

COLD-HARDINESS AND DORMANCY OF APPLE TREES.

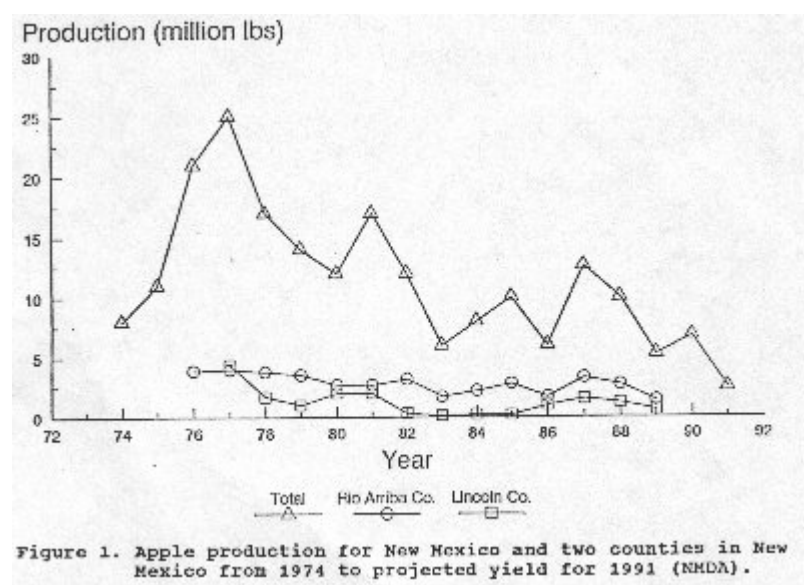
WHAT'S THE DIFFERENCE?

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Introduction: Apples are the most important fruit crop in New Mexico. There are over 160,000 trees in the state, but production varies tremendously from year to year. Since 1974, production has varied from 25 million pounds in 1977 to 2.5 million pounds estimated in 1991 (Fig. 1). In fact, yield has generally declined since 1977. It is possible that 1976 and 1977 were unusual years and average yields of about 10 million pounds should be expected. Regardless, it appears that yield fluctuates widely with little regard to management strategies. However, this is unlikely.



It is more likely that much of the fluctuation in annual yield is due to environmental factors which may be subject to management. Factors such as temperature and water availability can not be strictly controlled, but if biological principles are understood, these environmental factors can be used to increase yield rather than to simply allow "nature to take its course." Management of the environment can be used to increase yield as well as allowed to decrease yield.

In this conference, we will discuss different strategies to control frost injury in your apple orchard. My role is to introduce you to the biological and physical principles which form the foundation for these technologies. I will discuss the principles of cold-hardiness and dormancy and the roles of water and environment in regulating these phenomena. I also will use New Mexico climate and yield data to illustrate the potential for managing apple orchards.

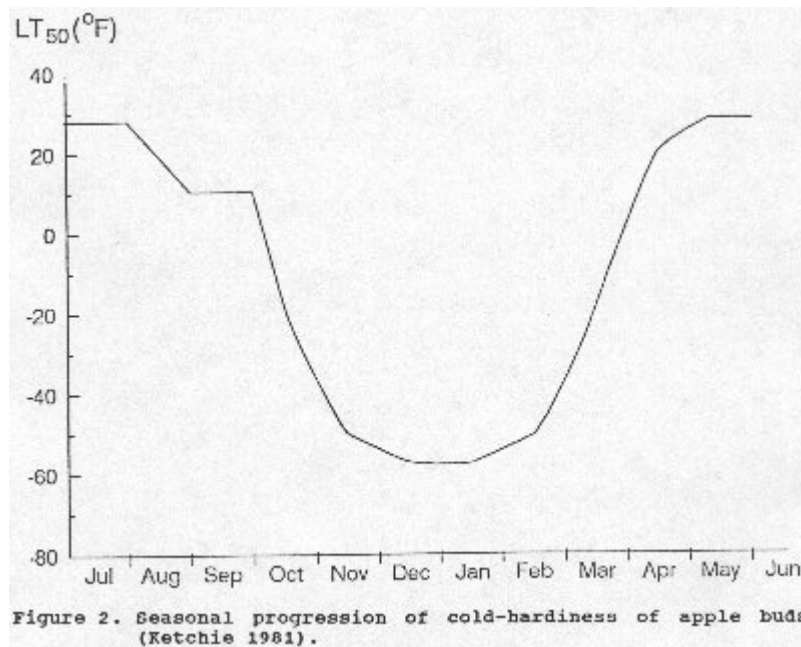
Cold-Hardiness: Cold-hardiness is the ability to survive freezing temperatures, and is determined by freezing tissue to known minimum temperatures. It is measured in terms of the temperature which is lethal to 50% of the population (LT₅₀). Occasionally, temperatures which kill 10% (LT₁₀) or 90% (LT₉₀) are also reported. Death is noted by wilting and necrosis of foliage or expanding buds, failure to break bud, or more sophisticated measures. Regardless, death results from irreparable damage to individual cell membranes brought about by ice formation. As the temperature drops below freezing, ice begins to form around nuclei outside the cell. Water migrates from inside the cell to outside to form additional ice. As water is lost, the cell membrane shrinks. Rarely, will ice form inside the cell. As the ice thaws, water

