Pressure and Composition of Intrastem Gases Produced in Wetwood of American Elm

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ABSTRACT

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Bacterial wetwood of American elm (*Ulmus americana*) is associated with positive intrastem gas pressures within affected wood. Comparative data were obtained on elemental gas composition and seasonal variation in the magnitude of gas pressure in nondiscolored sapwood and discolored wetwood. Gas composition was determined by gas chromatography, and gas pressures were monitored with a gauge cock. No positive gas pressure was observed in nondiscolored sapwood. Positive gas pressures in discolored wetwood increased from May through August, then declined. Mean gas composition in sapwood and wetwood was, respectively, CO_2, 5.4 and 8.8%; O_2, 18.9 and 7.2%; N_2, 74.7 and 32.8%; and CH_4, 0 and 47.2%. CH_4 levels were significantly higher and O_2 and N_2 levels significantly lower in discolored wetwood, where bacteria abound, than in nondiscolored sapwood, where bacteria are rare.

Bacterial wetwood of American elm (*Ulmus americana*) is associated with elevated intrastem gas pressure (3,8). The positive gas pressure was reported (3) to be produced in living elm stems within a central core of discolored wetwood surrounded by a ring of nondiscolored sapwood. The central core of discolored elm stem tissue occupies a position in the stem often considered heartwood. In American elm this central area is always discolored and associated with the condition described as wetwood. Thus, we contrast wetwood (discolored) with sapwood (nondiscolored, or clear and white).

Positive pressure may force liquid from the wetwood through wounds or traumatized sapwood, where it exits from branch crotches, pruned branch stubs, trunk cracks, or such mechanical wounds as holes made for the injection of systemic fungicides. The wetwood liquid "bleeds" from such wounds and flows down the bark, where it dries as a grayish white incrustation. Prolonged flow from a wound may result in a condition known as slime flux (3), in which the bleeding liquid is colonized by secondary microorganisms such as fungi, yeasts, or insects (3,9). Continuous liquid bleeding from wetwood has been shown to cause mortality of cambial tissue that becomes soaked, as well as localized mortality of turfgrass (3). Positive pressure produced in wetwood is believed to interfere with the successful injection of systemic fungicides into tree stems (2). Positive gas pressure has also been associated with bacterial wetwood in *Populus* spp. (5,7,10,12) and red oak (6).

This study was done to monitor gas pressures in sapwood and wetwood of elm on a seasonal basis and to determine the composition of the gases present using modern analytical methods. To investigate the development of wetwood throughout the stem, gas pressures were also monitored at different stem heights. In addition, elm gas may be of interest as a possible source of hydrocarbon fuel.

MATERIALS AND METHODS

Gas pressure determination. The trees in this study were 20–61 cm in diameter at 1.3-m stem height above mean ground level, growing on or within 2 km of the University of Maine campus in Orono. All study trees were affected with bacterial wetwood, based on observation of discolored, water-soaked, wetwood increment cores removed from study trees and evidence of bleeding from wounds.

Intrastem gas pressures of the trees were monitored weekly for periods up to 2 yr. Monitoring was done by a gauge cock method similar to Carter's (3). An increment borer was used to drill a 5-mm hole into the sapwood or through the sapwood into the discolored wetwood. The borehole was drilled at a 30° angle down into the stem to prevent liquid from clogging the gauge cock. A hand drill was used to enlarge the first 5 cm of the borehole to 0.79 cm. A 7.6-cm length of galvanized iron nipple (0.79 cm diam.), threaded at both ends, was forced tightly into the rebored hole and allowed to remain for at least 1 yr before data collection to minimize outside air contamination. Trees with gauge-cock-associated bleeding were not included in the study. A brass stopcock was firmly attached to the nipple. Pressure readings were made by attaching a calibrated pressure gauge to the stopcock and opening the valve (Fig. 1). After data collection, the stopcock valve was closed and the gauge removed.

Gauge cocks were installed at 1-m stem height in the sapwood and wetwood of 43 trees. They were also attached at the base of three pairs of twin stems of trees with no evidence of bleeding. To determine whether pressures varied at different vertical positions in a tree stem, three additional trees were fitted with gauge cocks at 3-m stem height. Gauge cocks were then placed at random in the upper stems and large branches at various heights from 5–9 m, depending on the sample tree.

Gas composition analysis. Gas samples were collected from sapwood and wetwood of five trees in a manner described by Zeikus and Ward (12). A rubber septum was inserted over the gauge cock orifice, the valve was opened, and a syringe was used to remove twice

Fig. 1. Gauge cock and gauge mounted on an elm stem showing an internal wetwood gas pressure of 0.7 kg/cm^2.

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the gas volume of the borehole. This gas was discarded and 20 ml of sapwood or 40 ml of wetwood gas was then drawn into the syringe and brought to the laboratory for analysis on a Perkin Elmer Model 900 gas chromatograph equipped with a thermal conductivity detector.

