SHORT COMMUNICATIONS

THE IMPORTANCE OF HIGH TEMPERATURES IN THE INDUCTION OF THE RESTING PHASE OF *PINUS ELLIOTTII**

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Whilst Vegis (1953, 1956) outlined the importance of high temperatures in the induction of a resting phase in plants, his findings have generally been overlooked by forest physiologists, who usually regard day length as the most important parameter in the induction of the resting phase (see, for example, Kramer and Kozlowski 1960 and Longman 1969). Two recent experiments growing seedlings of slash pine (*Pinus elliottii* Engelm. var *elliottii* L. & D.) in controlled environments have demonstrated the existence of a temperature × day length interaction in the induction of the resting phase and have shown the resting condition can be induced under constant day length by a change to a higher temperature regime.

The two experiments were conducted in the CSIRO phytotron at Canberra (Morse and Evans 1962). In the first experiment the seedlings were placed in cabinets illuminated by a combination of fluorescent and incandescent light giving an intensity of 2300 ± 100 f.c. at the leading shoots. In the second experiment the seedlings were in cabinets open to natural daylight for 8 hr followed by an additional 2 hr of low intensity (50 f.c.) incandescent light giving a total daily photoperiod of 10 hr. In both experiments illumination commenced at 8 a.m.

Temperatures (± 1°C) within each cabinet were held at two specific levels, a "day" temperature from 8 a.m. to 4 p.m. and a "night" temperature for the remainder of the 24-hr period. The day/night change of air temperature was rapid and regarded as instantaneous; soil temperature changes were slower but complete within 1 hr of the air temperature change.

In the first experiment 1-year-old seedlings from a Queensland nursery were air-freighted to Canberra and introduced to the phytotron after fumigation. The seedlings for the second experiment were raised from seed within the phytotron. To avoid position effects the locations of the seedlings within cabinets were interchanged randomly at intervals of 2 weeks.

Slash pine grows in height by a series of rapid episodic flushes of the main stem. The interval between flushes usually lasts only a few weeks; there is a transient terminal bud, whitish in colour and less than 1 cm long. Rapid extension growth of the previous flush continues throughout this period and well after flushing of the transient bud. At transient bud break the proximal shoot usually carries short (<8 cm) secondary needles and has succulent stem tissue.

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The onset of the resting condition occurs over several weeks. Initially the terminal bud is similar to a transient bud but fails to break, becomes several centimetres long, and develops brown scales. Concurrently the stem of the shoot below the bud completes extension growth and becomes woody. The secondary needles on this shoot continue elongating for some time after the initiation of the resting bud, eventually overtopping the bud and attaining a length of approximately 25 cm.

Seedlings were held initially in an open glasshouse at a 27/22°C day/night temperature under conditions of natural daylight with supplementary light to give a 16-hr photoperiod. Under these conditions the seedlings grew rapidly and had produced at least one, and usually more growth flushes when the experment commenced.

In the first experiment seedling behaviour was compared at three temperature regimes under decreasing day length. The respective temperature regimes selected, 28/17, 26/15, and 23/11°C correspond approximately to the mean daily maxima and minima for southern coastal Queensland in the months of January (summer), March (autumn), and July (winter). Within each cabinet there were seven seedlings. The initial day length within each cabinet of 16 hr was reduced by 1 hr every 3 weeks and the experiment was terminated after 200 days when the day length was 7 hr. Stem heights were measured from a fixed datum peg in each pot and mean height increments are shown in Figure 1.

All seedlings exhibited similar height growth patterns. Initially under long photoperiods height growth was rapid. Subsequently as photoperiod shortened height increments declined and in the final stages of the experiment were practically negligible. There was, however, a clear day length × temperature interaction in the induction of the resting phase. The higher the temperature regime the earlier in the experiment and the longer the day length at which the resting stage was induced. In the warmest cabinet at 28/17°C the decline in height increment commenced 50 days after the start of the experiment when the photoperiod was 14 hr and height increments became very small after 122 days (11-hr photoperiod). Equivalent values for the intermediate cabinet at 26/15°C were 73 days (13-hr photoperiod) and 122 days (11-hr photoperiod) and for the coolest cabinet at 23/11°C, 101 days (12-hr photoperiod) and 150 days (9-hr photoperiod) respectively (Fig. 1).

Cessation of height growth in the two warmer cabinets was accompanied by the development of the characteristic resting bud condition but this did not occur in the cabinet at the lowest temperature even though height growth ceased. Measurement of the time of cessation of needle elongation also confirmed the presence of the day length × temperature interaction despite some variation with position on the tree. Under the warmest regime elongation ceased over the period 79–178 days, under the intermediate regime over the period 91–178 days, and in the coolest cabinet over the period 91–191 days.

The second experiment confirmed the importance of high temperatures in the induction of the resting phase condition in slash pine. Throughout the experiment all seedlings were maintained under a constant day length of 10 hr (8 hr daylight and 2 hr low intensity incandescent light). Initially the 20 seedlings used were under a temperature regime of 23/11°C, but after 5 weeks 10 of these seedlings were transferred to an identical cabinet with a 28/17°C regime.

Fifty-four days after transfer the seedlings in the warmer cabinet had significantly lower height increment (at the 5% level) than those retained in the cooler cabinet (Fig. 1); after 98 days seedling height growth in the warmer cabinet had virtually ceased and was highly significantly ($P < 0{\cdot}01$) less than the rate in the cooler cabinet.

