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THE POTENTIAL IMPACT OF ICE-MINUS BACTERIA AS A FROST PROTECTANT IN NEW YORK TREE FRUIT PRODUCTION

John M. Love and William H. Lesser

Department of Agricultural Economics
New York State College of Agricultural and Life Sciences
A Statutory College of the State University
Cornell University, Ithaca, New York 14853

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ABSTRACT

Ice-nucleating bacteria, which are known to occur naturally on many crops and have been associated with frost damage, may be subject to control with genetically engineered bacteria, dubbed "ice-minus" bacteria. Ice-minus technology is designed to depress the critical temperature at which frost damage begins by displacing the natural population of ice-nucleating organisms, and a trial product has been tested in the field with strawberries. Although tests with bactericidal compounds have suggested other mechanisms for controlling the critical temperature in deciduous fruit crops, ice-minus may prove to be effective. This analysis examines the possibility of ice-minus being adopted by New York tree-fruit growers and the likelihood of it causing a major economic impact on the state's fruit industry.

New York's fruit industry is located primarily in two regions, where the climate and phenology of fruit production make it unlikely for frost damage to be a significant recurring problem. Site selection, on inclined grades or near Lake Ontario, are the preferred strategies in avoiding frost damage. In the years from 1940 to 1985, frosts were found to cause an average loss of 2 percent to 2.5 percent of apple production--the equivalent of about $50 an acre. However, frost problems were difficult to separate from poor pollination weather as a cause of significant yield reductions. With the possibility of repeated applications required for ice-minus to be efficacious and the average cost of applying sprays at $30 an acre, it was concluded that ice-minus is not likely to cause a significant direct impact on the New York fruit industry. A review of frost problems in major competing states, based on the use of Federal crop insurance coverage, found a low need for ice-minus technology. It was concluded that ice-minus would be unlikely to cause a significant indirect impact on the New York fruit industry.

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*Research Support Specialist and Associate Professor, respectively, in the Department of Agricultural Economics, Cornell University.

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Ice-nucleating bacteria are known to occur naturally on many crops and have been associated with frost damage (Gross, et al., Lindow, 1981 and 1983, Lindow and Connell, and Yankofsky). Their role as a primary agent causing frost damage in certain tree-fruit crops has been questioned scientifically (Proebsting and Gross), but the possibility exists that genetically engineered bacteria, dubbed "ice-minus" bacteria, will be developed as a frost protectant in apple orchards. The possibility of controlling ice-nucleation in plants with ice-minus bacteria, applied prior to the time of probable frost injury has drawn wide public attention. Initially, attention was focused on the environmental regulatory process and its control over the deliberate release of genetically-altered organisms. An early test of that regulatory process was completed in the spring of 1987 when the first field trial of ice-minus bacteria was approved and conducted. While field trials have not conclusively shown that ice-minus prevents frost damage, preliminary results indicate at least the potential of this product as a future agricultural technology (Marx).

Ice-minus technology is designed to depress the critical temperature at which frost damage begins by displacing the natural population of ice-nucleating organisms (Lindow, 1983). Ice-nucleating bacteria produce a substance that can cause ice to form at higher temperatures. If the engineered bacteria can displace the natural population, then the critical temperature for frost damage may be lowered. While the details are not yet known, it appears that ice minus must be applied well before the time of expected frost damage to allow the organism to become established and displace the naturally-occurring ice nucleating bacteria. As frosts cannot be predicted well in advance, ice minus is expected to be applied annually to provide protection should frost occur. If the organism is short-lived or the exposure period to frost damage is long, then repeated applications may be required to insure efficacy.

Critical temperature depression has been accomplished traditionally more by breeding for increased tolerance to low temperatures and crop/site selection to avoid planting susceptible crops in frost-prone areas. The other major class of frost prevention technology relies on orchard heating, accomplished by burning fuel in the orchard, by mixing the warmer air in a temperature inversion with ground-level cold air using orchard fans or helicopters, or by releasing the energy of freezing water (energy released when water applied from overhead sprinklers changes to ice). The economics of mechanical means of frost damage protection are notable in that the equipment need be operated, and variable costs incurred, only when a frost threat is imminent. Ice minus and site selection approaches effectively do not have a discretionary variable cost component.

Fruit growers may use several approaches concurrently to avoid frost damage, which typically occurs in the late spring on calm, clear nights when ground-level air temperatures drop to below critical temperatures for fruit buds, causing death of tissues which would normally develop into fruit. A crop loss in fruit trees can lead not only to higher average costs and lower total revenues in the current season, but can cause subsequent problems in controlling biennial bearing. Frost avoidance strategies may include planting in locations with a history of few frost problems, such as the leeward side of large bodies of water, and terrain with good air drainage. In frost-prone areas, one or more heating type technologies may be used, but cost is a major consideration, as use of these technologies raises variable costs. In compensation, some offsetting advantage is generally required to remain competitive, for example, lower land costs or closer proximity to markets.

The purpose of this report is to evaluate the potential impact of ice-minus and similar bacteria on the long-term structure and location of the New York tree fruit industry and related enterprises. Several subsidiary components are incorporated into this overall objective. The role of ice-minus bacteria must be considered in the context of alternative and complementary frost prevention technologies, many of which are in place in selected areas in New York State. The indirect impact of ice-minus bacteria applied in other regions of the country and possibly affecting the prices received by New York growers is another component of the overall appraisal of this product.

