USE OF TIME—TEMPERATURE MONITORS FOR CONTROLLING SEEDLING QUALITY IN STORAGE

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Abstract.--i—Point® time—temperature monitors (TTM) were evaluated for their use as quality indicators for loblolly pine seedlings. TTM indicators, activated at the time of seedling packing, accumulate the effects of time and temperature during seedling storage and change color when specified limits are exceeded. TTM indicators have considerable potential as a quality control method for seedling storage. The greatest limitation in their use is the lack of good data on the storage time—temperature relationships for tree seedlings. As experience is gained in this area, TTMs should become an important technique to monitor seedling quality in storage.

Additional keywords: loblolly pine, Pinus taeda, nursery seedlings, seedling quality

Seedlings are subjected to a variety of environmental conditions from the time of packing at the nursery until transplanting in the field. Normally, seedlings are placed in cold storage (33°— 38°F) after packing for a 48 hour period. Later, seedlings are moved from this cold storage unit into ambient conditions and loaded onto a refrigerated truck for transportation to field units. On arrival at the field unit, seedlings are removed from refrigerated transport into a second refrigerated storage facility. Seedlings remain under these conditions until needed for transplanting. At the time of scheduled planting, seedlings are removed from refrigeration and are subject to ambient conditions.

During this storage and transportation process, which may be 6-8 weeks, or longer, seedlings are subjected to a variety of temperatures. Normal cycling of cooling units, variation of temperatures within the units, malfunctions and improper loading and stacking techniques are some of the reasons for these variations. To further complicate the problem several different people are usually involved in the process, each of which is unaware of the seedling's previous treatment.

Recording thermometers are generally used in a central location in cold storage buildings to monitor temperature. These thermometers do not, however, monitor the conditions at the location of each seedling bag. Neither do these thermometers accumulate storage time of seedlings. Because of these shortcomings it was felt that some type of device was needed that would monitor temperatures and accumulate them over time for each bag of seedlings and indicate when certain specified limits were exceeded.

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TIME/TEMPERATURE MONITORS

Forest tree seedlings lose quality in storage even under the best conditions. They have a maximum storage life, dependent on seedling condition and storage environment and can endure some temperature variation. Exposures to higher temperatures decrease the life of the seedlings. If handling and transportation temperatures rise above optimum levels, quality changes occur more rapidly. Since absolute control of storage temperatures is not feasible and length of storage may vary due to a variety of environmental and managerial problems, seedling quality often declines prior to outplanting. Some means of monitoring this quality is highly desirable and time-temperature monitors can record accumulated seedling storage conditions.

What are TTM Monitors?

A time-temperature monitor (TTM) is a device that can keep track of the accumulated time and temperature to which a perishable substance is subjected, from the point of harvest to the time of use. Time-temperature monitors come in various types, most are complex automatic devices. However, they do provide a means of determining exposure to extreme temperatures and/or lengthy periods at more optimum temperatures and accumulate the conditions. The i-Point® TTM is an inexpensive monitor that integrates time and temperature handling conditions.

The i-Point TTM is designed specifically to monitor storage conditions of any perishable product. Figure 1 shows how a TTM can indicate shortening of product life or in this case seedling quality. The small indicator accumulates all temperature experiences. When a pre-selected time-temperature limit is exceeded, the TTM will react with an irreversible color change. This color change serves as an early warning system, indicating that some action must be taken to prevent product loss.

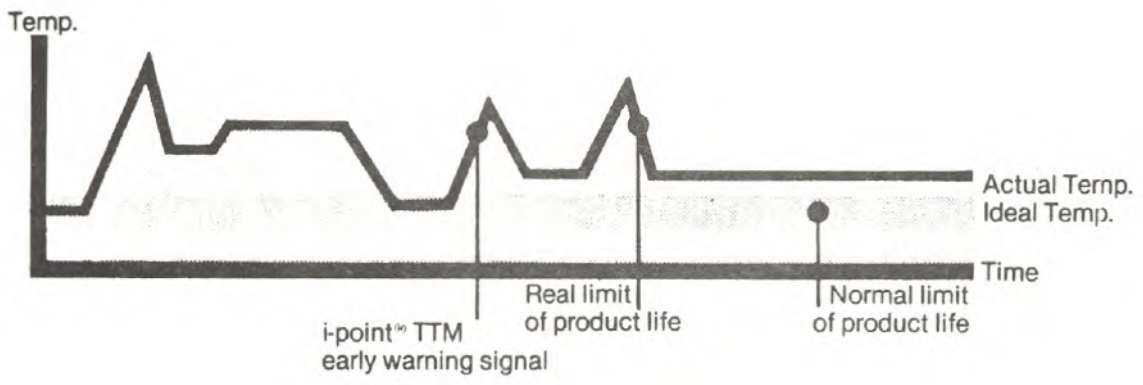

Figure 1.--Effects of temperature variability on the length of product life

How do TTM's work?