rushes into the cell again. The membrane can not expand to its original size and the membrane ruptures causing cell death. The lower the temperature, the more ice formed, the more water lost, and the greater the freezing damage.

Apple trees can survive temperatures ranging from about 28°F to below -60°F (Fig. 2). In the fall, short photoperiods and cool temperatures promote cold-hardiness to about 10°F. During mid-winter, buds can survive exposures to below -60°F with no damage. During the spring, cold-hardiness is a function of both environment and bud stage. Prior to budbreak, periods of warm weather can cause dehardening. However, the onset of cold weather can rapidly promote hardening to very low temperatures.

Cold-hardiness in the spring is a function of both environmental conditions and stage of plant development (Ballard et al. 1987). Once buds begin to break, and growth is evident, the trees rapidly deharden (Fig. 3). The LT₅₀ for buds in Stage 1 "Silver Tip", is about 9°F, and rapidly rises to 24°F in Stage 4 "Tight Cluster". At this point, an exposure for several hours to 24°F will result in the death of 50% of the blooms. Exposures to temperatures below 21°F will kill 90% of the blooms and the apple crop is lost. Beyond Stage 5 "First Pink", temperatures below 27°F will kill 50% of the blooms. The time period between Stage 1 and Stage 4 is about 2 weeks. During this period, dehardening is rapid and irreversible.

Dormancy: Dormancy is the inability to resume growth when placed in a favorable environment. By this, we mean, if it were feasible to move an apple tree into a greenhouse in late December, it would not begin to grow, or it would begin to grow unevenly after an extended exposure to warm temperatures. Dormancy is a complicated biological phenomenon that is only partially understood. Recently, additional terminology was proffered by Lang et al. (1987). They separated dormancy into three types; ecodormancy, endodormancy, and paradormancy. Ecodormancy is the cessation of growth induced by environmental factors. For example, in summer with excessive evaporative demand, high temperature and moisture stress, plants will cease active elongation. As soon as environmental conditions become favorable, growth will resume. Thus ecodormancy is a short term phenomenon induced and alleviated by the same variable, usually moisture.



As the environment continues to be unfavorable for growth through the summer, moisture stress coupled with shortened photoperiods and cooler night temperatures promote the induction of endodormancy. Endodormancy is the classic stage of dormancy where growth is controlled by plant growth regulators within the bud itself. Plants that are endodormant will not resume growth when placed in a favorable environment with adequate moisture, long photoperiods and warm temperatures. In order for growth to resume, the plants must be exposed to cool temperatures to satisfy what is called the Chilling Requirement. Often, apples can have the chilling required satisfied by early January. Once the chilling requirement is satisfied, plants will resume growth if the environment is favorable. However, usually apples enter ecodormancy following endodormancy because temperatures are unfavorable for growth. The third type of

dormancy, paradormancy, is regulated by buds elsewhere on the tree. Plants maintain apical dominance and prevent axillary buds from growing through paradormancy

