
- When root systems are small, need to keep phosphorus available to the plant. Phosphorus moves very little in the soil unless it is flooded
  - typically moves only 1/16"
- It helps when soil phosphorus levels are low

8 ❑ How much P should I add pre-plant?

- First, do a soil test.
  - Not everybody needs to add preplant phosphorus
- If very little P in the soil, up to 400 lb. / acre of an 0-46-0 fertilizer can be used.
  - This will boost soil phosphorus levels by 80 lb.
- Remember to incorporate well.

9 ❑ What type of pre-plant phosphorus fertilizer should I use?

- 0-46-0 (triple-superphosphate) is a very good material.
  - It contains 21% Calcium
  - If high calcium is a problem, do not use.
- Check your soil test reports
- Most other high content P products have a nitrogen source which is not advised at high application rates.

10 ❑ What is the difference between 0-0-50 and 0-0-62?

- Both materials are excellent sources of potassium
- 0-0-50 is potassium sulfate
- 0-0-60 or 0-0-62 is potassium chloride
- The chloride or sulfate fractions of these materials is important in cranberry production.

11 ❑ How does applying K in the fall enhance bud formation?

- Bud formation (and growth) is enhanced by two nutrients: Potassium and Nitrogen.

- They to hand-in-hand. When one of the two nutrients is missing, bud formation is reduced.

12 ❑ Continued......How does applying K in the fall enhance bud formation?

- When K low in the tissue:
  - One appl. of 0-0-50 at 100 lb. solved problem
  - Multiple applications and rates had no benefit
- When N & K were low in tissue:

  (K levels were adequate in the soil)
  - 8 lb/acre N enhanced bud formation and growth
  - The added N enhanced potassium uptake from the soil.

13 ❑ Will fall applications of K slow down vines and cause them to go dormant earlier?

- Yes.
- 0-0-60 (potassium chloride) will shut down vines for the winter.

14 ❑ How will fall applications of K slow down vines?

- Potassium chloride is a salt
  - Table salt is sodium chloride
- Salt stresses the plant and in reaction, the plant shuts down in an effort to keep from dying.
- Other salts could be used to accomplish the same effect.

15 ❑ Do I recommend fall applications of K to slow down vines?

- No. Must be willing to take extreme risks with your crop.
- Overapplication will cause:
  - leaf drop
  - slower emergence in the Spring
  - burnt root systems.
- KCl lowers fruit quality for fresh fruit.
- The benefits do not outweigh the risks

16 ❑ Is there a type of fertilizer that is better than any other?

- Two types of fertilizers:
  - **Manufactured fertilizers** have the same nutrient content in each pellet.
    - A superior fertilizer, but often more expensive
  - **Blended fertilizers** are a mixture of individual fertilizers in each bag.
    - Separates in the bag and is not evenly mixed
    - Bounces differently off the boom deflector plates
    - Blends with nitrogen often cause streaks

17 ❑ How should I determine which fertilizer to use in my program?

- Use a Complete Fertilizer in the early Spring when soils are cold
  - ex. 10-20-20 or 6-24-24
  - N, P, and K may not be available from the soil reserves
  -

18 ❑ How should I determine which fertilizer to use in my program?

- Refer to your soil and tissue test results
  - Without test results, it is impossible to determine what is actually contained in the soil
- Nitrogen is the most important nutrient, so this must always be considered first
- If soil is low in P, add materials high in this nutrient: 11-52-0 6-24-24
- If K is low and you don't need much nitrogen: 2-6-42.

19 ❑ What is the difference between liquid and foliar fertilizers?

- Liquid fertilizers:
  - Designed for chemigation use
  - Taken up by the root systems
  - Similar to granular fertilizers in solution
- Foliar fertilizers:
  - Designed for boom / mist application onto leaves.
  - Purer materials with harmful ingredients removed.
  - Much more costly but safer.

20 ❑ What proportion of our fertility program should be foliar fertilizers?

- **Granular fertilizers** should be the primary source of nutrition
  - Roots can choose which nutrients to absorb
  - Liquids will work, but must be uniform application
- **Foliar fertilizers** should be added to optimize your granular program.
  - Plants are forced to absorb all nutrients which land on leaves
  - Excellent for micronutrient additions or deficiencies
  - easy to get nutritional imbalance

21 ❑ How should I determine which fertilizer to use in my program?

- Use enough fertilizer to get a good distribution of material on the bed.
  - 75 to 100 lb / acre provides adequate coverage for nitrogen fertilizers

- Dispersal problems exaggerated when low volumes are used.

22 ❑ When should I use foliar fertilizers?

- Situations where foliars work well:
  - Early season when Casaron slowdown is noticed
  - Early fruitsizing when you can't get enough nutrients to your crop
  - Heavy crops in late season, especially during dry weather episodes
  - All applications of micronutrients

23 ❑ Continued....When should I use foliar fertilizers?

- Potential disadvantages:
  - Too much early season fertilizer could abort flower buds
  - Late season applications could alter the vegetative/reproductive ratio and affect next years crop.

24 ❑ How much N is carried over from one growing season to the next?

- Nitrogen carryover in the soil is minimal
- In the plant, the quantity stored in the tissue is very important.
  - In the fall, nutrients are transferred to stems and roots
  - If there is leaf drop, plants don't lose all their nutrients
- The amount of stored nitrogen appears to reflect the rate of bud break in the Spring.

25 ❑ What are the impacts of various herbicides on our nutritional program?

- Casaron
  - The primary herbicide which I've noticed to influence a nutritional program
  - A root pruner which will then affect the uptake of nutrients
  - Less root capacity equates to less nutrients, less growth, and low vigor
- Apply higher nitrogen quantities and more often; foliar another option early in season

26 ❑ How dry do my vines need to be when I fertilize?

- Thick vines capture fertilizer pellets
  - If moisture is on the leaves, fertilizers will dissolve.
  - All fertilizers have a salt content which burns tissue
  - I have seen a lot of leaf injury and some upright death.
  - Make sure all leaves and upper stems are dry, then water in well to remove fertilizer dust.

27 ❑ What do you think about applying sulfur or phosphorus on ice?

- I worry about even distribution with these two compounds
- Phosphorus may clump into areas when the ice thaws

  - P doesn't move much so you could get isolated deficiencies within small areas of the bed
- Sulfur is not active until the soil warms up. By then the dikes should be boom-ready.

The UW Cranberry Frost Forecasting System

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Introduction

Over the last two years, we have been developing an automated frost forecasting system for cranberry producing regions in Wisconsin. This system is unique in that it utilizes current weather observations from weather stations and satellites to update the initial forecast on an hourly basis. This research has been conducted as part of a project called TiSDat (Timely Satellite Data for Agricultural Management), funded by NASA under an initiative to provide increased public access to satellite data. It is a particularly timely issue now, as the National Weather Service discontinued its support of agricultural forecasts of this type in 1996.

The specific goals for this frost forecasting project are threefold. First, we strive to provide, in a timely manner, reliable forecasts of weather conditions relevant to protection against frost damage in cranberry bogs. These conditions include overnight vegetation temperatures and wind speeds. Second, we provide real-time forecast updates throughout the evening using the most recent weather measurements available. Finally, we provide easy access to these forecasts through the World Wide Web.

In this paper, we give a brief overview of the model used to make the forecasts and how it operates in practice. Forecast accuracy is compared with measurements made in two cranberry-growing regions in Wisconsin, and improvement through updates is demonstrated. We also provide a brief introduction to our cranberry forecast Web site.

Cranberry Bog Forecast Model

At the core of the TiSDat frost forecasting system is a computer model of energy transport in a cranberry bog microclimate. This model takes information from a regional forecast of weather conditions at 80 ft above the bog and scales these conditions down to bog level; conditions such as temperature, humidity, wind speed, and radiant energy from the sun and clouds. This scaling takes into account properties specific to the bog environment: the perpetually-saturated soil conditions, for example, and the thick mat of old vines beneath the new green vegetation that intercepts most of the incident radiant energy before it reaches the soil.

The model produces time traces predicting the evolution of air temperature, dewpoint and wind speed just above the bog throughout the course of the night. Most importantly, it predicts the overnight temperature course of the cranberry vines themselves. These bog forecasts yield advance warning of crop-damaging temperature conditions, along with an approximate time when minimum temperatures will occur overnight. The bog-level wind forecast can aid in making decisions concerning appropriate frost damage prevention measures.

Model Operation and Updating

The TiSDat cranberry forecast and forecast-updating system has been set up such that it runs automatically, with little human intervention beyond standard quality control. Initial conditions and updated weather observations are downloaded over the Internet as soon as they become available to assure that the forecasts and updates appear on our Web site in a timely fashion.

Currently, the upper boundary conditions in temperature, humidity and windspeed for our cranberry bog forecast model are provided by the CIMSS Regional Assimilation System CRAS, a regional forecast model run and maintained by the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin-Madison. The first CRAS forecast for the day is available at approximately 10:30AM CST. A cranberry bog forecast is then generated for specific cranberry-producing regions in Wisconsin; currently we are focusing on the areas around Cranmoor, Manitowish, and Shell Lake. These initial daily forecasts typically appear on out Web site by 11:00 AM.

As the day progresses, these initial bog forecasts are repeatedly compared with the most current observations of local weather conditions (obtained through the National Weather Surface and the state Department of Transportation) and cloud cover conditions (obtained through the GOES weather satellite). If the forecast and observations begin to deviate, the forecast is adjusted to reflect the newly-developing conditions and new time trace plots are transmitted to our Web site.

Most important to overnight bog-level temperatures, and perhaps most difficult to forecast in the long-term, is the development and propagation of regional cloud patterns. A sudden clearing of the sky overhead can result in a rapid drop in near-surface temperature of several degrees. Assimilating cloud cover information from current satellite images significantly improves the accuracy of our minimum temperature forecast. As an extra precaution, we always generate two forecasts: one assuming our current best guess at cloud development overnight, and another assuming the skies will be completely clear. The clear-sky forecast represents the worst-case scenario in terms of minimum overnight temperatures.

Forecast Verification

To aid in assessing the accuracy of our forecasts, we installed automated weather station towers in two cranberry bogs in Wisconsin: one in Cranmoor and one outside of Manitowish. These stations record half-hourly measurements of temperature, humidity and windspeed at two heights above the bog, and temperatures within the cranberry canopy itself. They also record downwelling solar and infrared radiation, important inputs to the model; the latter quantity relates to the amount of cloud cover present.

