
Outdoor cold frame tests in which air and soil temperatures were modified showed both to be involved in the timing of spring bud flush. The results indicated that warming the soil advanced the date of growth initiation and warming the air increased the rate of bud development once initiated. The latter had a 5.7:0.45 greater effect per degree celsius change in temperature.

INTRODUCTION

In species such as Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), which show a chilling requirement (Wommack 1964), bud-burst phenology is considered to be determined largely by rising temperatures in the spring (Wareing 1956). However, there is a question as to the relative importance of air and soil temperatures. Lavender et al. (1973) suggested that soil temperature played a major role, with cold soils (5°C) delaying bud flush. Timmis and Worrall (1974) observed no differences in flushing date between cold- and warm-root plants.

In 1970 and 1975, two experiments were established in raised nursery beds in Corvallis, OR, in which air and soil temperatures were artificially raised. Both experiments showed a combined influence of air and soil temperatures.

MATERIALS AND METHODS

Four temperature treatments, normal and heated air and (or) soil, were applied factorially and at random in a 2 x 2 arrangement in both experiments. All treatments were replicated twice. Plot size was 1.2 x 1.5 m. In experiment I (EI), plots included 5 seedlings per provenance from 40 provenances; in experiment II (EII), plots included 12 seedlings per provenance from 4 provenances. Provenances sampled Douglas-fir stands between 43 and 48°N latitude in western Oregon and Washington.

Warming of the air was achieved by placing a plastic tent over the plots. To permit air circulation into the tents, bottom edges of the plastic were supported 5 cm above the soil surface and ends of the tent frames were extended 10 cm beyond the framework of the raised beds. Soil was warmed with heating cables placed 15 cm below the soil surface and set to give an average temperature of 20°C, 10 cm below the soil surface. The temperature treatments were started when the seeds were sown. Temperatures were monitored in EI during the 6 to 8 weeks preceding and during bud flush. Air temperature was measured 2 cm above and soil temperature 10 cm below the soil surface.

Presence or absence of a flushed terminal bud was recorded on every seedling twice weekly (EI) and every other day (EII). A bud was considered flushed when green needles could first be seen between the bud scales. Mean date of flushing was calculated for each plot, and plot means were subjected to analysis of variance.

RESULTS AND DISCUSSION

Air temperature in the covered plots averaged 2.1°C warmer than in the uncovered plots over the 4 to 6 weeks prior to bud flush and 2.9°C warmer during the actual flushing period. Temperature differences between covered and uncovered plots varied with time of day and were greatest about 6 pm (about 5°C) and least about 6 am (about 0.5°C). Soil heat did not measurably affect air temperature.

Unheated soil warmed linearly with time from mid-February and remained constant with time in heated plots. Plastic tents raised soil temperature by about 4 and 1°C in soil-heated and unheated plots, respectively. During the 30 days prior to average date of bud flush for all plots, average soil temperatures of the soil-heated and unheated plots differed by 11.7°C.

Average date of terminal bud flush in EI was advanced by 7.7 and 3.5 days by increased air and soil temperatures, respectively. The comparable
Interaction between air and soil temperatures was
F = 15.65.  

average soil temperature.

growth process and the rate at which growth pro­
ceeds once initiated. Initiation has received the
major attention in previous physiological studies of
bud flush but, we believe our observations on the
differential effect of air and soil temperatures indi­
cate that rate of development, rather than the time
of initiation, has greater influence on bud-burst tim­
ing.

Lavender et al. (1973) advanced bud flush by
about 2 weeks by increasing soil temperature from
5 to 20°C or 0.9 days/1°C. Their temperature treat­
ments were started about 6 weeks before bud flush
and were applied to seedlings which had been main­
tained out of doors all winter until late February.
Day lengths were short (9 h) and air temperature
was a constant 20°C. In our experiments, at the
time of bud flushing, day lengths were intermediate
(about 13 h), average air temperature was about
10°C, contrasting soil temperatures about 9 and
21°C, and the plants had been outdoors until the
time of bud flush or until about mid-April.

While results of both tests show that soil temper­
ature plays a role in bud-burst phenology, our re­
sults indicate that the role is negligible unless other
external factors are favorable. In winter and early
spring, response to temperature is limited by in­
adequate chilling and short photoperiods (Flint
1974; Campbell and Sugano 1975). Later, the
influence of temperature increases as other factors
become less limiting (Brouwer 1964; Brouwer and
Kleinendorst 1967). Consequently, even though
soil temperature in soil-heated plots was 21°C
throughout the winter, bud flush was delayed until
spring, in fact, until just shortly before bud flush in
unheated plots.

Under natural and most nursery conditions, the
effect of early initiation of bud activity is probably
inconsequential because lack of chilling, short
photoperiods, and low air temperatures act indi­
vidually or in combination to slow the rate of de­
velopment or response to heat-unit accumulation.
Therefore, it appears that developmental rate is
usually of more importance in determining flushing
date than is the time at which measurable develop­
ment may have started.

We believe that several preconditioning factors
which influence developmental rates have often
been neglected or inadequately characterized when
the influence of individual environmental treat­
ments on bud flush has been studied. These factors, in addition to chilling duration and
photoperiod (Flint 1974; Campbell and Sugano
1975), include chilling temperature and length of
time between bud set and initiation of chilling
(Dormling et al. 1968; Sugano 1971). We also be­
lieve that the particular importance of these factors
is their influence on developmental rate or response
to heat-unit accumulation at low temperatures
(Vegis 1963). Much of the development toward bud
flush normally occurs in the moderately low tem­
peratures characteristic of early spring (5–10°C).
It was at these temperatures that we found a small
difference in air temperature to have a large effect
on bud-burst timing.

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