The analysis proceeds by reviewing the general location of fruit production in New York. Following that, the evidence of a potential frost problem is analyzed using published climatological and fruit tree phenological data. Actual instances of frost-related crop loss in fruit are established from reports of the New York Department of Agriculture and Markets. Several recent reports of estimated cost of production and use of existing technologies in fresh-market apple production are reviewed. Finally, the potential for ice-minus to be used in New York fruit production and its possible impacts are discussed in light of the available evidence.

THE FRUIT INDUSTRY IN NEW YORK

Location

The first step in describing the potential problem of frost damage in fruit production is to review the geographic location of orchards and the relative importance of individual crops. The major tree fruits in New York are apples, pears, peaches, sweet cherries, tart cherries, and plums and prunes (Table 1). In terms of New York and U.S. production, apple and tart cherry are the most important New York tree fruits, apples being far more important than any other. Apples are produced on 38 percent of New York's fruit farms, 84 percent of its fruit acreage, and account for 94 percent of its fruit production. By contrast, tart cherries are produced on 13 percent of the farms, 8 percent of the acreage, and account for only 2 percent of production.

Fruit is produced mainly in two regions of New York, east and west (Figure 1). The western counties produce about 50 percent more fruit than the east, and except for peaches, a portion of all fruit production has shifted to western counties during the last 40 years (Table 2). In the case of apples, the share of western production has increased apparently at the expense of production in counties other than eastern. That is, New York has tended to become more of a two-region state in fruit production.

Table 1. Number of farms, acres, production, and value of tree fruits in New York and approximate share of U.S. production, 1985

Fruit Crop	Number of Farms	Acres	Production	Share of U.S. Production
			Million pounds	Percent
Apple	1,043	68,520	1,084	14
Pear	447	2,868	28	2
Peach	377	2,260	13	2
Sweet Cherry	257	1,073	3	2
Tart Cherry	347	6,339	22	8
Plums and Prunes	274	827	5	-
Total	2,745	81,887	1,155	

SOURCE: New York Department of Agriculture and Markets

Table 2. New York fruit production: Distribution by year and region

Fruit Crop	Year	Region 1/		
		Eastern	Western	Other
			Percent	
Apple	1949	30	52	18
	1982	30	60	10
Pear	1949	27	49	24
	1982	35	58	7
Peach	1949	17	71	12
	1982	32	55	13
Sweet Cherry	1949	23	58	19
	1980	3	91	3
Tart Cherry	1949	6	75	19
	1980	1	97	2

1/ Eastern counties are Clinton, Columbia, Dutchess, Orange, Suffolk and Ulster; western counties are Monroe, Niagara, Orleans, and Wayne Counties.

SOURCE: Census of Agriculture (1949, 1982), New York Department of Agriculture and Markets (1980).

Climatology and Phenology

Westerly winds blowing over Lake Ontario in the spring lose energy to the lake, and this cooling effect lowers air temperatures in the leeward orchards of western New York. The lower temperatures delay fruit bud development, causing buds to remain hardy longer than buds in the eastern region. Full bloom dates in western New York average about 5 to 9 days later than in eastern areas, allowing western growers a greater chance of escaping late-spring frost damage (Table 3).

Table 3. Date of full bloom in New York: Fruit species and variety by region, 1925-1987 average

Fruit Crop	Region 1/ Lake Ontario	Region 1/ Hudson Valley	State Average
	May date		
Apple	18	9	15
Pear	13	6	11
Peach	11	4	8
Cherry, Sweet	7	2	6
Cherry, Tart	13	6	12

1/ Regional data include 1950-1970 only. Lake Ontario corresponds to the western region, Hudson Valley corresponds to the eastern region. The State averaged using New York State Department of Agriculture and Markets 1950-1952 weights.

SOURCE See Appendix.

Fruit buds develop at a rate which is strongly influenced by the available supply of energy, but some fruit trees begin development earlier than others and exhibit variable degrees of susceptibility to low temperatures, even in roughly comparable stages of development. Table 4 shows that for the major New York fruits maximum susceptibility to frost damage occurs at 21 to 25 degrees F during full bloom.