Comparisons between model predictions and measurements taken at our bog towers over the past growing season confirm the value of the updating system we have implemented. The accuracy of our initial forecast at 11AM is comparable to that obtained by American Weather Concepts (based on their statistics from 1996). Our forecast accuracy improves steadily throughout the course of the day.

Figure 1 demonstrates the updating system in action. The input CRAS forecast predicted cloudy skies over Cranmoor on May 14th 1997, when in fact it was clear that night. The cranberry forecast therefore predicted an overnight minimum bog temperature that was approximately 3° F too high. The 6PM GOES satellite image showed that this region was much clearer than initially forecast. The input CRAS forecast was statistically adjusted to reflect these new cloud conditions, and the bog model was rerun -- this updated forecast predicted a much better minimum temperature. The forecast continues to improve as the evening progressed -- by 8PM it was virtually perfect.

Web Access to the TiSDat Cranberry Forecast

Cranberry growers in Wisconsin can access the TiSDat cranberry forecast on the World Wide Web through our home page at **http://www.soils.wisc.edu/wimnext/**. Follow the link here labeled "Cranberry Bog Temperatures" and select the growing region of interest. We hope to expand this list of supported regions in the near future.

You are now on our cranberry forecast page. At the top of the page we let you know when the current forecast was produced and when you can expect our next update. Directly below this is a plot showing the current temperature forecast. The plot shows time traces of predicted temperature in the bog and at 5 ft above the bog. You have the option to overlay all measurements that have been collected up to the time of the current update.

Below this, you can view a forecast of an additional weather variable. Currently, you can choose between wind speed and dewpoint. By displaying wind speed, for example, you can easily determine what the winds will be like during the times a critical temperature threshold will be exceeded.

Conclusions

In conclusion, the UW frost forecasting system is unique in that it uses real-time surface and satellite weather observations to provide hourly improved forecasts of overnight frost conditions. The model outputs a full time trace of predicted temperatures and wind speeds throughout the evening, rather than just one, isolated minimum overnight temperature prediction. This should help growers in scheduling their frost protection activities. Access to the forecasts is fast and easy -- all forecasts and updates are published on the World Wide Web. User feedback on our homepage format is most welcome and encouraged! Send comments via the email link on the cranberry forecast page.

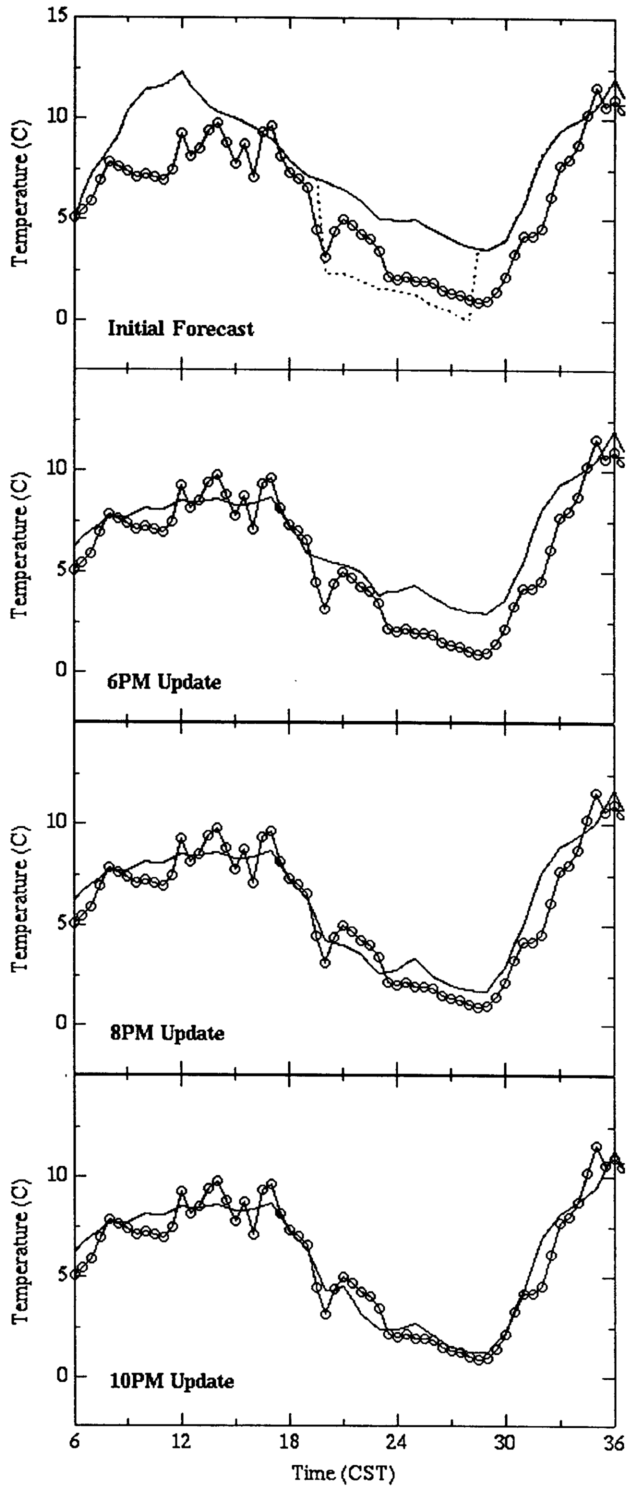

Figure 1: Effect of updates on minimum temperature forecast accuracy. Circles indicate measurements of bog temperature made with our automated weather station at Cranmoor; solid lines indicate the updated forecast at the time specified. The dotted line in the first frame shows a forecast assuming the skies will be clear overnight.

DIAGNOSING INSECT PROBLEMS

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Some insect problems are easier to diagnose than others. Insects that attack stems, leaves, flowers, or fruit are usually easy to see and fairly easy to identify. Insects that attack the root system are more difficult for two reasons. Often they are small or cryptically colored, making them difficult to find in the soil (white grubs are a notable exception). Second, sampling for soil insects is often very damaging to the planting. Another thing to keep in mind is that above ground symptoms may be similar for several different types of soil problems. Even root diseases or poor drainage may cause symptoms that are superficially similar to those cause by root-feeding insects.

Routine pest scouting is the best way to find and correctly identify potential pest problems before they become accute. Also, there is no substitute for an observant eye and a curious mind. The following is a brief synopsis for diagnosing some common cranberry insect problems.

Stem and Foliage Insects

Several types of caterpillars ("worms") feed on cranberry foliage. Only some of the most common ones will be mentioned. Other stem and foliage pests include dearness scale, flea beetle, and tipworm.

Blackheaded fireworm. Larva up to about 1/3 inch long; pale tan body with jet-black head. Spins silken webbing to tie leaves together. Two or three uprights may be tied together. Feed by removing the lower leaf surface; this is called skeletonizing. Remaining tissues turn reddish brown. Occur in spring and again during or just after bloom. Older larvae can be swept with insect net. Pheromone traps are available for monitoring adults.

Sparganothis fruitworm. Damage is similar to fireworm. Larva is about the same size, but with a pale colored head and the body has small but distinct spots. Activity may be a bit later in the growing season than fireworm. Monitoring as for fireworm.

Spanworms. Several types of spanworms can attack cranberry. All move in an "inchworm" fashion. Larvae may be brown or green, and from 1/4" long up to almost an inch. Sometimes buds and flowers may be eaten. Sweep sampling is an effective way of monitoring.

Dearness scale. Uncommon. Occurs as small white raised bumps on the stems. Vines become water stressed; stems become dry and brittle; foliage turns reddish. Best scouted by visual observation.

Flea beetle. Adults are small jumping beetles, black in color with a reddish head. They are easily picked up during sweep sampling. They skeletonize leaves in the summer, causing the leaves to turn brown as with fireworm. However, there is no silken webbing.

Tipworm. Our smallest insect pest of cranberry. The larvae are only about 2 mm long, and the adults are about the same size. They feed at the very apical growing point of the upright, causing leaves to cup around the tip, and eventually killing the tip. The best monitoring practice is to clip uprights and examine them under a microscope to find eggs and larvae.

Fruit Insects

In Wisconsin, there are three primary fruit pests.

Blackheaded fireworm. See above for larval description and monitoring. Second generation larvae can feed on the surface of the fruit but rarely do they tunnel inside. The fruit is left with a rough, open scar on the surface and usually becomes infected with secondary pathogens.

Sparganothis. See above for larval description and monitoring. Second generation larvae can feed on the surface of the fruit and will enter to the inside. The entry hole is rather rough in appearance. Fully developed larvae will pupate right in the fruit. Usually associated with the leaf injury described above.

Cranberry fruitworm. Never feed on foliage. Larvae get up to about 1/3 inch long, are pale colored with a pale head. Each larva will tunnel through several fruit. Entrance holes are very circular and clean, and often covered with a silken "window". A pheromone trap is available for adults. Monitor eggs by looking under the calyx lobes at the flower end of the fruit. Infested berries turn red prematurely; cut these with a knife to examine for larvae or injury.

Soil (Root and Runner) Insects

Cranberry girdler. This moth larva feeds near the soil surface on the roots and runners. The bark is chewed off of runners, causing girdling of the stems and resultant dieback of the uprights. Damage tends to be concentrated in patches from several to many feet in diameter. Damage occurs late in the growing season, and affected spots are often overlooked until the winter flood is removed the following spring. At this time, most of the foliage is lost. Examine runners for small patches of removed bark that appear to be chewed off. Pheromone traps are available to monitor adult moths.

Cranberry (redheaded) flea beetle. See description of the adult in leaf and stem section above. Larvae are small elongate pale cream colored insects that feed in the soil and do damage similar to cranberry girdler. However, the damage is done early in the growing season, and chewed areas of runners attempt to callous over, and may put out very weak uprights sprouting from near the area of damage. Larvae are very difficult to monitor.

White grubs. In Wisconsin, there is only one type of white grub that damages cranberry; this is the larva of the June beetle *Phyllophaga anxia*. The grubs live in cranberry soil for about three years. Because of their large size and typical **C** shape, they are easily diagnosed. In heavily infested areas the vines will appear as if affected by drought because the roots will have been removed by grub feeding. The cranberry sod will be very loose and easily lifted because there are few roots to anchor it to the soil. The grubs will usually be found right under the sod on the soil surface, or within the top few inches of soil.