The i-Point TTM is based on reaction processes similar to natural enzyme activity. Consequently, the TTM reacts at a slow rate under optimum temperature conditions, and at a faster rate as the temperature rises. When the combined time-temperature limits have been exceeded, the enzyme based liquid changes color indicating some decision must be made about use. The monitor is set or triggered at packing and will irreversibly change color from the initial green if time or temperature exceeds the specifications for which the monitor is selected. The colors change with time or temperature conditions from green to yellow, orange, and red. The colors can be coded with a word message or a number, for example:

GREEN = EXCELLENT = 0
YELLOW = GOOD = #1
ORANGE = UNCERTAIN = #2
RED = OVER EXPOSED = #3

The i-Point TTM is about the size of a small adhesive bandage and can be affixed to the bag or package by the adhesive back. Prior to being affixed to the product, the TTM is triggered with a special device that mixes the two chemicals in the strip and starts the enzymatic reaction. A green color develops as soon as the chemicals are mixed.

The rate of the chemical reaction can be specified by the manufacturer. A wide range of indicators are available. A few types are listed in Table 1. The time required at a given temperature for a given indicator to turn orange (Color 2) is called the life span of that particular indicator.

The cost of i-Point TTMs in small quantities is about 20 cents each. As use increases the cost per unit decreases.

Application of TTMs to seedling storage

Not only are a wide range of i-Point TTM indicators available, others can be developed for more specific conditions. The indicator ideal for the species of seedlings that we are most interested then must be selected. This becomes the most critical issue in the use of TTMs for control of seedling storage. What data do we use to identify the most appropriate type of indicator? It quickly becomes apparent that we do not have sufficient information to select the ideal type of TTM. For these evaluations, with loblolly pine, Type 2220 was used. At a constant storage temperature of 32°F, the color of Type 2220 changes to orange (#2) at 22 days and to red (#3) at 28 days (Table 1). You may want to use other types, depending upon your experience and the species being stored. For example, longleaf pine seedlings should probably be held for a shorter period and Type 2110 or 2140 may be more appropriate.

Table 1.--A comparison of different i-Point TTM indicators as affected by temperature

Time to color change at a temperature of:

Temp.	+20°C 68°F			+10°C 50°F			0°C 32°F		
Curve Type	1 Good	2 Uncertain	3 Overexposed	1 Good	2 Uncertain	3 Overexposed	1 Good	2 Uncertain	3 Overexposed
1001	0,4h	0,5h	0,65h	0,7h	0,9h	1,2h	1,9h	2,4h	3,1h
1003	1,2h	1,5h	2h	2,2h	2,8h	3,6h	5,8h	7,2h	9,4h
1008	3,3h	4,2h	5,5h	6,2h	7,7h	10h	15,4h	19h	25h
1020	8h	10h	13h	15h	19h	24h	1,6d	2d	2,6d
2020	7,2h	9h	12h	15h	20h	25h	1,6d	2d	2,6d
2040	15h	18h	24h	31h	40h	50h	3,2d	4d	5,2d
2080	1,2d	1,5d	2d	2,6d	3,3d	4,3d	6,4d	8d	10,4d
2110	1,7d	2,1d	2,8d	3,7d	4,6d	6d	8,8d	11d	14,3d
2140	2,1d	2,6d	3,4d	4,6d	5,7d	7,4d	11,2d	14d	18,2d
2180	2,7d	3,4d	4,4d	5,8d	7,3d	9,5d	14d	18d	23d
2220	3,3d	4,2d	5,4d	7,3d	9d	12d	17,6d	22d	28d
2340	5,2d	6,5d	8,4d	10,5d	13d	17d	27d	34d	44d

A CASE STUDY

Procedures

Five-thousand i-Point TTM indicators were obtained from i-Point Technologies Ltd., Suite 302, 1725 K Street, N.W., Washington, D.C. 20006. Type 2220 was selected for our tests. This indicator reacts to time-temperature as shown in Table 1. At 32°F temperature, color changes occur at 18, 22, and 28 days. Loblolly pine seedlings in the Ashe Nursery at Brooklyn, Mississippi were lifted in late December 1983 and January 1984 and packaged in K-P bags. As soon as a bag was strapped and tagged (date, seed source and destination), a TTM was activated and attached to the bag where it could be readily seen during storage. When the seedlings were removed from cold storage at the nursery, the color of the TTM was recorded on the bag near the monitor. Records of the storage temperatures were also maintained.

When received on the Ranger Districts (all on the National Forest in Mississippi), the TTM color was again recorded on the bags. A "Seedling Monitor Record" was completed for each seedling shipment. On this record, the TTM colors were recorded that were previously noted on the bags with the color

when the bags were removed from the cooler for planting. Cooler-room temperatures were also recorded.