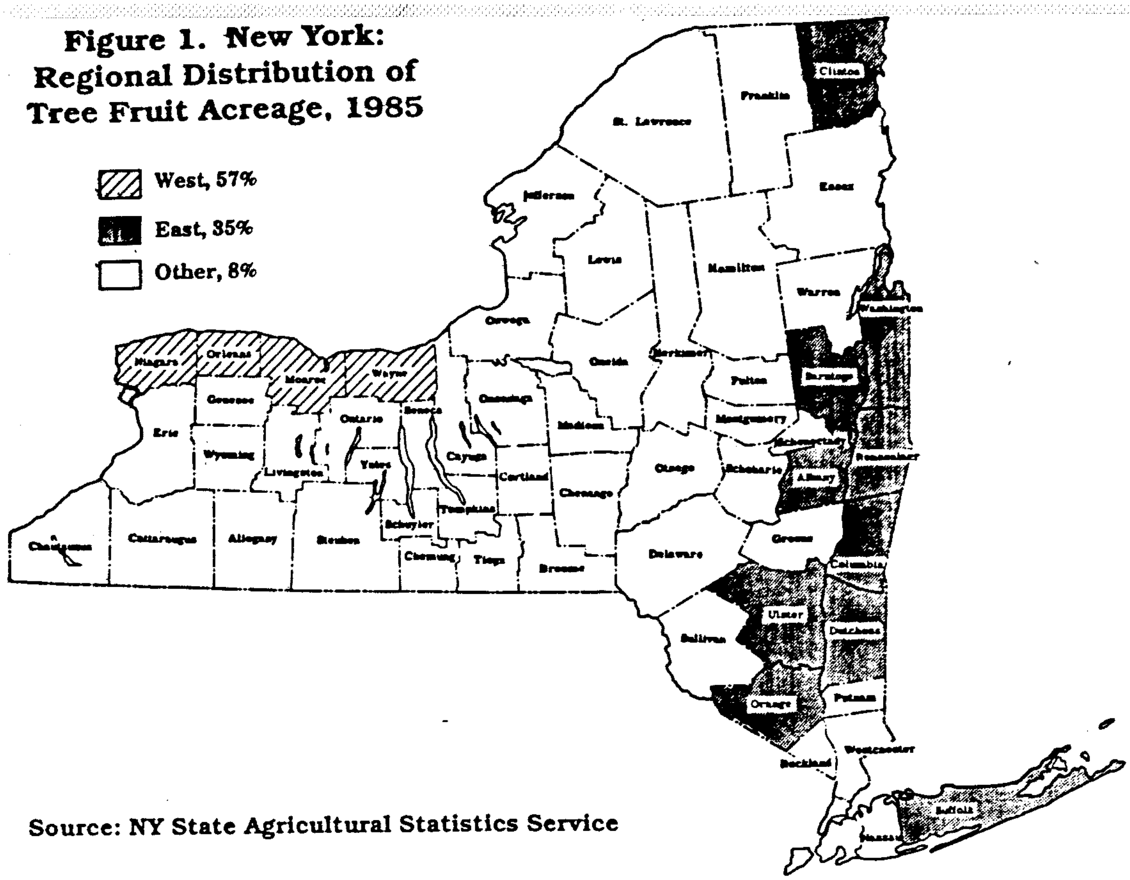
A ninety percent flower bud loss on fruit trees is generally referred to as "severe" frost damage (Ballard and Proebsting), although that level may vary with different fruit crops. A severe frost would normally occur when air temperatures fall to 24-28 degrees F. Based on the average distribution of temperatures in New York, a severe frost is not likely to occur after May 1 in most of the principal production areas (Figure 2). Fruit production farther inland from the Lake Ontario and Hudson Valley areas is more likely to experience a severe frost during bloom, but tree fruit production farther inland is less extensive. Thus, the combination of climatology and phenology of fruit trees in New York are such that widespread crop losses from frosts are expected to be uncommon in the principal fruit producing areas. Losses of economic significance may nonetheless be more prevalent. That issue is explored in the following section.