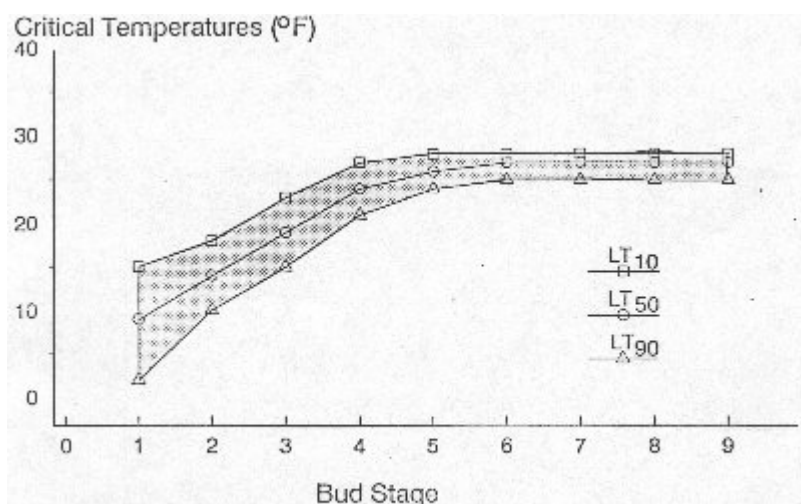


Figure 3. Critical temperatures for apple blossoms (Ballard et al. 1987).

The stage of plant development can be determined by tracking temperature during the dormant period. Typically, this might be from the autumnal equinox (September 23) until budbreak in the spring. The first step is to determine when the chilling requirement is satisfied. For Red Delicious apples, the chilling requirement is 1,234 chill units. A chill unit is the number of hours at a particular temperature. Chill units accumulate between 0°C and 15°C (32° and 60°F) (Fig. 4). Maximum accumulation (1 chill unit/hr) occurs at 43°F. Partial accumulation occurs at temperatures around 43°F, and no chill units accrue below freezing. Above 60°F, negative chill units accumulate.

Once the chilling requirement is satisfied, growth will resume as temperatures warm. Growth resumption can be predicted by tracking growth units. Growth units are the number of degree hours above 5° (41°F) (Fig. 4). Example, if the temperature averages 10 for 1 hr then 5 degree hours are accumulated. Bud stage is a function of the accumulation of growth units (Table 1). Bud break initiates after 3710 °F growth units accumulate, and progresses depending on the rate of accumulation. In New Mexico, wide fluctuations in day/night temperatures often results in a slow accumulation of chill units. However, in early spring, mild temperatures satisfy both the chilling requirement and the growth units (Fig. 4). Temperatures between 41°F and 60°F count for both.

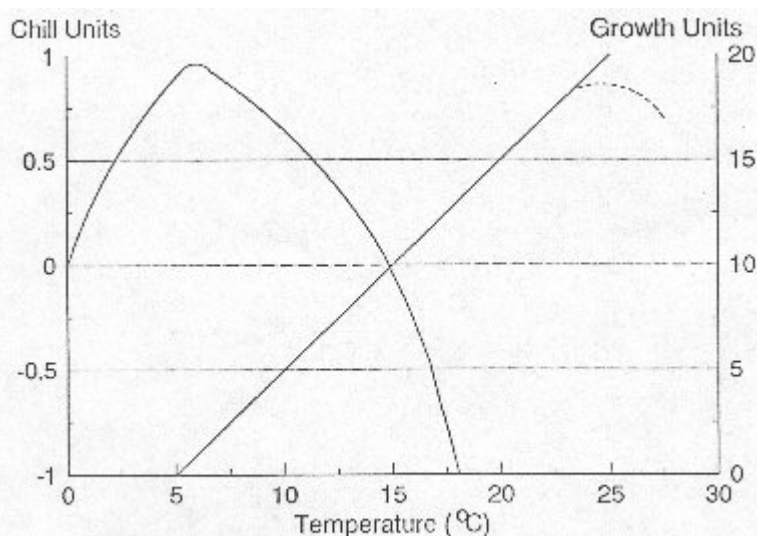


Figure 4. The relationship between chill unit accumulation and growth unit accumulation as a function of temperature.

This interaction between chilling requirement and growth unit accumulation is poorly understood. For example, if the chilling requirement is only partially satisfied, the tree will still break bud, but at a slower rate. Thus growth units can compensate at least partially for a lack of chilling hours. Thus, if only 900 chill units accrued during the winter, it is feasible that apples would require 4500 growth units to reach Stage 1 instead of 3710. It is very important that both chill units and growth units be monitored to develop an effective management tool for your apple orchard.

New Mexico Experience: As discussed earlier, apple yield in New Mexico is variable. Data from the Agriculture Science Center at Farmington (Gregory, pers. comm.) is available to examine yield, date of Full Bloom (Stage 7) and minimum temperature. Since 1976, yield varies from about 35 boxes/ac in 1983 to over 500 boxes/ac in 1981. During this same period, Full Bloom varied from April 18 to temperature and damage will occur.