General Tips for Insect Diagnosis

- Routinely use standard insect monitoring techniques.
- Be observant.
- Some insect activity occurs at night; night monitoring may sometimes be necessary.
- If you find something that you can't identify, use the university's insect diagnostic lab, which is in the Department of Entomology in Madison. The best approach is to take the specimens in to your county Extension office. They will assist you in filling out the appropriate diagnostic form and will send the materials into the lab for you. You will usually receive a response within one week. There is no charge for this service.

Update on Plant Biotechnology

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Previously, I have discussed with you various achievements in crop improvement using plant biotechnology (test-tube cloning; genetic engineering). Initially, we were talking just about 'blue sky' type of research which had great potential, but admittedly was not near commercialization. During the last few years, this situation had changed dramatically; today there are literally millions of acres planted to crops containing genes new to crops or using products obtained through biotechnology.

What I want to do here is to provide a very brief update on where and how plant biotechnology is being used in crop production. This overview is not intended to be exhaustive, but merely to provide a benchmark of progress.

There are roughly three major areas where plant biotechnology is being used in significant commercial settings:

1. GENOMICS
   - WHAT GENES DOES AN ORGANISM CONTAIN?
2. NEW PLANTS
   - RESISTANCE, TOLERANCE, QUALITY
3. NEW 'CHEMICAL' CONTROL AGENTS
   - BIOPESTICIDES

Plant genomics involves deciphering the genes and genetic relationships in crop plants. For example, there are major efforts underway to identify ALL the genes in some of our major crop species. In addition, such work has progressed well in cranberry with the published research from Nick Vorsa's laboratory in New Jersey.

The genetic improvement of our crop plants themselves is probably the most active area of plant biotechnology. As can be seen in Table 1, the majority of the work involves agronomic crops and either pest resistance using the B.t. genes or tolerance to broad-spectrum herbicides. However, there is also considerable work on using biotechnology to make plants produce economical products that they previously could not naturally synthesize. Most of these activities involve pharmaceuticals (Table 2) and are collectively being called 'pharming'.

In addition to using biotechnology to directly improve the crops we grow, various products used in crop production have been created using biotechnology. These primarily involve 'biopesticides' and 'biofungicides' (Table 3).

All this activity in introducing new crops and products has also been accompanied by considerable corporate restructuring. In most cases, such restructuring has involved extensive consolidation of companies to form large and multi-faceted conglomerates. A good example is Monsanto which has incorporated a large number of companies, some of which are listed in Table 4. These large conglomerates usually contain not only a unit that produces and markets select chemicals such as herbicides, but also seed companies (breeding, seed marketing), biotechnology research and development units, and a pharmaceutical arm.

One complication that has rapidly arisen in crop biotechnology and is a major limitation to the full use of this revolutionary tool is disputes over ownership of genes and molecular methodologies. For example, the use of B.t. genes is complicated by a multitude of patent infringement lawsuits between Mycogen, Monsanto, DeKalb Genetics, CIBA-Geigy, Pioneer Hi-Bred, and Plant Genetic Systems, among others. Unfortunately, such turmoil and uncertainty as to who-owns-what creates major problems when a smaller group, such as cranberry growers, wish to access the technology.

One previous complication, that of securing approvals to commercialize the genetically engineered crop, has been much reduced in importance, at least in the U.S. and Canada. Major problems with government approvals can be expected to arise, however, if the crop cannot pass a number of assessment criteria (Table 5).

In summary, the commercialization of crop biotechnology is certainly well along and very active. For example, in 1997 alone, more than 20 million acres of U.S. farm land were planted to crops engineered with the B.t. gene. Biotechnology is being utilized more and more routinely in normal, everyday plant breeding activities, but more and more the fruits of this labor are being sequestered by large, multi-faceted companies.

Table 1. Examples of crops that are presently being grown commercially and have been modified using biotechnology.

COMPANY	CROPS	NEW TRAITS
MONSANTO ('ROUND-UP READY')	CORN POTATO SOYBEAN	HERBICIDE TOLERANCE PEST RESISTANCE (Bt)
CALGENE ('BXN')	COTTON	PEST RESISTANCE (Bt) OIL QUALITY (SOAPS, DETERGENTS)
AGRAEVO ('LIBERTY LINK')	CORN CANOLA	HERBICIDE TOLERANCE
DEKALB GENETICS ('DEKALBt')	CORN	PEST RESISTANCE HERBICIDE TOLERANCE
DNAP ('FRESHWORLD')	TOMATO CARROT PEPPERS	LONG SHELF LIFE SWEETNESS
DUPONT ('OPTIMUM"	SOYBEANS	NUTRITIONAL OIL QUALITY
GARST SEEDS	CORN	HIGH pH TOLERANCE DISEASE RESISTANCE
NOVARTIS (' MAXIMIZER')	CORN	PEST RESISTANCE (Bt)
PIONEER HI-BRED ('IMI')	CORN CANOLA	HERBICIDE TOLERANCE
SEMINIS SEEDS ('FREEDOM II')	SQUASH	VIRUS RESISTANCE

Table 2. Some examples of advanced research that uses plant biotechnology to engineer plants to produce high valued pharmaceuticals ('molecular pharming').

- EDIBLE VACCINES
    - PROTEIN PRODUCED IN EDIBLE PLANT PARTS INDUCES IMMUNITY
        - BANANA
    - BEST WITH DISEASES THAT ATTACK MEMBRANES
        - DIARRHEA
- AUTOIMMUNE DISEASES
    - MULTIPLE SCLEROSIS
- PLANTIBODIES
    - PLANT PRODUCES MONOCLONAL (VERY PURE) ANTIBODIES
    - Example: TOOTH DECAY
        - *STREPTOCOCCUS MUTANS*
        - PREVENT COLONIZATION IN MOUTH BY EATING PLANT CONTAINING A 'PLANTIBODY' FOR THIS ORGANISM

Table 3. Biopesticide products that have involved biotechnology in their production.

COMPANY	PRODUCT	ACTION
AGRAQUEST	LAGINEX	MOSQUITO CONTROL
ECOGEN	ASPIRE, AQ-10 CONDOR/CUTLASS	PEST, DISEASE CONTROL ON VEGETABLES, FRUITS
MYCOGEN	MATTCH, MVPII, M-PERIL, M-PEDE,	PEST, DISEASE CONTOL ON VARIOUS CROPS

Table 4. The formation of a large and very diverse biotechnological conglomerate under the parent firm Monsanto.

MONSANTO =

- CALGENE
- DOW ELANCO/MYCOGEN
- AGRACETUS
- ECOGEN
- DEKALB GENETICS
- HOLDEN SEEDS
- CORN STATES INTERNATIONAL
- ASGROW
- MONSOY (Brazil)
- ++++++++++

Table 5. Some critical assessment criteria used to evaluate whether the commercial introduction of a genetically engineered crop will create an environmental or ecological hazard.

<u>WHAT IS THE POTENTIAL:</u>

- TO BECOME A WEED
    - IMPACT NATURAL HABITATS?
- FOR GENES TO MOVE TO WILD
- TO PRODUCE A TOXIN/ALLERGIN
- IMPACT ON NON-TARGET ORGANISMS
- IMPACT ON BIODIVERSITY

Understanding Cranberry Frost and Winter Hardiness

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Study of the cranberry plant's cold hardiness levels throughout the year has long been considered to be important by growers. Better and more complete information on the ability of the cranberry plant to reisist freezing stress damage will aid in making better frost and winter management decisions. The goals of our research program are to: 1) define seasonal changes in cranberry hardiness; 2) learn about the mechanisms the cranberry plant utilizes to survive freezing stress; 3) develop a predictive model linking plant development and hardiness, based on field temperatures; and 4) develop recommendations for improved frost and winter management. For the last two years we have focused on investigating leaf and bud hardiness in the spring and fall, fruit hardiness in the early fall, the possibility of significant hardiness changes under the winter ice, and the collection of field temperature data.

General methodology

Samples for all of our experiments were collected from 'Stevens' beds in the Nekoosa area. Samples were cut and moistened, and then transported on ice to our laboratory in Madison. Uprights were sorted, cut to a uniform length, and prepared in large test tubes for freezing in a circulating glycol (antifreeze) bath. Temperatures in the bath were lowered incrementally and held for 30 minutes. Samples were removed at given temperatures and then allowed to thaw slowly. Damage to parts of the uprights were evaluated visually both soon after the experiment as well as after a period of weeks during which the uprights were allowed to regrow in the laboratory or the greenhouse.

Spring leaf and bud hardiness

Q1: How hardy are terminal buds and leaves in the spring?

Q2: How does bud and leaf hardiness relate to crop phenology?

All spring samples were sorted according the stages of bud present. Those stages are: tight bud, swollen, cabbagehead, bud break, bud elongation, rough neck, hook, and bloom. Color illustrations of these stages were published in the February 1997 issue of *Cranberries* magazine. Changes in the distribution of bud stages present over time (ultimately related to climatic conditions) is referred to as the crop's phenology. In the spring of 1996 and 1997 our freezing experiments focused on defining the hardiness of buds and leaves at particular bud stages (and in 1996 throughout the growing season) (Figures 1 to 3 and Table 1). The most numerous bud stages present on a given sample date were selected for the freezing experiment.

A1: <u>Last year leaves</u> appear to be initially hardy to ~ 6 to 10 °F, then deacclimate some time in mid-May, eventually reaching a hardiness ~ 25 to 28 °F. <u>Current year leaves</u> are hardy to only 32 °F when first emerging. This new growth develops a hardiness of ~ 20 °F by early summer. <u>Terminal buds</u> appear to be hardy to ~ -10 to -8 °F when the winter flood is first drained. By the time of bud break they can only resist temperatures to ~ 28 to 30 °F.

A2: The cranberry plant becomes more sensitive with changes in phenology (across bud stages). However, deacclimation can occur without changes in phenology (within a given bud stage).

What next? Our studies show that cranberry hardiness and phenology are related to the temperatures the plants experience. From the data we are collecting, our goal is to develop a model to predict both development and hardiness during the spring.

Early fall fruit hardiness

Q3: Can fruits survive temperatures much below 32 °F ?

Q4: Are there differences in fruit hardiness based on degree of ripening?

We tested fruits that were <50% blush/red and >50% blush/red (Figures 4 and 5). Damage was evaluated as the percent watersoaking seen on the cut surface of fruits. When damage was induced, less ripe fruits typically showed more severe damage. This pattern of damage suggests that cranberry fruit survive freezing stress by supercooling (the avoidance of the formation of ice in the tissues, or the maintenance of liquid water at sub-freezing temperatures). This idea is supported by observations we made using the technique of infrared video thermography (IVT). Using IVT, we are able to "watch" freezing events as the heat given off by freezing water is visually depicted on a television monitor. This work suggested that cranberry fruit do not self-nucleate (freeze from within) and that the only external source of ice propagation is through the calyx end of the fruit. We also performed duration experiments on fruit and found that ripe fruits were able to withstand 25°F for up to one hour.