RESULTS

Gas pressure. No measurable gas pressure was recorded in nondiscolored sapwood throughout the study period. Figure 2 shows the monthly mean gas pressures in wetwood of 23 trees with no evidence of bleeding on the bark. From November through April no pressure was measured in wetwood. Beginning in May, higher pressures associated with temperature increases were recorded. Values were highest in August, when pressures up to 1.41 kg/cm^2 were observed. Wetwood gas pressure in individual trees showed similar seasonal fluctuations, but pressure magnitudes among trees were highly variable. No correlation was observed among trees showing no bleeding, trees that had bled previously, and gas pressures. Ten trees that were actively bleeding from varied types of bole wounds during the study period (ie, injection holes, trunk cracks, mechanical abrasions) did not show any measurable gas pressure. One tree was observed actively bleeding from a bole injection wound at 0.5 m for a period of 1 yr. During this time no measurable gas pressure was recorded in the wetwood core at 2.7 m. One month after cessation of active bleeding, however, pressure was recorded in wetwood. These data are presented in Figure 3.

Gas pressure recorded in twin-stem trees followed similar annual patterns, but pressures varied (Fig. 4). A similar pattern was observed in trees where gas pressure was monitored at different vertical positions on the stem (Fig. 5).

Gas composition. Results of the gas composition analysis are presented in Table 1. CO_2 in the wetwood gas mixture showed the least variation among the sample trees. A high value of 88% methane was recorded in wetwood gas of one tree. Gas composition in the sapwood showed slightly reduced O_2 and N_2 values and elevated CO_2 values (but not significant differences) from those present in the atmosphere. No methane was detected in any sample of gas from sapwood tissue.

DISCUSSION

Positive gas pressures were always associated with discolored wetwood but never with nondiscolored sapwood. All pressures followed a similar seasonal pattern. Because bacteria are normally associated with wetwood in elm (3), these patterns probably reflect the growth and temperature requirements of the bacterial populations present in wetwood. Pressure was present in wetwood at least to a vertical height of 9 m in trees averaging 10–20 m. This helps explain the bleeding commonly associated with pruned branch stubs and other crown wounds. Pressure and tree height were not correlated, although some of the highest pressure values were recorded at 3 m or more.

On trees with actively bleeding wounds on the main stem, no pressure was recorded at distances of at least 1 m from the bleeding wound. These data support Carter's recommendation of using drains to relieve pressure (3). Bleeding from stem wounds is thus minimized, along with subsequent mortality of cambial tissue (4). Drain tubes, however, would allow the entrance of oxygen into the stem, increasing risk of fungal-caused decay.

Positive intrastem gas pressure could interfere with the passive movement of systemic fungicides injected into elm stems for the control of Dutch elm

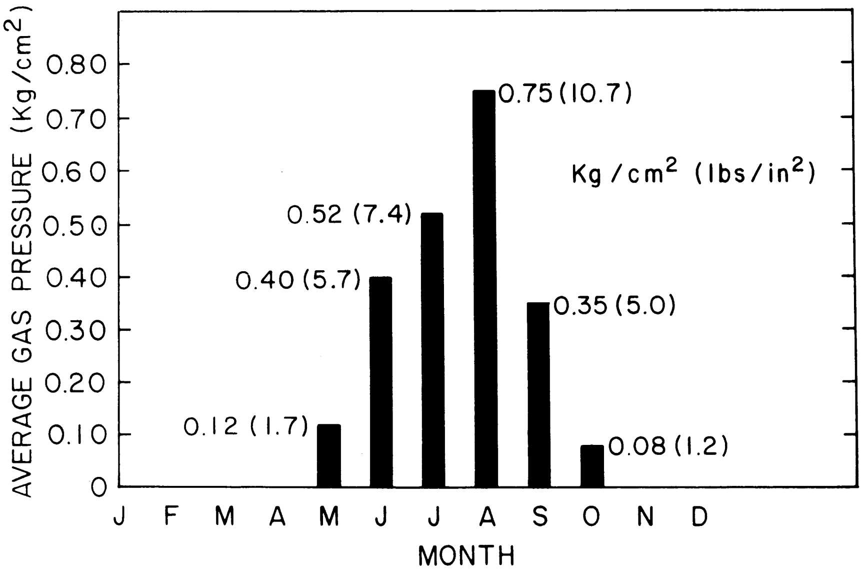

Fig. 2. Mean monthly gas pressures of 23 American elm trees with no evidence of active bleeding.