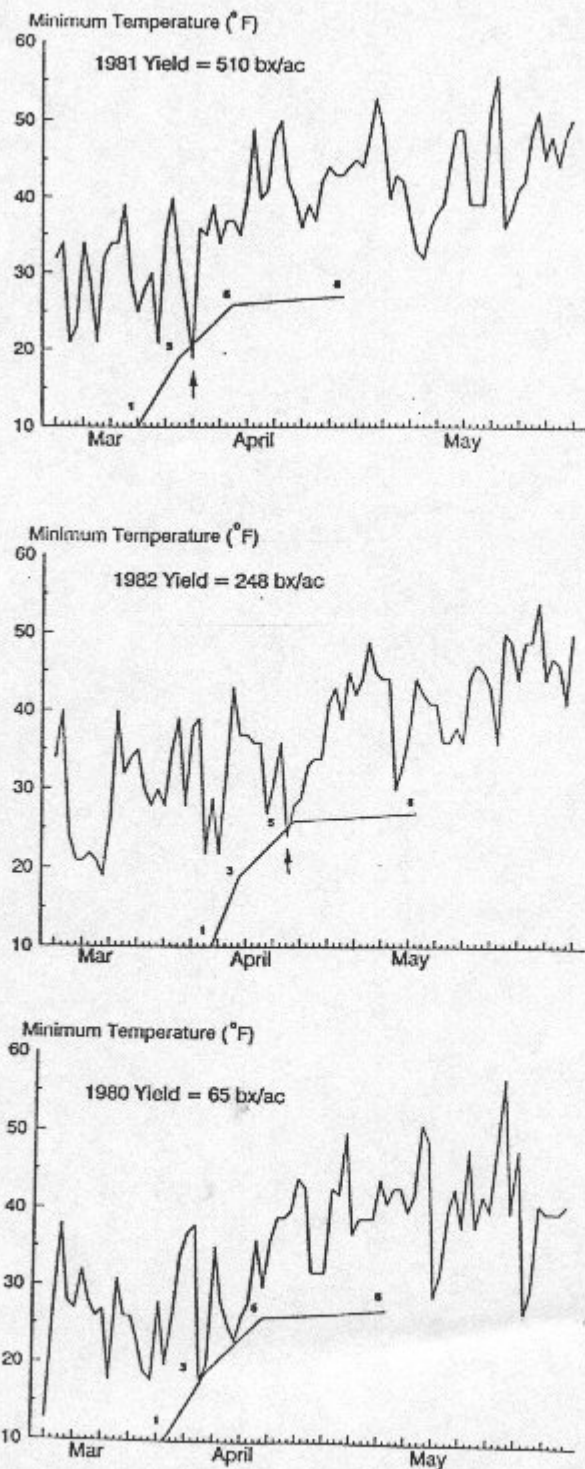
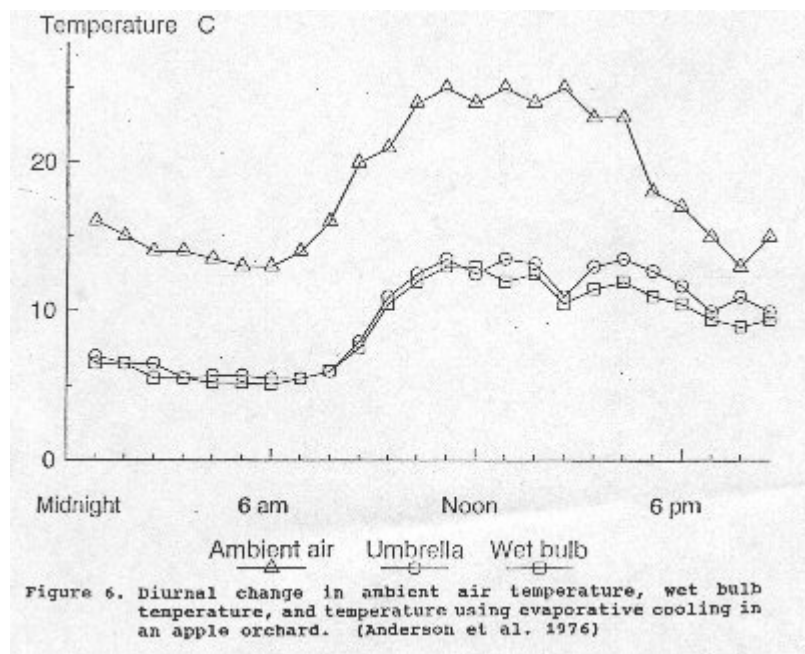