A3: Full size fruit appear to be able to survive temperatures down to ~ 25 °F for up to one hour.

A4: Less ripe fruits were found to be more sensitive to sub-freezing temperatures than more ripe fruits.

What next? Further study of the development and structure of fruits will increase our understanding of how they survive freezing stress.

Fall leaf and bud hardiness

Q5: How does leaf and bud hardiness change in the fall?

In the fall of 1996 we sampled uprights weekly from three different beds and performed freezing experiments. Sampling began in mid-September and continued until mid-December just prior to the winter flood. After thawing, uprights were given additional chilling hours to break dormancy, and then were planted in the greenhouse. Figure 6 depicts the changes in hardiness throughout the fall.

A5: By the beginning of November, buds and leaves are hardy to ~ -15 °F. Some hardiness was temporarily lost as a result of the flooding and physical damage associated with harvest.

What next? We are repeating this set of experiments to confirm these data.

Hardiness levels under the winter ice

Q6: Does the hardiness of the cranberry plant change under the winter ice?

In mid-March of 1997 we obtained samples from under the winter ice. In relation to hardiness levels in mid-December (just before the winter flood) and mid- April (just after removal of the winter flood), cranberry bud and leaf hardiness levels (°F) were determined as follows:

	12/18/96	3/10/97	4/15/97
leaves	≤ -13	~ 14	10
buds	≤ -13	~ -4	≤ -8

A6: It appears as though leaves deacclimate somewhat under the ice, while the hardiness of buds do not appear to change greatly.

What next? We will be repeating this experiment to confirm these data.

Conclusion

A picture of the cyclical nature of the cold hardiness of the cranberry plant is gradually emerging from our data. We are looking forward to further study of hardiness levels, as well as to the creation of a predictive development and hardiness model, and to continued study of bud and fruit development.

Acknowledgements

We thank Dr. Jonathan D. Smith for providing valuable help and field facilities for the conduct of these studies. Financial support for this research was provided by the Wisconsin State Cranberry Board and by the College of Agriculture and Life Sciences, University of Wisconsin-Madison.

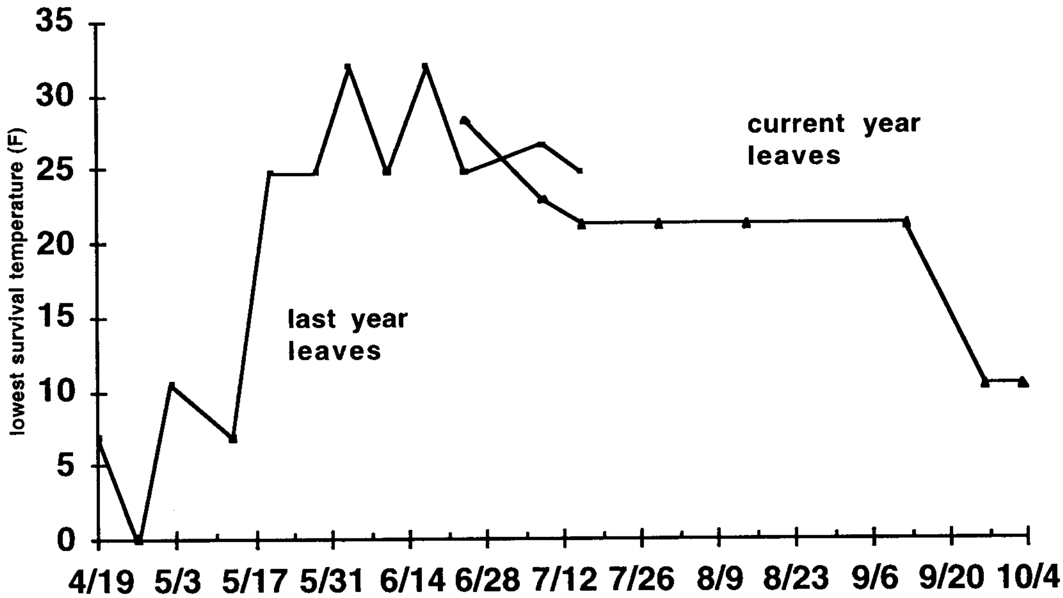

Figure 1. Lowest survival temperatures of last and current year leaves from samples collected throughout the 1996 growing season.

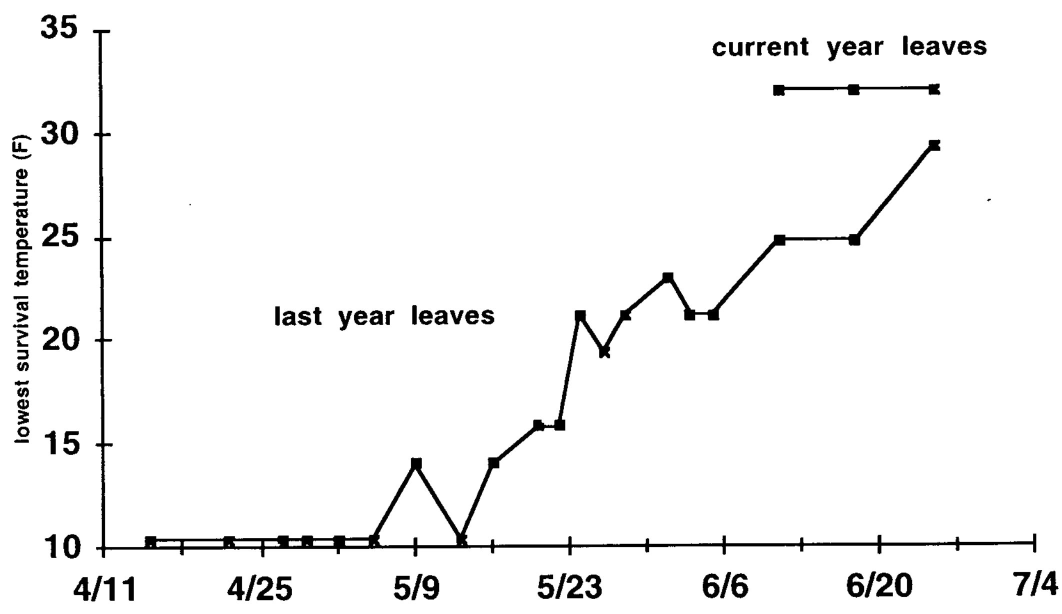

Figure 2. Lowest survival temperatures of last and current year leaves from samples collected in the spring of 1997.

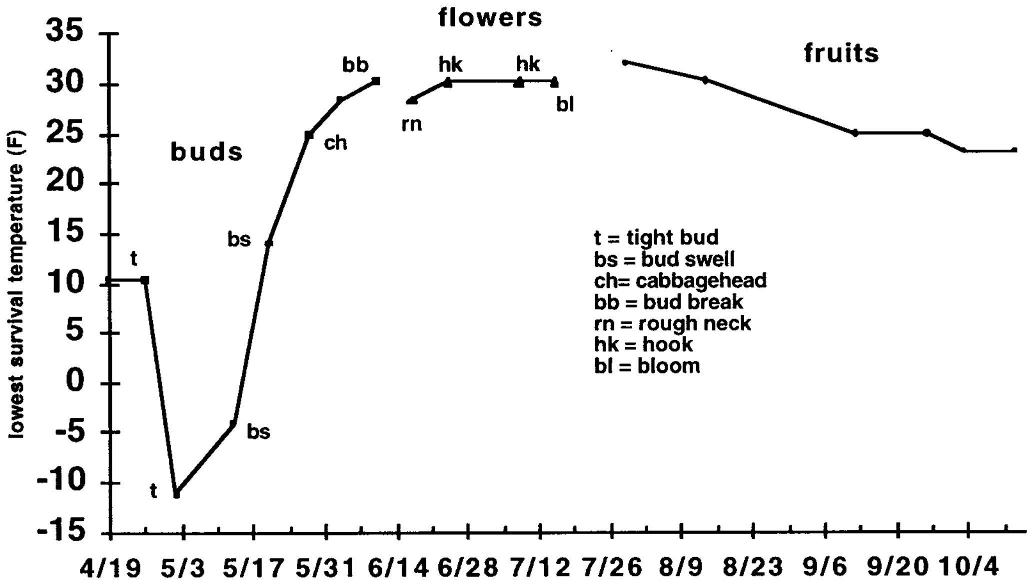

Figure 3. Lowest survival temperatures of terminal buds, flowers, and fruits from samples collected throughout the 1996 growing season.

	T	BS	CH	BB	BE	RN	EH	HK
4/15	≤ -8	≤ -8						
4/22	~ 0	~ 0						
4/27	≤ -8	≤ -8						
4/29	≤ -8	≤ -8						
5/2	3	3						
5/5	≤ -4	≤ 0						
5/9	~ 10	~ 10						
5/13	10	16						
5/16	10	14						
5/20	10	~ 23						
5/22	14	23						
5/24	21	25						
5/26	25	25						
5/28	25	25	28					
5/30		28	28	32				
6/1		> 25	28	28				
6/3			28	28	29			
6/5				30	30	32		
6/11					30	32		
6/18						30	32	32
6/25								32

Table 1. Lowest survival temperatures of terminal buds (°F) from samples collected in the spring of 1997. T=tight, BS=bud swell, CH=cabbagehead, BB=bud break, BE=bud elongation, RN=roughneck, EH=early hook, and HK=hook.

