CHEMICAL CONTROL OF TREE GROWTH BY BARK PAINTING[1]

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Abstract. Environmental constraints have forced the development of alternate application methods for controlling tree growth with chemicals. The two methods with the most promise, bark painting and trunk injection, have some technical problems associated with them that must be solved before either procedure can be fully exploited. The most important problem for chemicals applied by bark painting is that of transversing the suberized layer just below the outer bark. Trunk injection confronts two major problems in some trees, namely that of forcing solutions into small xylem vessels and sectorial-type distribution in wood with straight grain. Some results of trials with both techniques are discussed.

Foliar spraying of trees under electrical distribution lines, probably the most reliable and least expensive application procedure for controlling growth, is now generally unacceptable in populated areas. Techniques such as trunk injection, bark painting (banding), and root-zone injection, that apply the growth regulator directly to the tree are now being used or are under development (Arron, 1985; Bowles, 1985; Brown, 1978; Domir, 1978; Hield et al., 1978; Sachs et al., 1977; Sachs and Hield, 1978). The experience of some electric utility companies suggests that bark painting is the most economical of the three alternatives to spraying. Pacific Gas & Electric Co. estimates $1.50/tree for bark painting compared to $9.00/tree for trunk injection and greater than $20.00/tree for pruning, with no data for root-zone applications. Economic advantage, simplicity compared to trunk injection, and the still unresolved environmental problems connected with root-zone application, were the reasons for emphasizing bark painting in this presentation and also in research programs sponsored primarily by utility companies. However, a February 1986 meeting of utility arborists in San Francisco (hosted by Chevron Chem. Co.) revealed considerable success in some areas with trunk injection procedures. For this reason some attention will be given to work accomplished with injection of growth regulators.

The growth regulators used by utility arborists fall roughly into two categories, terminal bud inhibitors and subapical meristematic inhibitors (also called "growth retardants"; Sachs and Hackett, 1972; Domir, 1978). The terminal bud inhibitors, such as maleic hydrazide (Slo-Gro from Uniroyal), chlorfluorenol esters (also called "morphactins" and sold as Maintain by Uniroyal, manufactured by Celamerck, and dikegulac (Atrinal from Hofman La Roche), have been used by arborists in foliar spray, bark banding, and trunk-injection formulations (for review of trunk injection work see Domir and Roberts, 1983). Owing primarily to their inherently greater biological activity, the morphactins are the best of this group for bark painting (Backhaus et al., 1976; Sachs and Hield, 1978); several of this class of compounds have been used more or less successfully for trunk injection but foliar damage is usually observed and regrowth is variable (Arron, 1985).

The subapical meristematic (gibberellin biosynthesis) inhibitors have been used commercially by pot plant growers and some deciduous fruit tree growers since the early 1960s. These compounds did not have sufficient biological activity or were too costly to be of value to arborists (see Sachs et al., 1977, for growth regulation following injection of daminozide; Sachs and Hield, 1978). However, new representatives of this class of regulator have been introduced by Elanco (Cutless), ICI (Clipper), Sumitomo/Ortho (Prunit), and BASF (tetracyclasis) all of which possess sufficiently high biological activity to make them candidates for use in utility line maintenance pro-

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grams. Results from small tests with bark painting of two of these compounds, applying *0.125 to 5 g active ingredient* per orchard-sized tree, indicate acceptable growth control for long periods. Arron (1985) and others at the Chevron symposium reported excellent growth control with no phytotoxicity following injection of Cutless and Clipper.

The subapical inhibitors have certain advantages for general horticultural use. Since they block some step in gibberellin biosynthesis, there is an antidote (an expensive one!) for overdosage. In addition, since they do not kill the terminal bud, near normal leaf and flower initiation continues when dosages that inhibit stem elongation are applied. Hence, most current research is with the subapical inhibitors. This paper, however, emphasizes work accomplished with the morphactins since studies with this compound are more complete and serve as a model for research on all bark-applied growth regulators.

Application Methodology and Problems

Bark painting. Trunk-injected chemicals, since they are forced directly into the xylem, avoid some of the problems initially facing bark-applied compounds. The latter face a barrier not unlike that found on the surface of leaves, namely, a waxy, non-wetting layer of suberin (cutin, on the leaves), external to the cortical and active phloem tissues (Backhaus et al., 1980; see Fig. 1 for detailed view of trunk cross section). Some kind of solvent system or mechanical disruption of the suberin, greatly assists passage of a growth regulator cross this layer (Table 1). Comparisons for pine, a species relatively sensitive to regulation by bark-applied morphactins, and walnut, a species relatively resistant to such treatment (but sensitive to foliar applications) reveal a perhaps two to three fold thicker suberin layer in walnut than in pine. Discontinuities are not apparent in the suberin layers of walnut, whereas in pine these layers are more loosely packed with many cracks. It is not surprising, then, that movement of chlorfluorenol esters across bark strips of walnut is about 1/4 that across pine bark strips (Fig. 2). Also, in both pine and walnut a large portion of the unaltered chlorfluorenol esters, up to 90%, may remain in or on the surface of the bark at the site of application (Backhaus et al., 1980). Hence, the thickness and integrity of the suberized layer, and perhaps the retention of chemical in the spongy, fibrous exterior bark, determine the effective

Table 1. The effect of suberin removal on morphactin hydrolysis and transport across bark disks of pine and walnut.