Figure 1. New York: Regional Distribution of Tree Fruit Acreage, 1985

West, 57%

East, 35%

Other, 8%

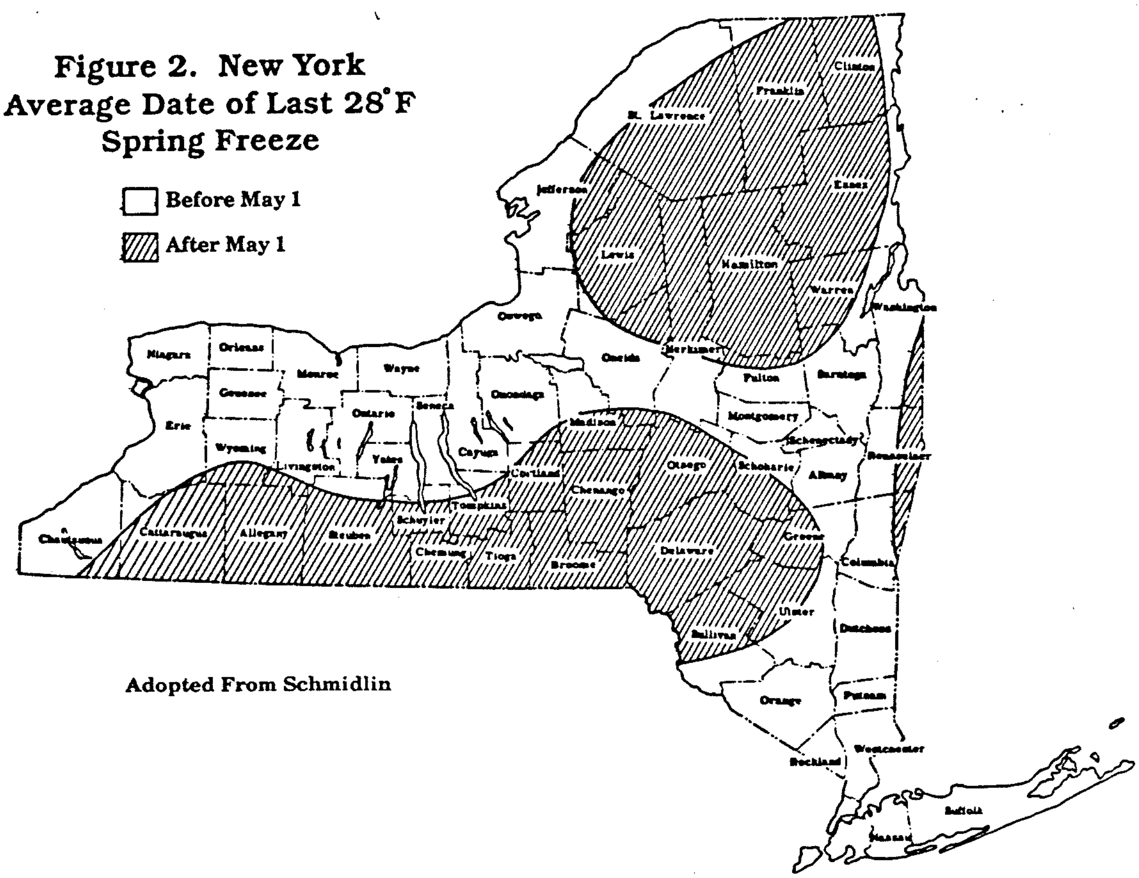


Source: NY State Agricultural Statistics Service

Figure 2. New York Average Date of Last 28°F Spring Freeze

Before May 1

After May 1



Adopted From Schmidlin

Table 4. Critical temperatures required to kill 90 percent of flower buds at various stages of fruit tree development

Stages of development	Cherry	Peach	Prune	Pear	Apple
	Degrees Fahrenheit				
Initial					
First swelling	1	0	1	-	-
Scales separating	-	-	-	0	-
Silver tip	-	-	-	-	0
Intermediate					
First white	23	-	18	15	-
First pink	-	15	-	-	21
Final					
Full bloom	25	23	21	23	24

SOURCE: Ballard and Proebsting.

IMPACT OF FROST DAMAGE

Incidence of Frost Damage in New York

For the purposes here, a threshold level of 20 percent or more of trend production is set as the criterion for a significant economic loss in order to identify years when frost may have played a role in reduced output. A 20-percent loss on average New York apple farms results in a yield reduction of about 80 bushels per acre, or about one standard deviation from the mean. In economic terms, the 1979-86 average farm price of New York apples is about $4.20 per bushel (New York State Department of Agriculture and Markets), suggesting that a 20-percent yield loss would be valued at $336 per acre. The estimated 1986 total costs of apple production in eastern New York is $2472 per acre, comprising 82 percent for pre-harvest, fixed, and nonbearing acreage maintenance and 18 percent for harvesting costs (Table 5), the harvest costs being nearly the same in western New York in 1986 (DeMarree). The total cost of production estimates for the Lake Ontario fruit-producing region are 15 percent to 25 percent below those for the Hudson Valley (DeMarree, personal communication).

With average statewide yields for 1982 through 1986 of about 400 bushels an acre (New York State Department of Agriculture and Markets), the approximate contribution to fixed costs in 1986 was about $660 an acre. This figure, like any aggregate number averaged for production over several years, is only an approximation of the returns to individual producers during any one year. Moreover, yields tend to be higher and costs lower in western New York, explaining in part how producers can remain in business while not covering all reported costs. Assuming that the yield loss does not cause market prices to rise sharply (a reasonable condition when frost damage is localized), a 20-percent yield loss would reduce the contribution to fixed costs by roughly 50 percent. Thus while the 20 percent level for establishing significant economic impact is somewhat arbitrary, it is a level which may cause economic hardship to apple producers.

Table 5. New York apple production costs, eastern region, 1986

	Dollars per acre	Percent
Bearing acreage		
Variable		
Pre-harvest	866	35
Harvest	457	18
Total variable	1,323	53
Fixed	1,020	41
Non-bearing acreage maintenance	129	5
Total costs	2,472	100

SOURCE: Castaldi and Forshey

Examination of a 45-year trend in production (data for 1940 to 1985) indicates a total of 28 years when at least one fruit crop had production more than 20 percent below trend (Appendix B). The range among fruit types was 15 years for sweet cherry to 7 years (15 percent of the seasons) for the hardier apple. The estimates, of course, incorporate all causes of reduced production and probably overstate the importance of frost alone.

To isolate frost as a damage source from other causes, the annual June 1 conditions as reported in the New York State Department of Agriculture and Markets Fruit Crop Report were used. According to those reports, severe spring frosts were associated with between 0.5 and 18 percent of the seasons during 1940 and 1985, depending on the crop (Table 6). Frost damage on apple occurred in about 9 percent of the seasons. However, the concurrence of frost, poor pollinating weather, and other causes of reduced fruit set confounds the problem of isolating the damage due to frosts alone.

Table 6. Climatic causes of below-normal production following reduced fruit "set" in New York 1940-1985 1/

Fruit crop	Low winter temperatures	Spring frosts	Cool, rainy weather	other 2/	All causes 3/
			Number of years		
Apple		4	7		7
Pear	1	3	6	1	10
Peach	7	2	1		8
Cherry					
Sweet	3	8	2	5	15
Tart	1	5	6	3	9

1/ Below-normal annual production is less than 80 percent of trend.
2/ Sweet cherry: no indication in 1943, 1965, 1952, 1986, brown rot in 1947; pear, no information in 1968; tart cherry, no information for 1960, 1966, 1977.
3/ The number of years of below-normal production may be less than the sum when multiple causes affect any single year's production.