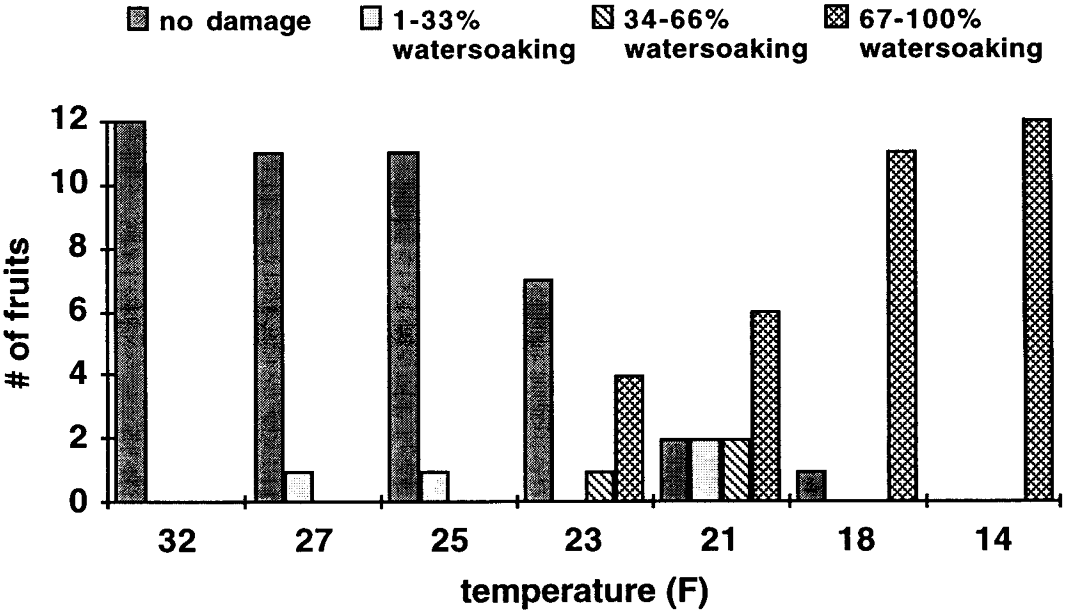

Figure 4. Severity of freezing damage to cranberry fruits <50% blush. A total of 12 fruits was tested at each temperature. Sample was collected on 9/17/97.

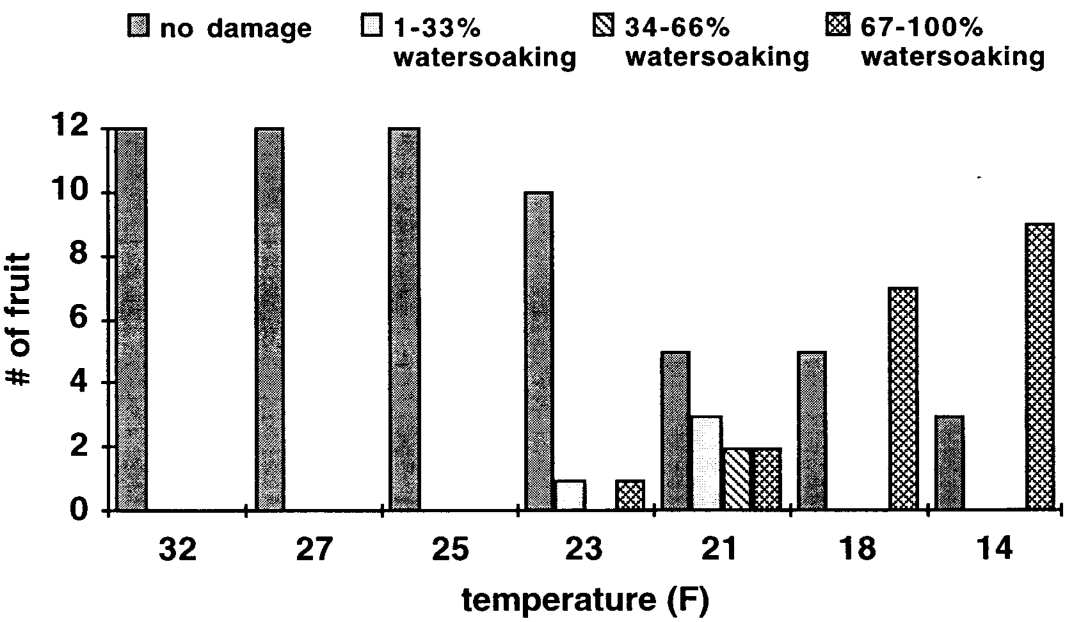

Figure 5. Severity of freezing damage to cranberry fruits >50% blush. A total of 12 fruits was tested at each temperature. Sample was collected on 9/17/97.

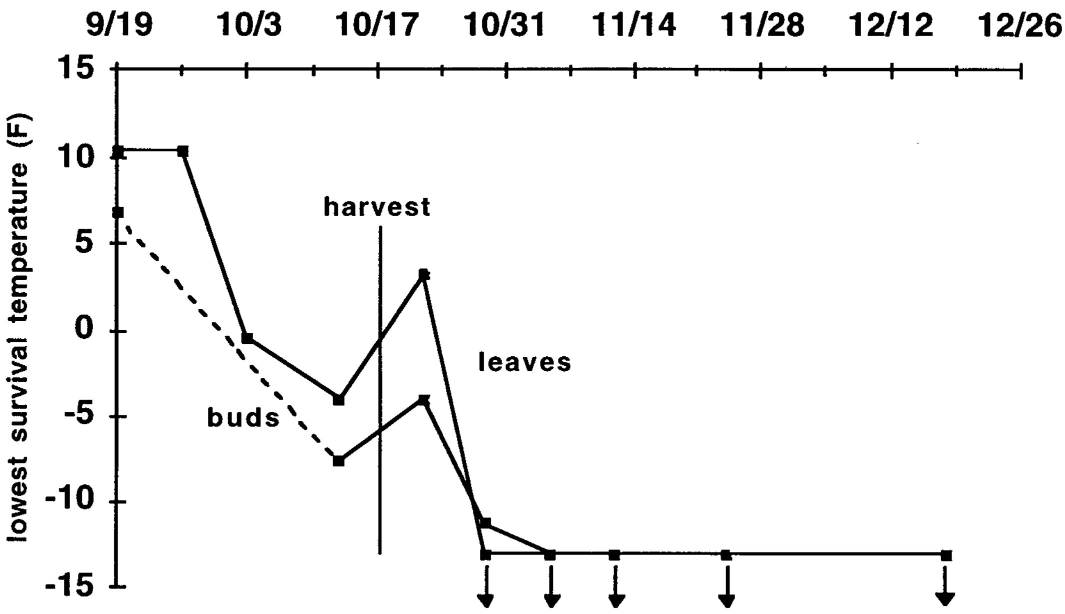

Figure 6. Lowest survival temperatures of terminal buds and leaves from samples collected in the fall of 1996.

Using Natural Lipids to Accelerate Ripening and Uniform Color Development and Promote Shelf Life of Cranberries

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Introduction

Cranberry fruit ripens in late fall when the crop is subjected to frost daily. Wisconsin growers are forced to harvest less than ripe fruits. Some seasons such as in 1995 and 1997 we do not get good color development due to less than optimal environmental conditions. Unripe fruit means less natural color and flavor and thus less economic yield. We have also found that more ripened fruit means better shelf life. Thus the goal of our study is find natural (environmentally safe) means to accelerate ripening and promote shelf life of cranberry fruit. No such product is currently available to our growers. The following were the **specific objectives of our 1997 studies:**

1) To investigate the effect of **pre-harvest spray application of natural lipid (LPE) on color** production (ripening) of cranberry fruit intended for both fresh and juice markets.

2) To investigate the effect of **pre-harvest LPE spray application on the shelf life** of cranberry fruits intended for fresh markets.

3) To investigate the effect of **post-harvest LPE dip treatment on the shelf life** of cranberry fruits intended for fresh markets.

What is LPE?

LPE is a natural fat molecule which is part of the membranes in all plants and animals. The molecule contains two parts, a polar head group that sticks out of membrane and a fatty acid tail which is buried into the membrane. We have recently found that both the length of the fatty acid tail and degree of unsaturation (it is more saturated when extracted from animal source and more unsaturated when extracted from plant source) determines the bioactivity of LPE molecule.

Desirable Attributes of LPE

1. LPE is a natural fat present in all plants and animals. It can be extracted from cheap raw products such as egg yolk, bovine brain and soybeans. For our experiments we are using LPE extracted from egg yolks.
2. LPE can accelerate fruit ripening (color development) while at the same time improving shelf life. No such product is currently available.
3. Both pre and post harvest application of LPE have been found to enhance shelf life. This has been demonstrated for several fruits including apples, tomatoes, peaches and grapes.
4. LPE treatment to cut flowers can enhance the shelf life.
5. LPE has been found to retard the process senescence or aging in plants. It has been shown that LPE treatment can inhibit enzymes that are activated during senescence (that lead to breakdown of cell membranes e.g. phosholipase D)

General Methodology

A commercial cranberry bed (cultivar Stevens) established near Yellow River, Wisconsin, was used to conduct the field work. LPE applications were made both pre- and post-harvest:

1. Pre-harvest LPE spray applications:

LPE (200 ppm) spray applications were made in two different bogs two weeks before the harvest. Plot size was 2×2 meter (about 40 square feet). For fruit color, samples were harvested one and two weeks after spray application. Anthocyanin content of fruits were measured by using standard commercial techniques (by extracting in 85:15 v/v HCl and ethanol mixture). For determination of shelf life wet harvested fruits were stored in commercial cold storage. After five weeks of storage the percent marketable fruits were determined.

2. Post-harvest LPE treatments:

Commercially wet harvested cranberry fruits were dipped into various solutions at room temperature for 15 and 30 minutes. The dip solution contained 0, 50 or 100 ppm LPE. After dip treatments berries were drained and kept in cold storage. Ethylene and CO_2 (respiration) production by the fruit was measured using a gas chromatography after two to three weeks of storage. The percent marketable berry was determined after two months of cold storage.

Results

Both pre- and post-harvest LPE treatments improved the quality and shelf life of cranberry fruits (Figure 1 and 2). Pre-harvest LPE sprays resulted in better color (at harvest). Our results show that an application of 200 ppm LPE sprays can increase 33% anthocyanin accumulation over the control. Also, these berries had improved shelf life. We found a18% increase in marketable fruits after five weeks of cold storage (Figure 1).

Post-harvest LPE treatments also increased the percent marketable berries after two months of storage (Figure 2). Berries that were dipped for 15 minutes in 50 ppm LPE solution had 21% increase in the marketable fruits over the control. Ethylene production and respiration by the fruit was found lower in 50 ppm LPE treated fruits as compared to control (Figure 3).

Conclusion

Pre- and post-harvest LPE treatments have the potential to improve cranberry fruit color and improve its storability.

Acknowledgments

We thank Dr. Jonathan D. Smith for providing valuable help and facilities for the conduct of these studies. Financial support for this research was provided by the Wisconsin State Cranberry Board and by the College of Agriculture and Life Sciences, University of Wisconsin-Madison.

