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TEMPERATURE RELATIONSHIP IN ROOT INITIATION AND DEVELOPMENT OF CUTTINGS[1]

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Optimum temperatures for rooting of cuttings have long been accepted to be in the range of 20 to 25°C. Many studies have been carried out to support this assumption (2,5). However most studies on rooting temperatures have involved only one evaluation — that of root development after a set time period. Few studies have actually looked at root initiation and root development as two separate plant processes. Likewise, few workers have noted the time required for root initiation at different temperatures and actual root numbers initiated at different temperatures.

Hartmann and Kester (2) state that 21°-27°C day and 15°C night is optimum for most plant species. Below 21°C rooting is reduced and slowed down. At temperatures of 23°-27°C root inhibition often occurs as well as root injury. Howard (4) has shown that easily-rooted plum cuttings root best at 20°C. However, he noted that shy-rooting clones root more readily at 25°C.

A few workers throughout the last 50 years have looked at root initiation and root development as two separate processes in regard to temperature response. Sykes (8) showed that at temperatures of 30°-33°C, hop cuttings showed little delay in callusing and development of small roots, but these roots failed

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to extend. He concluded that the optimum temperature for rooting was 22°C and that supra-optimal temperatures appeared to inhibit root development without adversely affecting initiation. Howard (3), also worked with hops, found that at 27°C roots emerged in 4 days whereas at 22°C, no emergency occurred until the 10th day. Also cuttings required 6 days to obtain 10 roots per cutting at 27°C whereas 17 days were required at 22°C.

Work carried out in the Netherlands in 1927 (9) separated the temperature response of these two processes. The highest root count with hyacinth bulbs occurred at 27°C within a temperature range of 12.5°-27°C. However, root extension was greater and faster at 17°C and at all lower temperatures. It appeared that the greatest root initiation took place at 27°C but subsequent root elongation was greatest at 17°C.

Nightingale (6) working with apple and peach roots found that the greatest fresh weight of roots was obtained at 15°C, and root quality decreased as temperature increased. However callus and root formation was greatest at 30°C, but cells did not live as long at this temperature as at 25°C or less.

To understand how temperature affects root initiation and root development it is necessary to look at the two processes involved. Root initiation is basically cell division. Initiation is controlled by the rate of cell division and by the number of cells dividing. Root development, herein defined as that part of root growth subsequent to initiation, includes cell elongation and differentiation as well as cell division. Burholt (1) found that the maximum growth rate of sunflower roots occurred at 25°C. At higher temperatures this rate decreased and completely stopped at 37°C. The actual cell division continued to increase after 25°C and reached a peak between 30°-35°C. However, 25°C was the point which gave the maximum cell size and cell elongation. Above 25°C cell division continued to increase but cell size and the number of cells dividing decreased. This information indicates that total root growth may have two optimum temperatures, one for initiation and one for root elongation.

Preliminary studies by the author to determine the optimum temperature for air-rooting of cuttings suggested that root initiation would occur at temperatures as high as 35°C. Experiments were set up to study the effect of temperature on rooting of cuttings.

METHODS AND MATERIALS

Experiments were carried out using high humidity polyethylene chambers within larger growth chambers. Cuttings were rooted in air so that root initiation and development could be more readily observed and tabulated. Humidification was supplied by Bete PT10 atomization nozzles suspended above the cuttings. Cuttings were washed in Captan solution and basal ends were treated with 1000 ppm IBA in talc before placing in the rooting chamber. All cuttings were suspended utilizing polystyrene strips through which the cuttings were placed in prepunched holes. Entire cuttings were exposed to the treatment temperatures.

Each temperature trial consisted of 2 temperature with four blocks per temperature and 10 cuttings per block in a split block design. Temperatures were provided by two separate growth cabinets. Humidity and lighting were kept equal in each chamber. Trials were carried out with *Chrysanthemum* × 'Bright Golden Anne' cuttings, under a 16 hour lighting period.