Results

A number of the seedling shipments were received in the field and were outplanted before any color changes were noted on the TTMs. However, several shipments were held until changes to colors 2 and 3 occurred. Four examples are shown in Table 2 where the days to reach color 2 are shown. Seedlings shipped to districts A and B were planted soon after the change of the TTM to color 2. In these two shipments the temperatures related well to length of storage. Using the Type 2220 curve in Figure 2, the integrated storage temperatures for 14 and 16 days to color change were 39° and 41°F. Seedlings shipped to district C took 24 days to change to color 2. This indicates that they were stored at lower temperatures, averaging about 30°F. A check of the records indicate that temperatures were lower than planned.

Seedlings at district D reached color 2 in 12 days. Use of Figure 2 indicates that the temperature must have been at about 45°F for the change in color to occur this early in storage. Cooler records confirmed that the unit was not cooling properly. The results do show that TTM can serve as a quality-control technique for seedling storage. However, since no correlation of these results were made with field performance, the color changes could not be related to seedling survival.

Table 2.--Average number of days to reach color 2 on four different ranger districts and the integrated storage temperatures

Ranger District	Lifting date	Days to reach Color 2	Days to reach Color 3	Integrated storage temperature 1/
		days	days	°F
A	12/20/83	14	--	41
B	12/20/83	16	--	39
C	1/12/84	24	--	30
D	1/12/84	12	16	45

a/ Determined from the curve of TTM Type 2220 on Figure 2.

CONCLUSIONS

i-Point monitors were shown to be a potential quality control method for seedling storage. At this time, however, we do not have sufficient biological information to specify the type of TTM indicator that closely relates storage conditions to field performance. Further research is needed to develop these relationships.

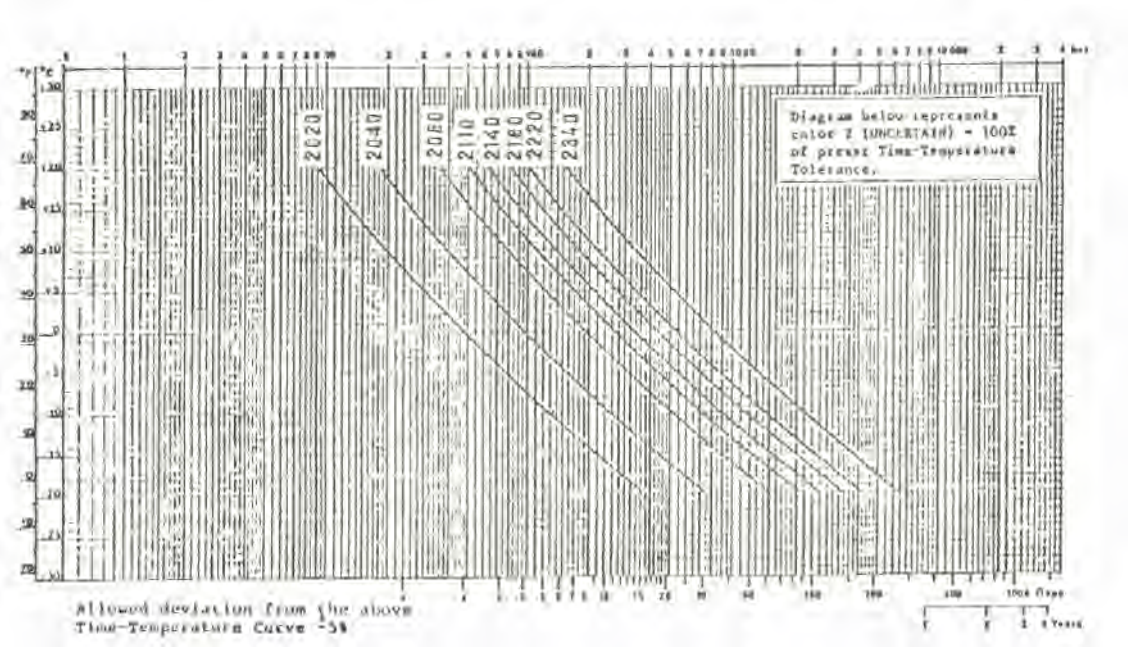

Figure 2.--Time—temperature curves for several i—Point TTM indicators. The curves represent days to color 2 at different temperatures.

Even without knowledge of these relationships, TTMs can be a useful tool in monitoring seedling storage. They can serve as a means to detect the effects of cooler failures and lengthy storage. In fact, they will integrate the effects of both of these variables and alert the silviculturist of problem situations that require immediate action.

The psychological benefits of the TTMs may be one of their greatest values to us. Because of their presence people are seemingly more aware that seedlings are perishable products and must be cared for properly. This results in closer inspection and greater care of seedlings.