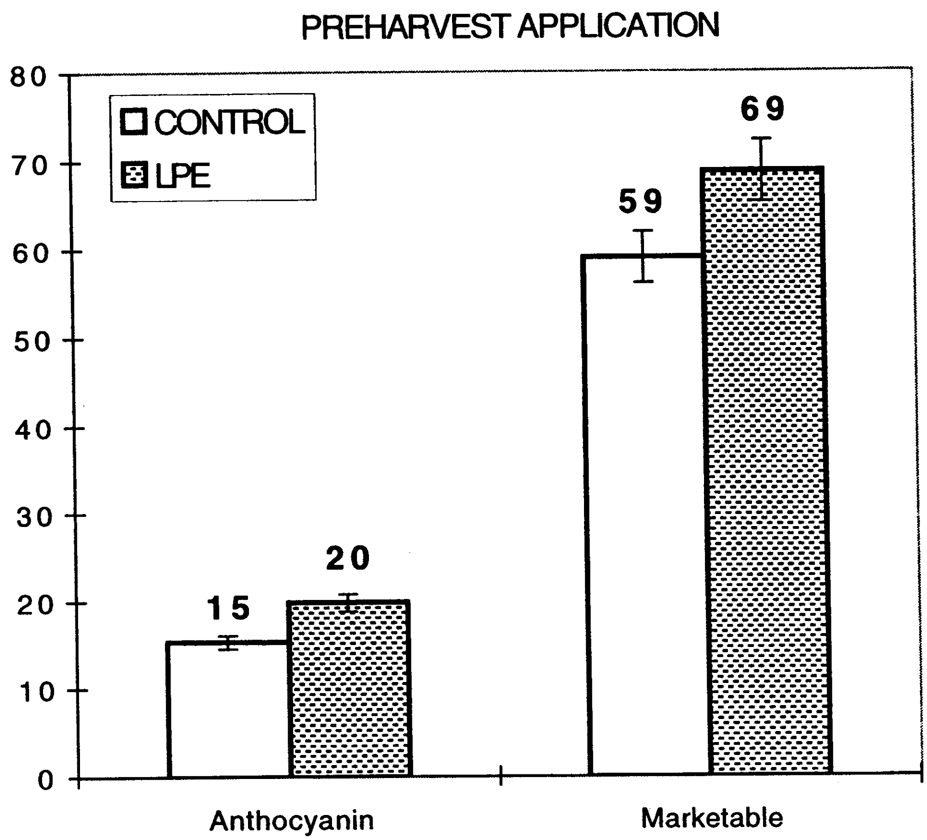

Figure 1: Effect of pre-harvest application of LPE on fruit ripening (color) at harvest and shelf life during storage. Spray application of LPE (200 ppm) were made on a commercial field. For fruit color, samples were harvested one week after spray application. For shelf life, wet harvested fruits were stored in commercial cold storage facility for five weeks. Treatments were applied to four separate plots with in a field. From each plots duplicated samples were evaluated for marketable quality.

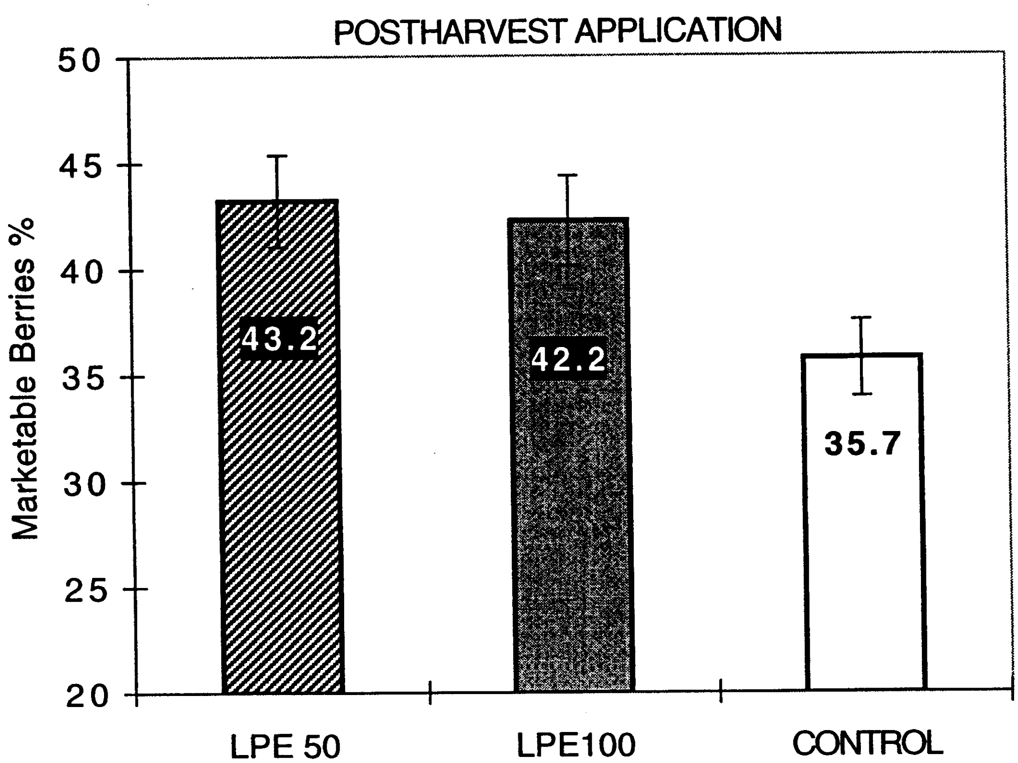

Figure 2: Effect of post-harvest dip treatments with LPE on shelf life of cranberry fruits. Berries were dipped for 15 minute in various solutions at room temperature. Marketable berries were counted after two month cold storage. Each sample consisted of 500 grams of sample. Values are mean ±SE of four separate samples.

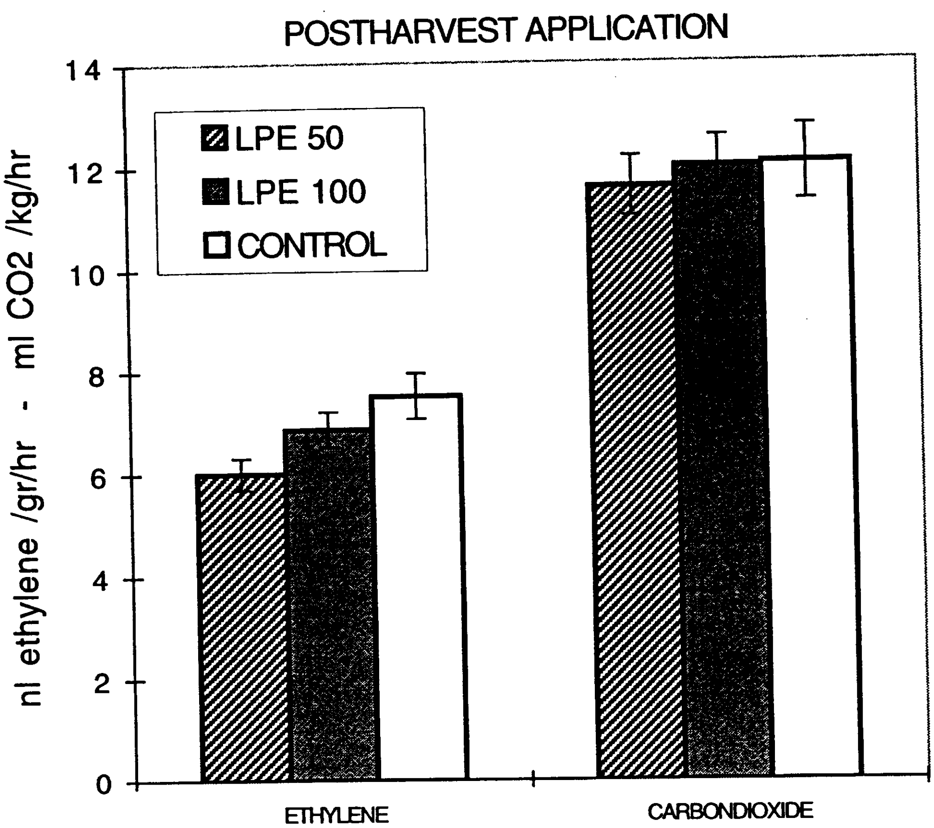

Figure 3: Effect of post-harvest dip treatments on fruit respiration and fruit ethylene production. Cranberries were dipped for 15 minutes in various solutions of LPE at room temperature. Then, fruits were stored in cold room. Two to three weeks later ethylene and carbondioxide measurement were made. For this purpose 50 gram of berries were incubated at room temperature in sealed (air tight) jars for 24 hours for ethylene and 30 minutes for carbondioxide. Ethylene and CO_2 given off by the fruit was quantified by injecting 1 ml. of gas into gas chromatograph (Shimadzu GC-9AM). Data are mean ±SE of four separate measurements.

Relationship between Fruit Color (ripening) and Shelf Life of Cranberries: Physiological and Anatomical Explanation

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Introduction

In general it is agreed that ripened cranberries store better. However no data on this aspect are currently available. This study was conducted with the **following objectives** in mind:

1. To determine qualitative relationship between fruit color (ripening) and shelf life.
2. To determine the physiological properties of the fruit (ethylene production, respiration) that might explain the observed relationship between fruit color and shelf life.
3. To determine the anatomical properties of the fruit (fruit cuticle thickness, wax, sealing of the calyx end) that might explain the observed relationship between fruit color and shelf life.

The fruit develops color in the outer two cell layers in response to low temperatures and incident light. Berries at the top of the canopy generally develop full red color whereas fruits in the lower part of the canopy (especially under dense canopies) can remain white (snow balls) even at harvest time. This is especially true for Wisconsin grown cranberries. Wet harvested cranberries are stored for 1-2 months and sold at Thanksgiving and Christmas time. We investigated if the storage quality of fruit is dependent on ripening state.

General Methodology

Wet harvested cranberries (cultivar Stevens) were sorted into four different ripening stages along with size of berries: dark red (55-59/100g), light red (57-65/100 g), blush (61-68/100 g) and white (63-69/100g). Berries were rated for quality after 4 and 7 weeks of storage. In addition, fruit respiration (CO_2) and ethylene production, as well as anthocyanin content were measured after 4 weeks of storage.

Results

There were large differences in anthocyanin content among the groups selected (Figure 1). About four times more anthocyanin accumulation was observed in dark red berries as compared to light red berries.