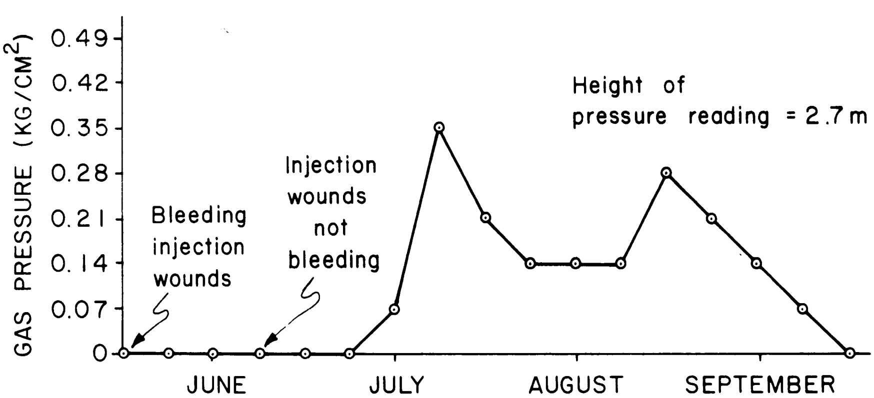

Fig. 3. An American elm with no measurable wetwood gas pressure (June) until bleeding ceased (July).

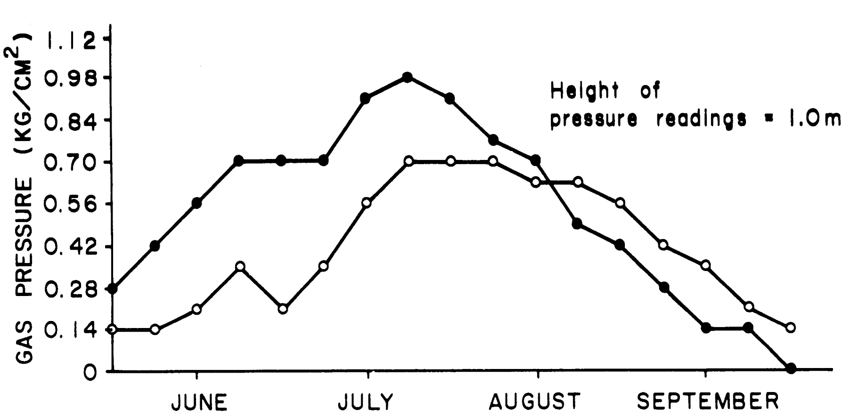

Fig. 4. Average monthly gas pressures in each stem of a twin-stem elm tree.

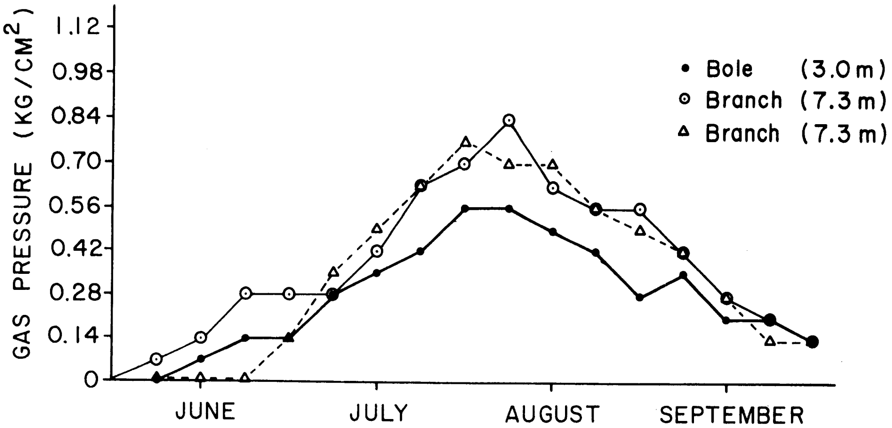

Fig. 5. Sample tree data showing that wetwood gas pressures at different stem heights follow similar seasonal patterns, while pressure magnitudes vary.

Table 1. Gas composition in sapwood and wetwood of American elm

	Gas composition (%)[a]			
Wood type	CO_2	CH_4	O_2	N_2
Nondiscolored sapwood	5.4	0.0	18.9	74.7
Discolored wetwood	8.8	47.2**[b]	7.2*[b]	32.8**[b]

[a] Values shown are means of two samples for each of five trees.
[b] * = Differs from nondiscolored sapwood gas at $P = 0.05$; ** = differs from nondiscolored sapwood gas at $P = 0.01$.

disease. Thus, care should be taken to keep injection holes as shallow as possible (1.5 cm) to avoid penetrating the central wetwood core.

Data obtained on composition of elm wetwood gas are comparable with earlier results obtained for elm and poplar (3,7). Results differ slightly for both sapwood and wetwood gas composition from those presented by Zeikus and Ward for cottonwood and white poplar (12). This may be due to expected variation among tree species or differences in the wetwood-associated bacterial microflora due to geographic location. The elevated CO_2 values in elm sapwood gas compared with those in the atmosphere could be the result of metabolic action of the living wood cells and of the facultatively anaerobic bacterium *Enterobacter cloacae* (*Erwinia nimipressuralis* Cart.), a strong producer of CO_2 in culture (3) and frequently associated with elm injection wounds (1).

The reduced O_2 content and formation of methane in wetwood of elm and other tree species has been shown to be microbial in origin (11,12). Anaerobic conditions necessary for the microbial evolution of methane would inhibit the growth of most wood-inhabiting fungi, possibly representing a naturally evolved defense mechanism of benefit to the host tree (10). None of the study trees showed evidence of internal wood decay.

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