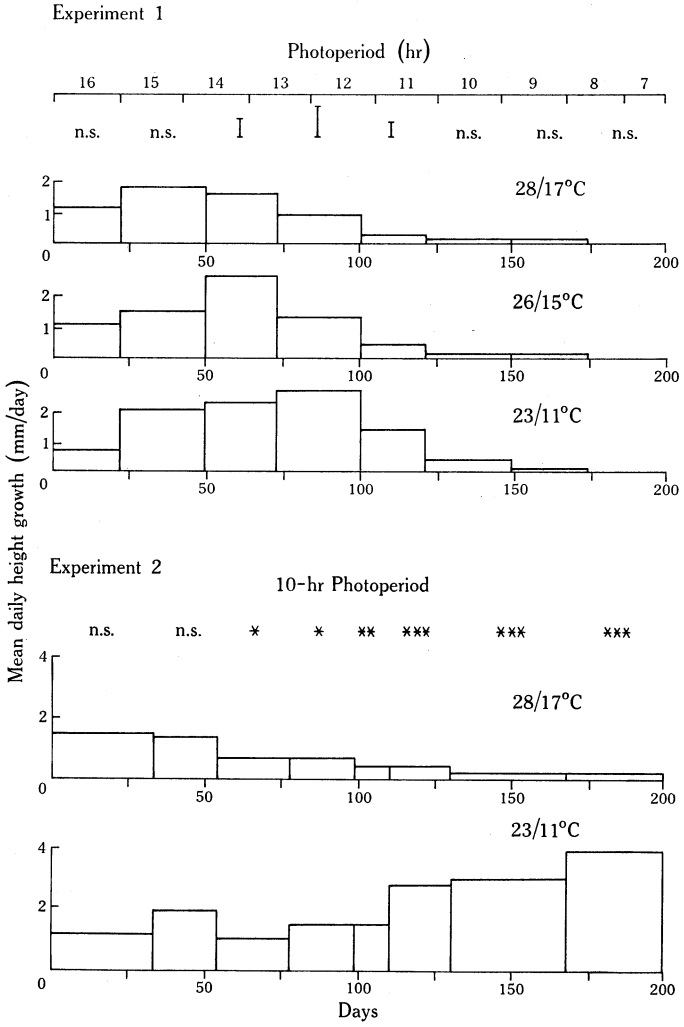

Fig. 1.—Histograms detailing the mean daily height growth of the seedlings in each treatment over the periods indicated. The differences necessary for significance at the 0·05 level are indicated for experiment 1 by bars whilst in experiment 2 *, **, and *** indicate the differences significant at the 0·05, 0·01, and 0·001 levels, respectively. In both cases n.s. indicates the differences were not significant at the 0·05 level.

In the warmer cabinet all seedlings had set resting buds after 78 days, some having done so 33 days after the transfer. Terminal shoots of seedlings in this cabinet

had a definite woody texture after 168 days, when secondary needles were long (*c.* 20 cm in length) and the rate of needle elongation had slowed. In the cooler cabinet in contrast rapid stem elongation continued with periodic bud setting and flushing until the experiment was terminated. At no time was there any indication of the induction of a resting phase.

Field studies of slash pine in Queensland have indicated shorter seasons of height growth in warmer latitudes and, in the tropics, the induction of resting buds before the summer solstice (Slee 1972). This pattern of growth may be due to rising temperatures under the comparatively short day lengths of the State. For example, 14 hr (sunrise–sunset) is the maximum day length for Brisbane (27°S.). Possibly a temperature × day length interaction could also explain the well-documented cessation of height growth before midsummer in many temperate species in other parts of the world.

Control of bud setting affects both quality and quantity of timber production. Larson (1962, 1964) and Gordon and Larson (1968) showed induction of the terminal bud in the temperate species *Pinus resinosa* induced a consequent change in photosynthate distribution within the tree and increased the density of wood produced. Ambient temperatures may control setting of terminal buds in tropical species and if this is so wood density would be expected to be greater when those species were grown in warmer areas. Preliminary data for *P. caribaea* indicate such a pattern in Queensland (Slee and Nikles 1968).

Temperature induction of terminal bud set in a subtropical conifer may have considerable physiological, ecological, and economic significance. Day length has been accepted for many years as an important criterion for seed source selection in cool temperate species. Appraisal of temperature regimes may prove equally important in provenance selection within the tree species of the tropics and subtropics.

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References

Gordon, J. C., and Larson, P. R. (1968).—*Pl. Physiol., Lancaster* **43**, 1617.

Kramer, P. J., and Kozlowski, T. T. (1960).—"Physiology of Trees." (McGraw-Hill Book Company: New York.)

Larson, P. R. (1962).—*Am. J. Bot.* **49**, 132.

Larson, P. R. (1964).—In "The Formation of Wood in Forest Trees". (Ed. M. B. Zimmerman.) p. 345. (Academic Press: New York.)

Longman, K. A. (1969).—In "Dormancy and Survival". p. 471. [Symposia of the Society for Experimental Biology No. 23.]

Morse, R. N., and Evans, L. T. (1962).—*J. Agric. engng Res.* **7**, 128.

Slee, M. U. (1972).—*Euphytica* **21**, 129.

Slee, M. U., and Nikles, D. G. N. (1968).—Paper to 9th Br. Commonw. Forestry Conf., New Delhi, India, 1968. (Qld. Dept. Forestry: Brisbane.)

Vegis, A. (1953).—*Experientia* **9**, 462.

Vegis, A. (1956).—*Experientia* **12**, 94.