The storage quality of the fruit was significantly effected by the ripening stage at the time of storage (Figure 2). At the end of the 7 weeks of storage the percent marketable berries were 82, 75, 63 and 56 in dark red, light red, blush and white group respectively. Between 4 to 7 weeks of storage only 6% of the dark red berries spoiled as compared to 17% of white berries spoiled in the same period.

A higher respiration rate appears to be associated with poor shelf life (Figure 3). Carbondioxide production by the fruit was doubled in the white berries as compared to dark red berries.

Rate of ethylene production by the fruit did not change significantly among the four groups (Figure 4). It is interesting to note that ethylene production by the fruit is much lower than respiration rate.

There were significant differences in total soluble solids (brix) content of the four groups. **The berries that had higher anthocyanin content, had also had higher soluble solids measured (Figure 5).**

Our result also show that cranberry fruit has variable cuticle thickness at different ripening stage. We found that **ripened fruit had thicker cuticle**. Cuticle thickness of white berries was about 1.62 µm, and of dark red berries was 2.33 µm. (Figure 6).

Although there are no data available at this point, some of our recent observations suggest that dark red berries have more wax accumulation on the berry surface and at the calyx end of the fruit. The observations suggest that during ripening fruit surface is more sealed off from the environment which might help to reduce the penetration of organism in the fruit during wet harvest. These observations may help to explain better shelf life of ripened fruit.

Conclusion

Our study showed that ripened cranberries have better storage life and higher quality. As fruit ripens, rate of anthocyanin accumulation increases rapidly. Our results show that low fruit respiration and thicker cuticle contribute to better shelf life of ripened fruit.

Acknowledgments

We thank Dr. Jonathan D. Smith for providing valuable help and facilities for the conduct of these studies. Financial support for this research was provided by the Wisconsin State Cranberry Board and by the College of Agriculture and Life Sciences, University of Wisconsin-Madison.

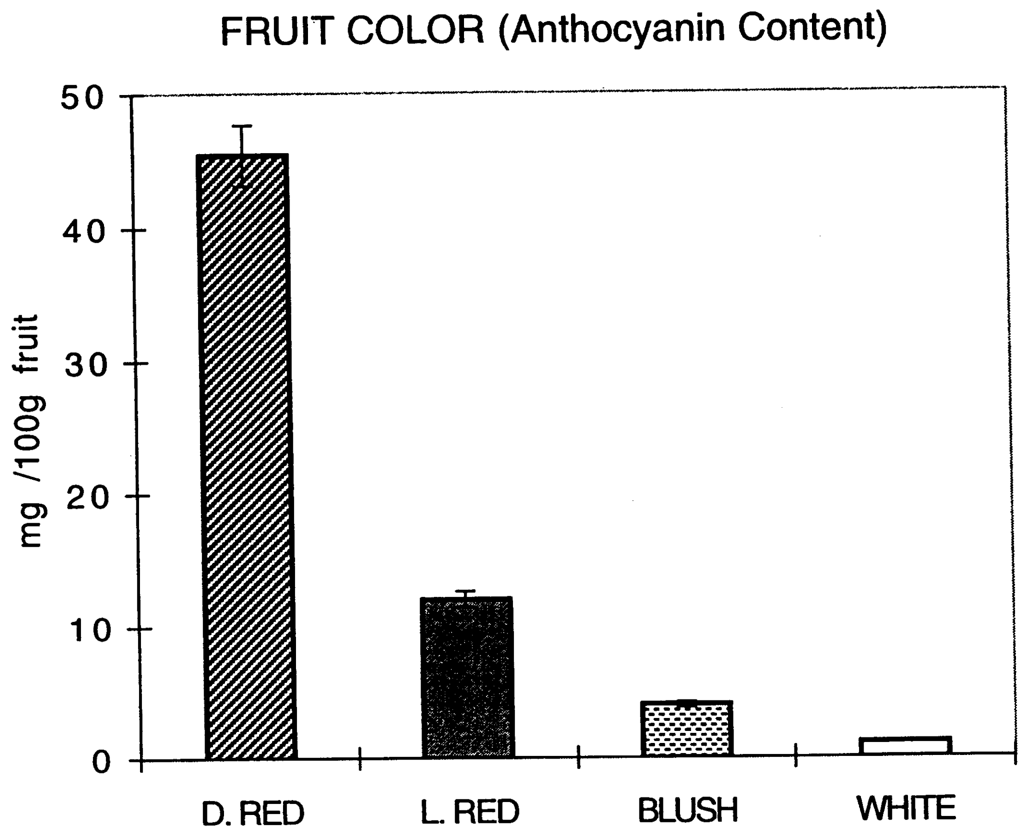

Figure 1: Anthocyanin (color) contents of cranberry fruit as related to ripening stage. Wet harvested cranberry (cultivar Stevens) fruits were sorted in four different categories depending upon the fruit color. For anthocyanin contents 100 g. of fruit were ground in 1.5 N HC1 and ethanol (15:85 v/v) buffer solution. Anthocyanin contents were quantified with a spectrophotometer (535 nm). Data are mean ±SE of three separate measurements. D.Red:dark red, L.Red:light red.

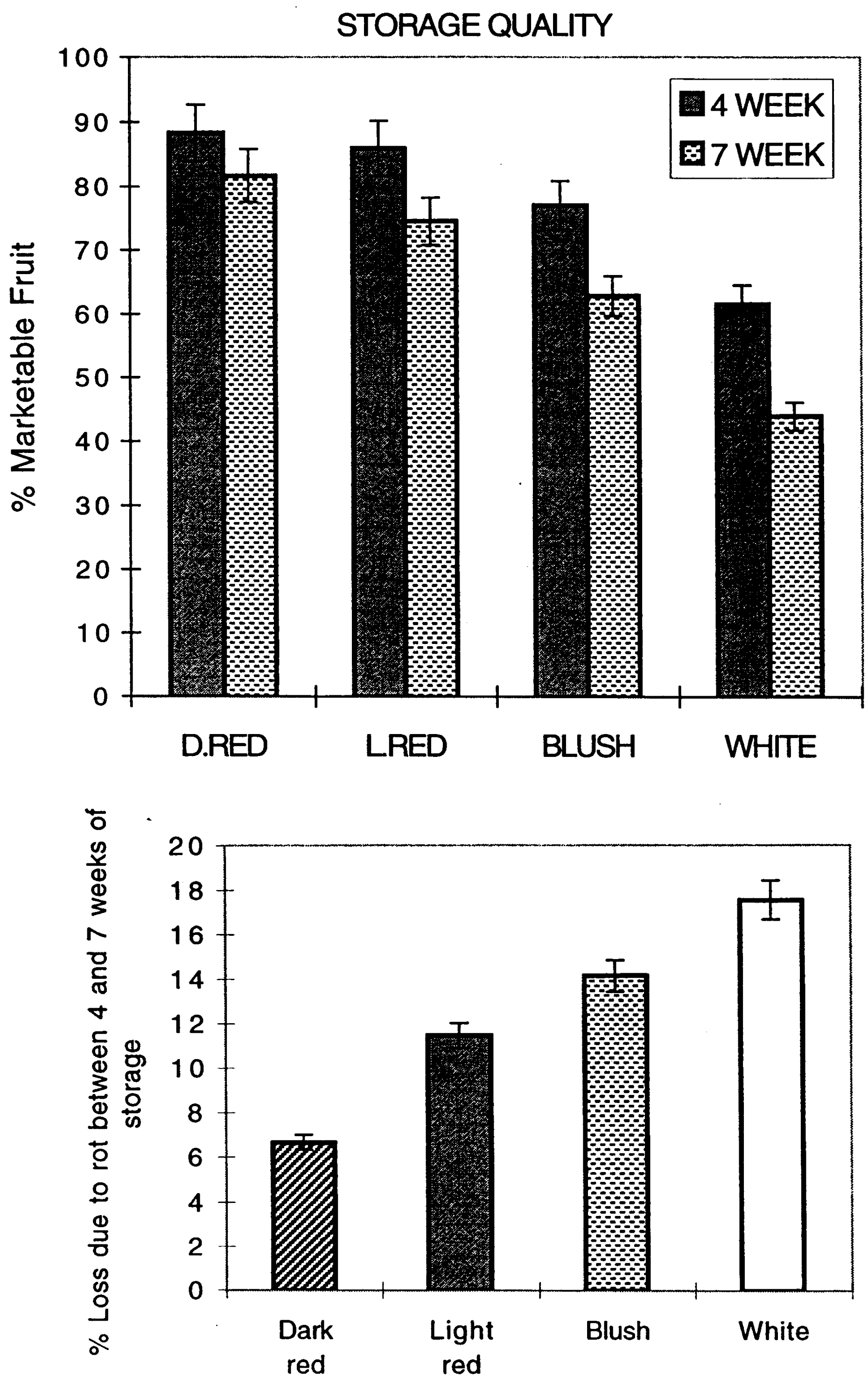

Figure 2: Impact of fruit color on shelf life. Fruits were stored in a commercial cold storage for 4 and 7 weeks and evaluated for marketable quality. Data are mean ±SE of five separate measurements.