SOURCE: New York Department of Agriculture and Markets. See Appendix.

To illustrate the problem of concurrent causes of reduced fruit production, the New York fruit industry's experience with spring frosts is often told in relation to the infamous 1945 episode. The New York Agricultural Statistics Service reported in its May 1, 1945 'Special Fruit Crop Report':

> The fruit situation in New York is very uncertain at this time. All fruits have suffered more or less from the freezes after they came into bloom and from the poor pollinating weather. During March the buds developed very rapidly and on April 1 were far in advance of what they usually are at that date. About April 6 there were several mornings when the temperature dropped to below freezing. Several of the fruits were practically in full bloom in some areas at this time. In these areas a large number of the fruit buds were severely damaged. Also, during this period and again beginning about April 15, there were many cold cloudy or rainy days during which the bees failed to fly and hence failed to give the fruit blossoms good pollination. Freezing temperatures about April 22 again did varying damage to fruit buds over the State with heaviest injury in the Eastern Counties. The results are that all fruits have suffered to some extent but it will be some time yet before the exact condition can be determined.

The result was markedly less production of apple, pear, and tart cherry (Table 7). Total New York production of apples was 87 percent less, pear was 73 percent less, and tart cherry was 63 percent less than average. The peach and sweet cherry crops were not affected, probably because of their different stages of development.

When analyzing the impact of climate on fruit set during this unusual spring of 1945, a Cornell University pomologist stated "...frost injury was responsible for a loss of crop in some of the early [blooming] orchards but there was relative little actual frost damage to the flower parts [of fruit trees] in a large majority of the orchards. The failure of the fruit to set was due to the long period of

Table 7. New York fruit production: 1935-44 average, 1945-1947

	Fruit Type				
				Cherry	
Year	Apple	Pear	Peach	Sweet	Tart
	-------1,000 Bushels------			-------Tons-------	
1935-44 avg.	16,306	1,025	1,431	2,114	19,571
1945	2,106	272	1,660	2,600	7,300
1946	15,116	693	1,682	1,400	15,500
1947	15,045	960	1,440	2,200	14,800

SOURCE: New York State Department of Agriculture and Markets

cool, cloudy, wet weather which set in just prior to the peak of apple bloom" (Hoffman). The concurrence of poor pollination weather, winter kill, early-season disease problems, and frost damage often obscures the effect of any single cause of reduced fruit set. The years in which strong anecdotal evidence (as reported in Fruit Crop Reports) points to a role for frost damage in significantly lower production are listed in Table 8, but in many cases, these are years in which other factors are also cited as important.

The available evidence then suggests that frost damage is, for all New York tree fruits but sweet cherries, implicated in less than 10 percent of the seasons since 1940. The range of yield loss is about 20 to 50 percent (excluding 1945). Using a one-in-ten-year average rate of incidence of frost damage on apple with a 20 to 25 percent average loss, the projected annual damage ranges between 2 percent to 2.5 percent of production. Assuming this estimated range of average annual loss is due entirely to frost damage, it amounts to roughly 50 dollars per acre (see Table 5). Growers are expected over time to adopt successful strategies to minimize the impacts of late-spring frosts, provided that the annualized fixed and variable costs of these strategies do not exceed the estimated frost-related loss of $50 an acre on average.

Table 8. Years from 1945 to 1985, when fruit production was more than 20 percent below normal and frost damage was reported 1/

Apple	Pear	Peach	Sweet Cherry	Tart Cherry
1945(85)	1945(69)	1967(55)	1946(50)	1945(61)
1948(25)	1957(21)	1976(36)	1947(26)	1947(23)
1956(21)	1976(52)		1956(62)	1956(34)
1981(22)			1967(24)	1976(42)
			1976(34)	1981(67)
			1977(51)	
			1981(43)	

1/ Numbers in parentheses are percent below trend production.

SOURCE: See Appendix.

Frost Prevention in New York

Based on this evidence it appears the average New York tree fruit producer may be willing to spend an additional $50 annually to avoid frost damage. There are several approaches, or combinations of approaches, which might be taken, including site selection, traditional technologies and, depending on cost, availability, and effectiveness, ice minus bacteria. For the traditional technologies, protection is about three degrees below freezing or to about 29 degrees F (Conklin). A detailed calculation of the relative profitability of these strategies exceeds the scope of this study. It is, however, possible to use the costs of traditional technologies to project the cost range for ice minus if it is to be economically viable in New York.