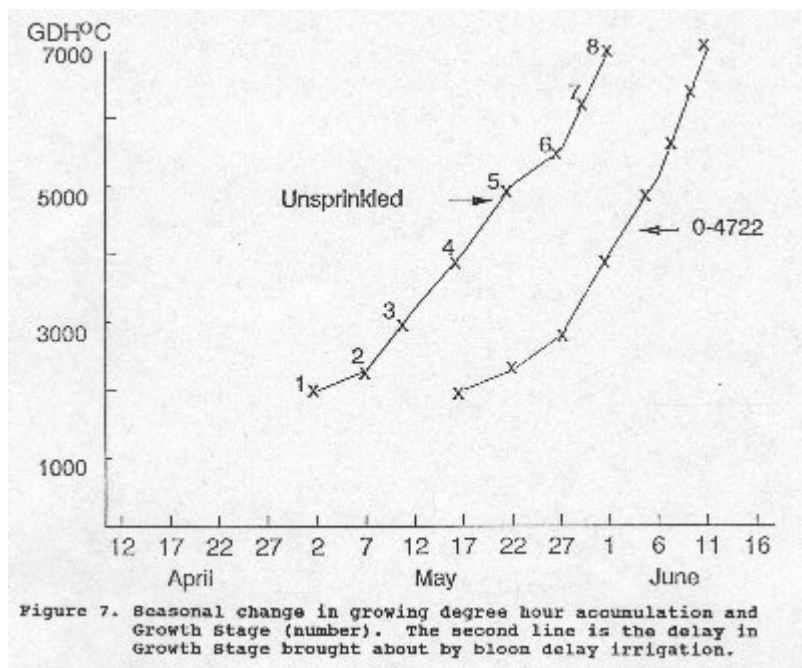
Figure 5. Minimum temperatures and Growth Stage development for apples on the Agriculture Science Center in Farmington for 1981, 1982, and 1980.

Heat of Vaporization. Heat of vaporization is essentially evaporative cooling. This feature of water allows growers to delay blooming of apples. Again, it takes energy in the form of heat to vaporize water; to change water from a liquid to a gas. The water molecule extracts this heat from the apple bud. This cooling of the bud reduces the accumulation of Growth Units. Conceivably, Growth Unit accumulation could be delayed well past the possibility of a late freeze.

Evaporative cooling can be effective in reducing bud temperature and subsequent Growth Unit accumulation (Fig. 6). Over the course of a day, sprinkler irrigation reduces temperature 10-15°C compared to ambient air temperature. In fact, temperature in this example, was maintained near the wet bulb temperature which is the maximum cooling possible.



Through the early Spring, evaporative cooling can effectively delay bud development (Fig. 7). Stage 8, Full Bloom, was delayed about 10 days, but more importantly, Stage 1, Silver Tip, was delayed about 15 days, and Stage 3, Half-inch Green, was delayed about 17 days. Beyond Stage 3, there is little difference in cold-hardiness, and the rate of progression through the subsequent stages in relatively unimportant. A 25°F exposure will do as much damage to a Stage 5 bud as a Stage 8 bud. The prospect of delaying Stages 1-3 up to two weeks and other stages up to 10 days would have in high-yielding apple crops in Farmington in 4 of 5 years. Instead, from 1976 to 1985, high yields were obtained in only 1 of 5 years. Not only is this technology biologically feasible, it is economically practical (Griffin et al.).



Conclusion: Apple bud development is regulated by temperature for both the satisfaction of the chilling requirement to break dormancy and the accumulation of growth units to resume growth. Temperature in apple orchards can be modified by water management to suppress bud development, protect against ice formation, and ameliorate occurrence of subfreezing temperatures. Today, the speakers will discuss how you can implement these important technologies into your production program.

Table 1. Growth stages and growth units for Red Delicious apples (Griffin et al.).

	Stage	Growth Units	Growth Units
		°F	°C
1	Silver Tip	3710	2061
2	Green Tip	4580	2544
3	Half-inch Green	5580	3100
4	Tight Cluster	7090	3939
5	First Pink	8740	4856
6	Full Pink	9740	5394
7	First Bloom	11110	6172
8	Full Bloom	12480	6933
9	Post Bloom		
10	Harvest	98000	54440

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