A range of temperature combinations were evaluated. These included the following combinations: 1) 22° and 35°C; 2) 30° and 35°C; 3) 25° and 30°C, and 4) 25°, 30°C and 30° until emergence, then 25°C. Combinations 2, 3 and 4 were replicated in time to allow for statistical analysis. Cuttings were evaluated for the number of days to root emergence, number of roots per cutting, and degree of rooting.

Degree of rooting was determined on a scale of 0 to 5: 0 — no rooting; 1 — slight root emergence; 2 — a few roots developing; 3 — several roots developing; 4 — many well developed primary roots, and 5 — well developed roots with secondary branching.

In addition to chrysanthemums, cuttings of *Forsythia* × *intermedia* 'Lynwood' were rooted at 30°C and 25°C. The experimental design was the same except it was not replicated in time.

Root and root hair development was studied at various temperatures using a low power microscope.

RESULTS

Chrysanthemum. 22° versus 35° temperature: Roots at 35° emerged quicker and were greater in number than roots at 22°. Roots at 22°, however, showed more rapid root elongation and a far greater number of root hairs. Roots at 35° tended to deteriorate after several days at this temperature and new growth was very slow. Roots at 35° were superior to roots at 22° in terms of mass and number on day 15 (Table 1). However, subsequent to this, roots at 22° rapidly surpassed 35° roots in root elongation, mass and quality.

30° versus 35°C temperatures. The roots on 30° cuttings emerged 1 day earlier than roots on 35° cuttings and the root number was significantly higher at 30°. The "degree of rooting" taken on day 9 of the second trial was greater for 30° than for 35° (Table 1).

Roots on cuttings at 35° grew to 1 cm in length and then appeared to stop. New root growth turned brown within 2 days at 35°. Root hairs did not develop at this temperature.

Roots at 30° grew considerably faster than those at 35°. However, roots at 30° as well, turned brown after 4 days or more exposure to this temperature. Root hairs which initially were well developed tended to deteriorate after the second day. It was clear that 35° was beyond the optimum temperature for both root initiation and root development for chrysanthemum cuttings.

Table 1. Rooting of *Chrysanthemum* × 'Bright Golden Anne' at various temperatures.

Temperature	Degree of rooting	No. of roots/cutting
22°C	1.3	
35°C	2.1	
30°C	2.9	15.3 a*
35°C	2.3	8.8 b

* Means followed by the same letters are not significantly different at the 1% level of the L.S.D. Test.

25°C versus 30°C temperatures. Root emergence during these trials was 2 days earlier at 30° than at 25°. Both number of roots per cutting and the degree of rooting was greater at 30° than at 25° when taken on day 10 (Table 2). The final root count per cutting on day 21 was also greater at 30°. However, the final length and mass of roots was greater at 25°.

Root elongation was much greater and root hairs were shorter and thicker at 25° than at 30°. Root hairs at 25° lasted for extended periods of time, whereas at 30° root hairs deteriorated within 2 days of development.

At 30° roots elongated to a maximum of 1.5 cm in 21 days of rooting with considerable dieback of root tips. Roots at 25° were up to 3 cm in length by the 21st day and secondary branching was developing. Subsequently the final root weight per cutting was much greater at 25° than at 30°.

25°C and 30°C versus 30°C until emergence followed by 25°C. Because of the early results of 25° and 30° comparisons a third treatment was utilized in the last two trials. Cuttings were kept at 30° until root emergence and then transferred to 25° for root development. Under this treatment the number of roots per cutting remained the same as for those at constant 30°. (Table 2) This suggested that all roots were initiated prior to the first root emergence.

Table 2. Effects of temperature on root initiation and development in cuttings of *Chrysanthemum* × 'Bright Golden Anne'.