One frost-prevention strategy is site selection. This choice, indicated by shifts in production over the past four decades (Table 2), seems to be the preferred approach, although other factors including rising land values in the Hudson Valley influence this migration. For producers operating in other areas, particularly Columbia, Dutchess, Ulster and Clinton Counties, an alternative choice is the use of mechanical devices including fans and heaters (Stiles). The estimated total costs of operating selected frost protection technologies in the Hudson Valley of eastern New York indicate a range of $211 to $939 an acre of apples (Table 9). On a total cost basis the figures are out of line with the projections of annual losses. Indeed, Castaldi (1987) estimated a per bushel price of $13 to $16.65, depending on variety, to cover the cost of operating combined wind machines and heaters. This price is above the range of statewide prices during the 1980's, suggesting that many of these technologies are not economically viable for many operators. However, the variable operating costs of wind machines is $40 an acre (Table 9), which is closer to the projected annual loss from frost. Thus an operator with this equipment in place would be expected to operate it annually if needed, and additional equipment might be acquired if means were found to reduce the significant fixed costs. If the frost threat occurred less than annually, then the savings in annual variable costs can be used to offset some of the fixed costs.

Based on these data and estimates, a tentative conclusion can be reached. The annualized cost of frost-related damage to tree fruit production in New York is relatively modest using the traditional set of frost-prevention technologies, perhaps as much as $50 an acre for apples. This is large enough to affect the profitability of the enterprise but not as large as the total costs of using frost prevention devices. For ice minus to be adopted by "risk neutral" apple growers, it appears that the annualized applied cost would have to be on the order of $50 an acre. Considering the 1986 labor cost of spraying an acre of apple trees is about $30 an acre (Castaldi and Forshey), then ice minus, which would need to be applied at least once annually, must be very effective and long lived to be economically viable in New York State. In relation to the question of efficacy, experiments with bactericides on Washington fruit trees over a six-year period suggested that factors other than ice-nucleating bacteria were responsible for frost damage (Proebsting, and Gross).

Table 9. Summary of annual operating costs per acre for selected frost protection technologies in Hudson Valley of eastern New York 1/

	Technology		
Cost	Wind machine	Wind machine plus heaters	Stack heaters
		Dollars	
Variable			
fuel and lubrication	184	784	6,000
other	237	394	500
total	421	1,178	6,500
Fixed			
depreciation	785	860	747
interest on investment	785	841	560
labor	25	125	1,395
other	90	108	183
total	1,685	1,934	2,885
Total	2,106	3,112	9,385
per hour	105	156	469
per acre	211	311	939
per bushel	0.32	0.47	1.44

1/ Based on a 10-acre block of apple trees.

SOURCE: Castaldi (1987)

The need for this product may further decline in the future if the trend over the past four decades to concentrate tree fruit production in the Lake Ontario region continues. This region appears to provide more natural frost prevention than other producing areas around the State. Considering these factors, the direct role for ice minus in New York State tree fruit sector appears limited.

Frost Damage in Competing Regions

Frost damage on fruit crops elsewhere in the United States is a related concern if reducing the problem significantly would affect New York fruit prices. A detailed examination of frost damage across the country exceeds the scope of this analysis. Nonetheless, insight may be gained by examining data on Federal crop insurance.

If the purchase of policies suggests the presence of a significant frost threat, then the problem appears limited, as only nine counties in three other states (North Carolina, Oregon, and Washington) carried Federal insurance for apples during 1963-1983. Annual indemnities paid to apple producers averaged only one million dollars during 1982 to 1984, compared to an average U.S. crop value of $872 million (U.S. Department of Agriculture). Of that one million dollars average annual indemnity, 77 percent is paid out for frost, freeze, and other cold damage which could include poor pollination.

It may be argued that the limited use of crop insurance against frost-related losses in fruit is due to problems of supplying insurance, rather than the lack of widespread demand. If administrative costs raise the cost of insurance, then growers will find profitable alternatives, such as investment in wind machines and orchard heaters. However, historically New York growers have obtained Federal crop insurance for grape acreage and other states' growers have obtained insurance for tree fruit acreage (for example, cherry acreage in Michigan), suggesting that need and not prohibitive transaction costs are limiting the demand for this insurance.

As in New York, the possibility exists elsewhere that frost damage is averted through the use of available equipment rather than avoided by site selection and other passive approaches. However, the high cost of operating current frost protection equipment means its widespread use is economically viable only if an area has a strong comparative advantage in cost or prices. This might occur in limited areas where producers can capitalize on high early-season prices or above-average quality, but there is no indication of a broad cost-of-production advantage for tree fruits, especially apple, in frost-prone areas outside New York State.

SUMMARY AND CONCLUSIONS

The potential need for ice-minus bacteria in the New York tree fruit industry is examined by evaluating the likelihood of frosts occurring when fruit buds are susceptible, and tabulating the record of actual frost damage. The available climatological and phenological evidence suggests that severe frost damage is rare in the major fruit producing regions of the state. However, losses of economic significance, set here at yields 20 percent or more below trend, occur between 0.5 and 18 percent of the seasons between 1940 and 1985. Even these figures overstate the effect of frost alone as many years of below-average production are beset by multiple causes including cool, rainy weather causing poor pollination.

For apples, the annualized loss associated with frost damage was estimated at $50 an acre. At this level of cost, most forms of frost prevention equipment are uneconomical, explaining in part the ongoing relocation of fruit production to the Lake Ontario region, where the frost threat is lower. For ice minus to be competitive in New York apple production, it must cost less than $50 applied an acre per year. Thus it would seem to have a major impact only if it is economical and long-lived. Further field experimentation is required for sufficient efficacy and production cost data to be useful in analyzing specifically the cost competitiveness of this product.