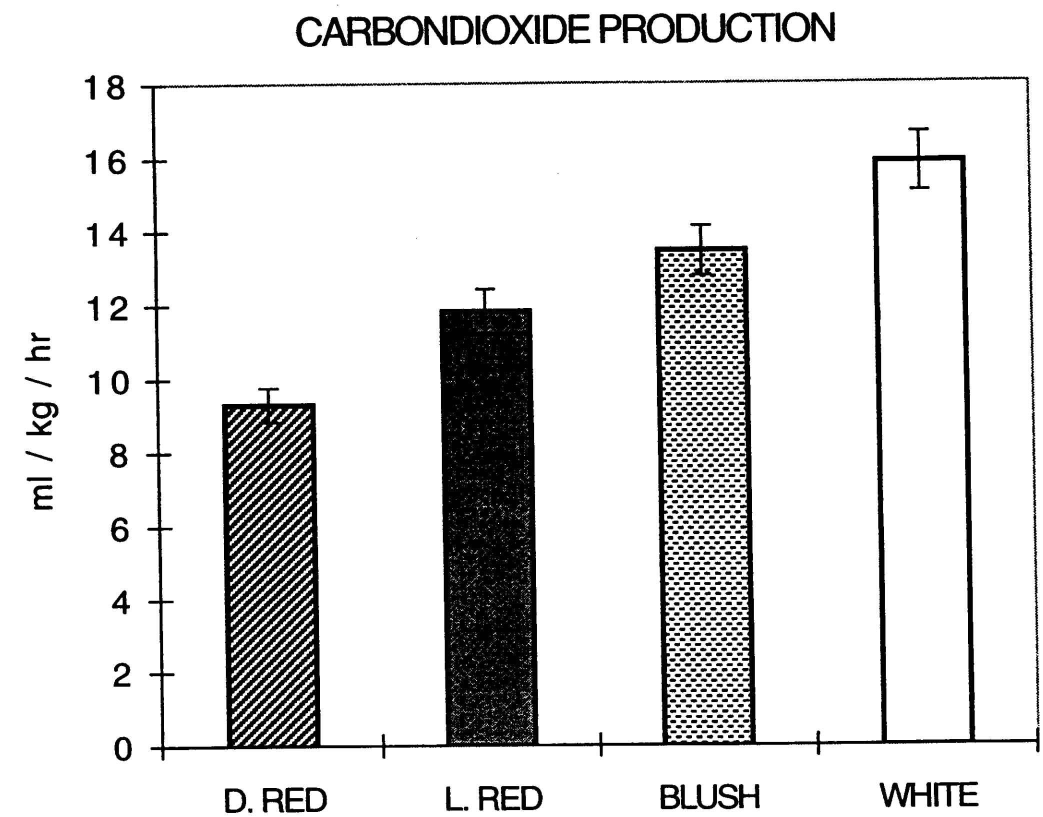

Figure 3: Fruit color as related to fruit respiration. For fruit respiration measurement 50 grams of berries were incubated in sealed (air tight) glass jars for 30 minutes. Carbondioxide given off by the fruit was quantified by injecting 1 ml. of gas into a gas chromatograph (Shimadzu GC-9AM) equipped with Methanizer and integrator. Data are mean ±SE of four separate measurements.

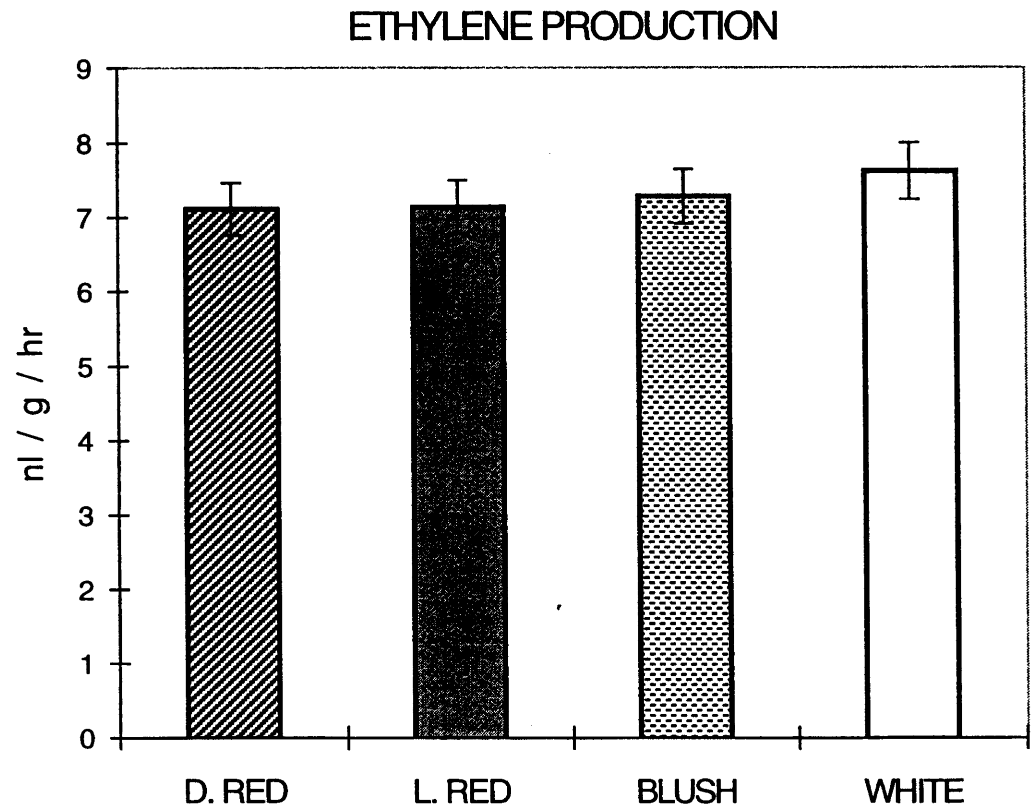

Figure 4: Fruit color as related to ethylene production by fruit. For ethylene measurement 50 grams of berries were incubated in sealed (air tight) glass jars for 24 hours. Ethylene given off by the fruit was quantified by injecting 1 ml. of gas into a gas chromatograph (Shimadzu GC-9AM) equipped with flame ionization detector and integrator. Data are mean ±SE of four separate measurements.

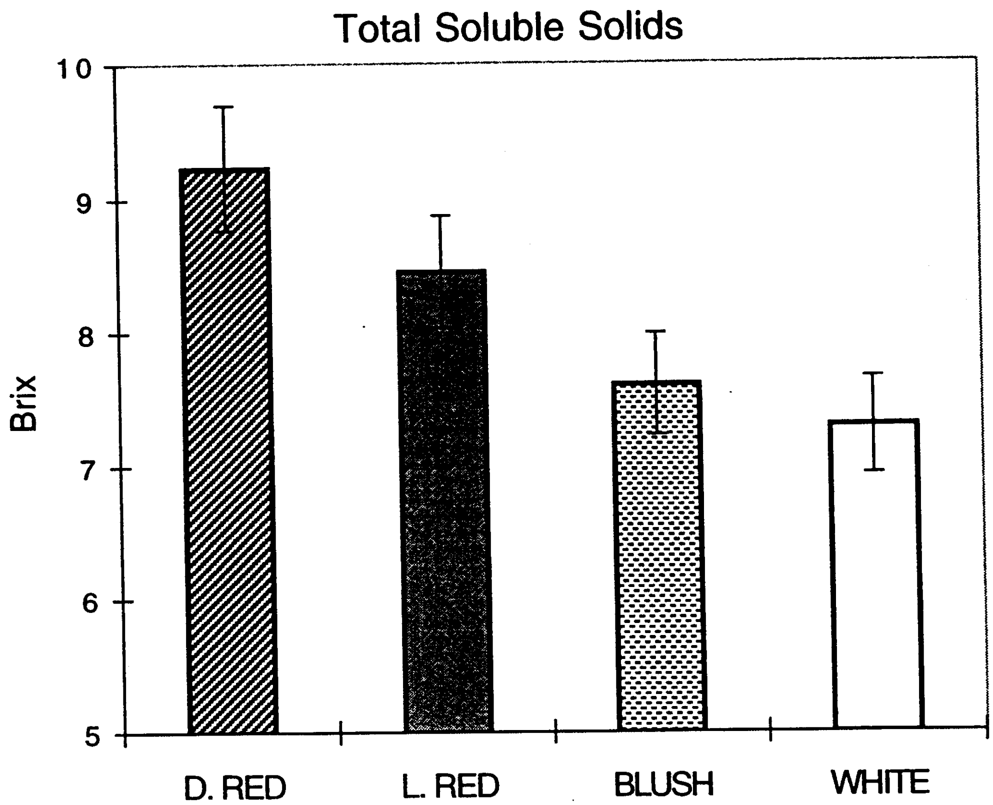

Figure 5: Fruit color as related to total soluble solids (TSS). Fruit juice was extracted and TSS was measured as brix by using hand refracrometer. Data are mean ±SE of seven separate measurements.

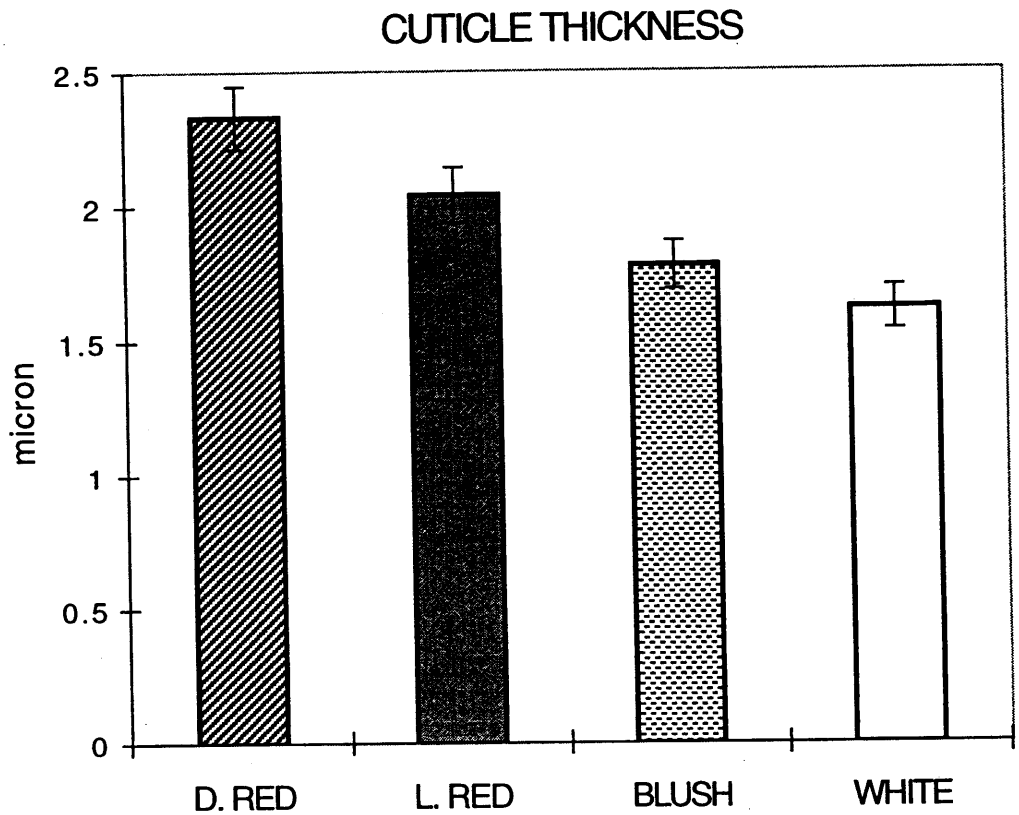

Figure 6: Fruit color as related to fruit cuticle thickness. Fruit cross section (150 µm) were made using a vibrotome. Cuticle was measured with the help of a light microscope equipped with a video output. Data are mean ±SE of twenty separate measurements.