Temperature	Degree of rooting			No. roots per cutting			Days to	Fresh Wt. roots
	Time I	Time II	Ave.	Time I	Time II	Ave.	Emergence	(mg/cutting)
25°C	1.6	2.9	2.2a*	12.6	5.8	9.2a	8	341.3
30°C	2.2	3.4	2.8b	20.7	9.2	14.9b	6	269.5
initiated 30°C developed 25°C				20.9	10.5	15.9b	6	539.3
Coef. Var.			17.5%			18.0%		

* Means in the same column followed by the same letters are not significantly different at the 1% level of the F test and HSD test.

However, the final root size of the transferred cuttings differed greatly from those at constant 30° and also from those at 25°. The roots of transferred cuttings grew as rapidly as those at constant 25°. Since the transferred cuttings had a significantly greater root number, the final root weight per cutting was much greater.

Forsythia. The number of days to 50% root emergence was recorded for forsythia (Table 3). It was found that at 25°, forsythia required 13 days for roots to emerge whereas at 30°, roots emerged in 9.3 days. The number of roots initiated at 30° was much greater than those at 25°. Roots at 30° however, were smaller in diameter and lacked root hair development.

Table. 3. The effects of temperature on the rooting of *Forsythia* × *intermedia* cuttings in air.

Temperature	Days to 50% rooting	No. roots per cutting	
		Day 15	Day 20
25°C	13.0	2.4	5.2
30°C	9.3	6.2	9.1

DISCUSSION

The rooting response to temperature was very similar in both chrysanthemums and forsythia. The high temperature of 30°C resulted in more rapid root initiation, shorter emergence time, and more roots per cutting. However, subsequent root development including elongation, diameter, and root hair development; secondary branching occurred more readily at the lower temperature of 25°C. This supports the concept that roots have two optimum temperatures for total growth, one for initiation and one for elongation and development.

When cuttings are subject to both of these optimum temperatures in sequence, total rooting time can be reduced significantly and the final root size will be greater than for cuttings held constant at either a high or low temperature.

An optimum temperature graph for root initiation and development is proposed (Figure 1). This graph, based on these studies, is offered as a generalized temperature relationship to the rooting of many plant species.