While the potential within New York seems limited, that outside the state seems so as well, at least for apple. This judgement is based on the low utilization of Federal crop insurance in tree fruit production. If as assumed the lack of producer participation in this program indicates a low level of frost and related damage, the apparent need for ice minus in other fruit producing regions also seems limited. As a result of these factors the expected impact, both direct and indirect, of ice minus on New York tree fruit production seems limited unless it proves to be a very economical and long-lived product.

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APPENDIX

Calculating Full Bloom Dates

The purpose of calculating full bloom (FB) dates for fruit trees in New York is to examine the joint likelihood of buds or flowers reaching a susceptible stage of development during a period when critical temperatures are reached. The New York Department of Agriculture and Markets (NYDAM) published a series of average FB dates in the annual June 1 issue of Fruit Crop Report until 1971. For estimates of FB after 1970, a series was constructed by comparing field data from two sources (Forshey with Blanpied) with NYDAM and comparing NYDAM average FB dates for apple with FB dates for pear, peach, sweet cherry, and tart cherry.

FB dates for 1925 to 1970

The FB dates, averaged over the State, are given for the major tree fruits in New York in the annual June 1 Fruit Crop Report, beginning with 1940 (including the 15-year historical record) until 1953. Beginning in 1953 (with corrections for 1950 to 1952), average FB dates are given for the Lake Ontario and Hudson Valley Regions, but not averaged for the State. The State averages for 1950 to 1952 imply the weights used (in the 1953 report) to combine the regions in those 3 years, and those weights are carried forward to calculate a State average for 1953 to 1970.

The phenological relationships between apple and pear, peach, sweet cherry, and tart cherry were estimated by correlating State average FB dates of each of the latter 4 fruit types with the FB dates of apple, using 1925-1970 data (Appendix Table 1).

FB dates for 1971-1975

Forshey provided FB dates for 1960 to 1987 in the Hudson Valley on apple (Appendix Table 2). Forshey's FB dates were correlated with NYDAM FB dates for the Hudson Valley using 1960-1970 data ($r=0.85$). Hudson Valley FB dates for apple were correlated with Lake Ontario FB dates for apple using 1950 to 1970 data ($r=0.74$). From these 2 calculations, given Forshey's FB dates on McIntosh in Poughkeepsie, a series was constructed for the Lake Ontario and Hudson Valley regions' apple crops during 1971-1975.

FB dates for 1976-1987

Blanpied provided a range of FB dates for the Lake Ontario and Hudson Valley regions' apple crops (Appendix Table 3). The mid-point of each range was used to represent the State average FB dates on apple in text Table 3.

FB dates for other fruits, 1971-1987

The relationships calculated in Table A1 were used to estimate FB dates for pear, peach, sweet cherry and tart cherry during 1971 to 1987. The estimated FB dates for apple in the Lake Ontario and Hudson Valley regions during 1971-1987 were used to calculate a State average and adjusted to reflect the relationship between apple and the other four major fruits reported in text Table 3.

Measuring the Incidence of Frost Damage

The purpose of indentifying years of below-normal production of fruit crops in New York is to summarize the anecdotal evidence relating frost occurrence to frost injury. Production of pear, peach, sweet cherry, and tart cherry demonstrate two trends during 1940 to 1985, while apple production is best fit with a single trend (Appendix Table 4). Straight-line trends were estimated statistically for the 1940-1985 period of annual production data from the New York Agricultural Statistics Service (Appendix Table 5).

The estimated signs and magnitudes of the trend parameters for New York production are less important than their utility in identifying average production. Because perennial crop acreage is almost constant during short periods of time, highly variable production is likely to be related to changes in weather or crop biology. Crop biology is partially controlled by cultural practices, so years in which actual production is less than 80 percent of average (trend) are identified as "below-normal" (Appendix Table 6).

Appendix Table 1. Correlations of FB dates between apple and four other fruit types 1/

Fruit crop	Correlation statistic		
	Constant	Slope	R-square
Pear	- 3.86	0.996	0.98
Peach	- 7.51	1.00	0.93
Sweet Cherry	-11.82	1.019	0.95
Tart Cherry	- 1.76	0.987	0.96

1/ 1925-1970 data for pear and peach; 1928-1970 data for sweet cherry and tart cherry.

Appendix Table 2. McIntosh apple at Poughkeepsie, New York: Date of full bloom, 1960-1987

Year	Month	Day	Year	Month	Day
1960	May	6	1974	May	5
1961	May	15	1975	May	14
1962	May	5	1976	April	20
1963	May	8	1977	April	22
1964	May	10	1978	May	15
1965	May	12	1979	May	8
1966	May	20	1980	May	5
1967	May	18	1981	May	2
1968	May	2	1982	May	9
1969	May	11	1983	May	7
1970	May	10	1984	May	15
1971	May	19	1985	April	29
1972	May	16	1986	April	30
1973	May	2	1987	May	1

SOURCE: Forshey.