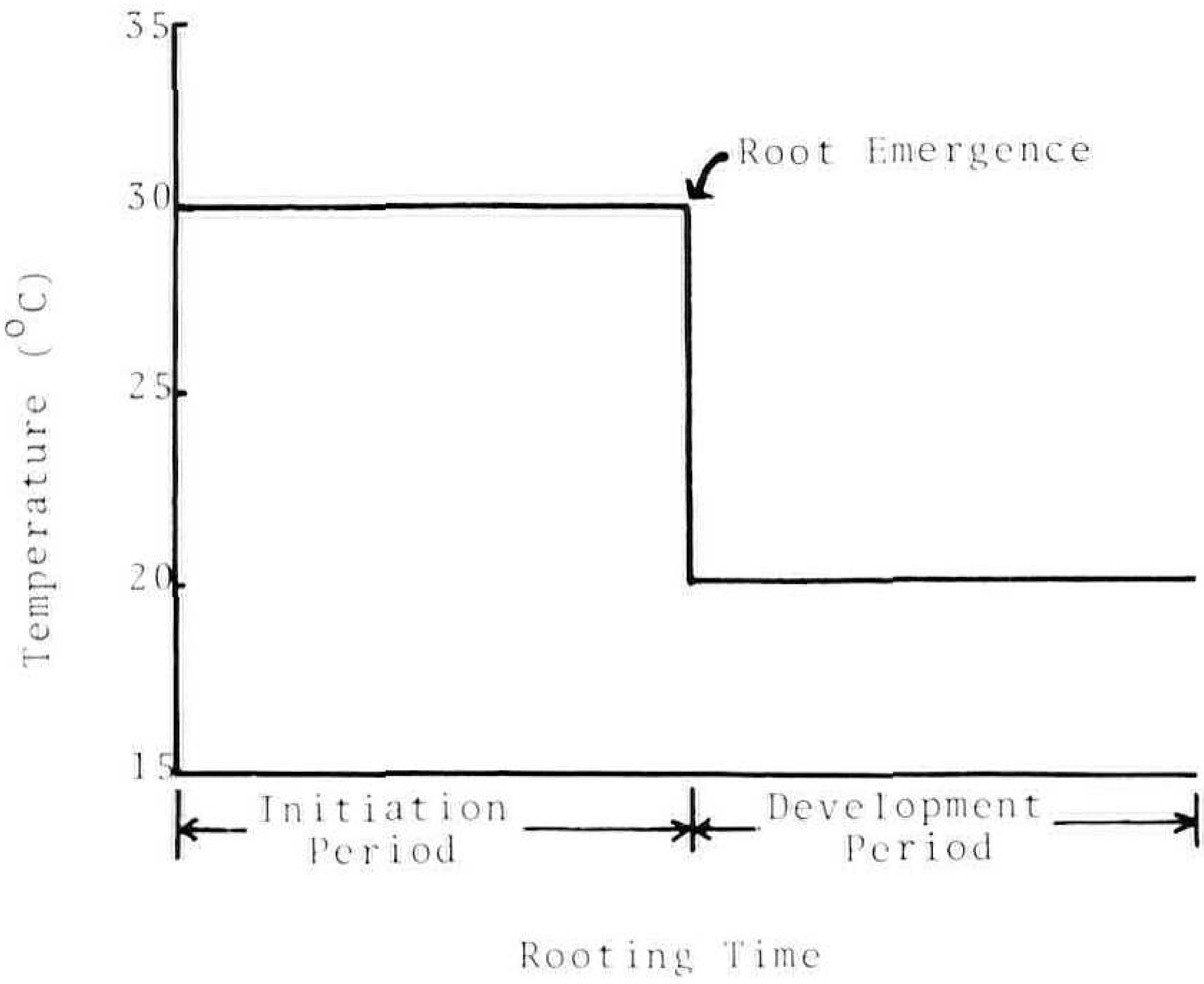

Figure 1. Proposed temperature regime for maximum rooting of cuttings of many plant species.

These studies have not pinpointed the optimum temperatures for any one species but have merely shown that the two rooting processes respond to different temperatures. In the past, propagators have realized this point, but have failed to utilize this knowledge. It is suggested here, that propagation time may be reduced significantly by providing the optimum temperature for each rooting process.

Even with the two readily rooted species used in these studies, emergence time was reduced by 30% and root number was increased by 60% to 80%. Howard (4) states that difficult-to-root species respond more to increased temperature than easily-rooted species.

The reason for the increased rate of initiation at the higher temperature is not entirely clear. Burholt (1) suggested that the rate of cell division increase to a maximum between 30° and 35°C. This alone may be the sole explanation. But we also observed that plants are much more responsive to auxin at the higher temperatures. The advantage of auxin application over no auxin was far greater at 30° than at 25°C. It has also been noted by Scott (7) that auxin activity in roots is much greater at higher temperatures. Since we are still unable to explain the role of auxin in root initiation it is difficult at this time to tie these two processes of mitotic cell division and increased auxin activity together.

SUMMARY

Cuttings of both chrysanthemums and forsythia were shown to have maximum root initiation at 30°C. Maximum root development including elongation, diameter, root hair development and secondary branching was shown to occur at temperatures below 30°C (25°C in these experiments). The greatest total root growth in chrysanthemums occurred when roots were initiated at 30°C and allowed to develop at 25°C.

It is proposed that root growth of most species, if not all, can be divided into two processes, root initiation and root development, each having a temperature optima. From the results of these studies and from the literature, it appears that the optimum temperature for root initiation of many species is in the area of 27° to 33°C. Whereas the optimum temperature for root development may be lower, in the range of 17° to 25°C. It is proposed that significant advantages in terms of rooting time and root quality may be gained by utilizing a two temperature system in the rooting of cuttings.

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