Appendix Table 3. Full Bloom dates for apple in New York, 1976-1987

	Region	
Year	Lake Ontario	Hudson Valley
1976	May 5 - May 10	April 20 - April 26
1977	May 5 - May 8	April 21 - April 23
1978	May 22 - May 28	May 15 - May 22
1979	May 10 - May 16	May 7 - May 9
1980	May 16 - May 23	May 5 - May 8
1981	May 7 - May 15	May 2 - May 4
1982	May 10 - May 14	May 7 - May 12
1983	May 19 - May 23	May 4 - May 15
1984	May 19 - May 26	May 15 - May 16
1985	May 7 - May 12	April 26 - May 2
1986	May 8 - May 12	April 28 - May 2
1987	May 5 - May 12	May 2 - May 7

SOURCE: Blanpied.

Appendix Table 4. Trends in production of fruits in New York, 1940-1985

Fruit crop and period	Trend statistic 1/			
	Constant	Slope	R-square	Observations
Apple (Mlbs)				
1940-85	563.5	11.37	0.54	46
Pear (tons)				
1940-53	24,480	-1,082.7	0.26	14
1954-85	11,864	225.2	0.32	32
Peach (Mlbs)				
1940-63	74.9	-1.73	0.29	24
1964-85	19.0	-0.35	0.24	22
Cherry, sweet (tons)				
1940-69	2,010	135.7	0.41	30
1970-85	4,624	-140.2	0.19	16
Cherry, tart (Mlbs)				
1940-65	34.24	0.585	0.12	26
1966-85	31.09	-0.651	0.14	20

1/Trend variable equals 0, 1, 2, ... T_p where T_p is the total number of observations in each period.

Appendix Table 5. New York Fruit: Annual production, 1940-1985

Year	Apples	Peaches	Pears	Cherries Sweet	Cherries Tart
	Thousand bushels		-------- Tons -------		
1940	12,936	1,380	1,670	1,750	20,000
1941	16,302	1,649	848	2,500	14,500
1942	18,997	1,615	1,241	2,800	27,000
1943	13,602	95	528	600	11,900
1944	17,010	1,824	1,157	2,900	22,100
1945	2,160	1,660	272	2,600	7,300
1946	15,116	1,682	693	1,400	15,500
1947	15,045	1,440	960	2,200	14,800
1948	11,750	1,114	384	3,000	20,500
1949	20,090	1,428	1,195	2,900	17,500
1950	18,700	1,023	1,066	4,400	27,100
1951	17,291	1,312	486	6,000	30,200
1952	11,395	1,311	396	3,500	19,100
1953	13,120	1,247	462	3,200	21,600
1954	19,000	1,150	340	5,400	24,700
1955	19,700	1,400	700	6,600	31,200
1956	14,100	1,030	510	1,600	14,400
1957	15,600	150	460	2,700	21,000
1958	22,000	1,390	625	6,100	22,000
1959	19,500	1,120	570	6,700	18,500
1960	17,500	680	525	3,700	11,000
1961	24,100	725	750	5,000	31,200
1962	22,300	550	630	4,500	19,700
1963	20,400	540	720	4,400	20,300
1964	21,500	520	780	8,200	32,000
1965	23,000	360	700	3,800	25,100

SOURCE: United States Department of Agriculture.

Appendix Table 5, continued. New York Fruit: Annual production, 1940-1985

Year	Apples	Peaches	Tart Cherries[1]	Pears	Sweet Cherries
	-------Million pounds-------			-------- Tons -------	
1966	930	22.5	12.0	20,600	4,400
1967	955	8.0	44.2	17,200	4,300
1968	830	18.0	28.6	9,300	4,900
1969	855	20.8	30.6	18,000	7,300
1970	995	16.5	39.6	13,500	3,400
1971	1,050	19.0	42.0	18,000	6,500
1972	770	17.0	34.0	18,500	4,500
1973	720	15.0	21.2	12,600	3,400
1974	900	15.0	16.2	14,000	2,600
1975	1,020	16.0	27.4	20,000	6,800
1976	820	9.5	14.3	8,000	2,500
1977	900	13.0	11.8	16,000	1,800
1978	1,080	16.0	18.9	18,500	3,500
1979	1,035	6.7	27.3	18,000	4,200
1980	1,100	13.0	30.4	21,000	5,100
1981	800	9.0	7.0	17,000	1,750
1982	1,130	14.5	21.0	19,000	3,500
1983	1,100	17.0	23.0	19,000	3,200
1984	1,020	11.0	26.0	20,000	2,400
1985	1,090	14.5	22.5	16,000	1,600

[1]Reported tons: 1966 - 6,000, 1967 - 22,100, 1968 - 14,300, 1969 - 15,300,

SOURCE: United States Department of Agriculture (1966 - 1969), New York Department of Agriculture and Markets (1970 - 1985).

Appendix Table 6. Years of below-normal production of fruits in New York, 1940-1985 1/

Apple	Pear	Peach	Sweet Cherry	Tart Cherry
1945	1941	1943	1943	1943
1948	1943	1957	1946	1945
1952	1945	1962	1947	1947
1953	1948	1963	1956	1956
1956	1952	1967	1957	1960
1973	1954	1976	1960	1966
1981	1957	1979	1965	1974
	1968	1981	1966	1976
	1973		1967	1977
	1976		1970	1981
			1974	
			1976	
			1977	
			1981	
			1985	

1/ Below normal is defined as 20 percent or more below trend (see Appendix Table 4).