Sample	Total ^{14}C recovered in receiver cell dpm/day*	^{14}C hydrolyzed to morphactin acid %
Pine, suberin removed	31,362 ± 4,015	92.0 ± 1.0
Pine, suberin intact	896 ± 122	92.6 ± 2.6
Walnut, suberin removed	9,687 ± 372	83.3 ± 2.7
Walnut, suberin intact	34 ± 9	88.7 ± 2.2

*Values denote ^{14}C-radioactivity collected from the receiver cell of the diffusion chamber after a 24-h period (dpm/day). Rates shown are the highest rates observed for each species at 28°C and are the average of three determinations ± SEM.

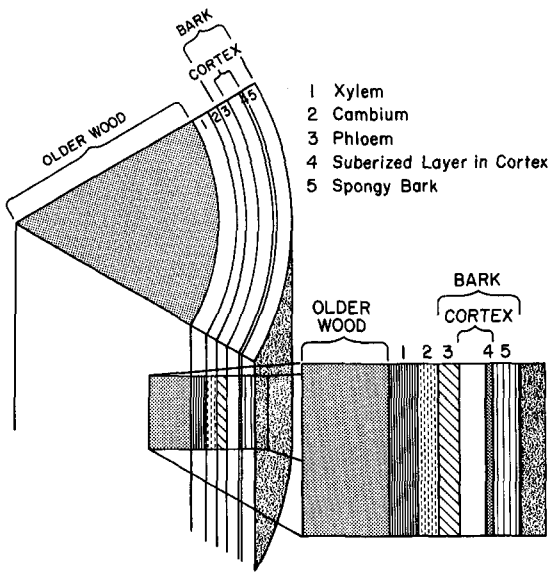

Figure 1. Diagrammatic representation of cross section of a tree trunk showing important structural features that limit movement of chemicals across the bark and into the xylem. The most important barrier is the suberized tissue (4) immediately below the spongy, fibrous bark (5) which absorbs much of the applied solution. Injury to the cambium (2) and perhaps the phloem (3) is a particularly important consideration in bark painting applications. Injectors must be placed through the cambial layer into the "new" wood region of the xylem (1).

dosage of a chemical for a species as much as the intrinsic activity of the chemical applied.

Movement upwards. Since phloem transport in the lower trunk is downward toward the root system, the xylem tissue is the only route available for chemicals to move from trunk or root zone applications to the tops of trees (Chaney, 1986). Once having crossed the suberized layer, a compound must be *pulled* into the xylem (which is under reduced pressure relative to other tissues). Trunk-injected materials are pushed into xylem vessels or remain in the injection cavity and are then pulled into the undamaged, functioning cells surrounding the wound. The xylem empties chemicals into the leaves and other tissues where water is transpired. The chemicals must then diffuse from the ends of xylem elements and further movement is from cell-to-cell. What is more likely in the case of compounds "dumped" into mature leaves, is that these compounds enter the phloem system for further transport along with photosynthetic assimilates to meristematic tissues.

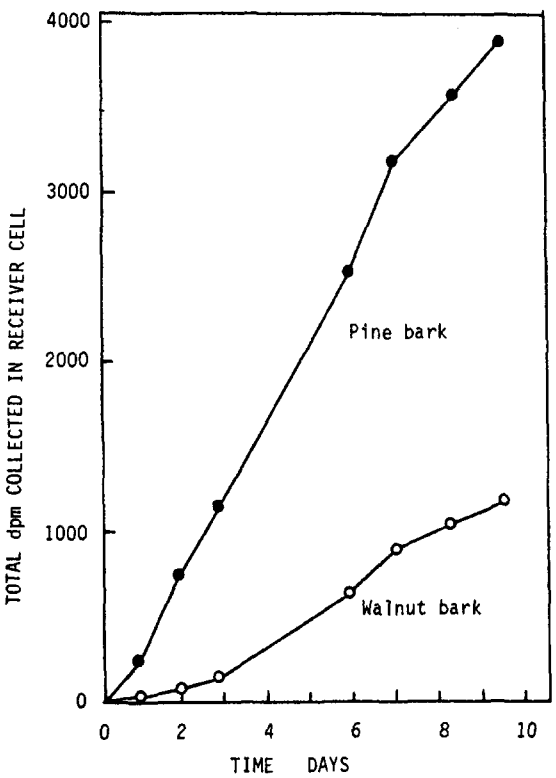

Figure 2. Diffusion of ^{14}C-labeled chlorfluorenol across excised pine and walnut bark. A diffusion chamber, as described in the text, was used. The inner part of the diffusion chamber was assayed periodically for radioactivity moving across the bark. The radiolabeled chlorfluorenol was applied in a solution containing a total of 1% chlorfluorenol esters in a mixture similar to that found in Maintain. Temperature was held at 23°C. From: Backhaus et al. (1980).

To move in the xylem, chemicals must be water soluble, or be attached to compounds that confer water solubility. Compounds with limited water solubility will precipitate in the xylem. If the tissues are not so badly damaged at the time of entry that wound reactions and compartmentalization occur (Campana, 1977; Chaney, 1986), the precipitate will slowly dissolve into the transpiration stream. In the case of the chlorfluorenol esters (morphactins), de-esterification occurred in the cambium or the xylem prior to movement upward in the xylem (Neumann et al., 1977).

Some naturally occurring growth regulators, such as cytokinins, auxins, and gibberellins, are often derivatized, as they are absorbed and stored by plant tissues. There is little research published on this important aspect of tree growth regulator modification. For this reason our program has as one of its tasks the study of the metabolism of the newer compounds in plant tissues.

Timing and frequency of application. There is some controversy concerning whether growth regulator applications should be made immediately at the time of pruning or shortly thereafter when a few leaves have appeared. This is a critical consideration with apical meristem inhibitors such as the morphactins, but not nearly as important with the subapical inhibitors because of their much less drastic action on leaf initiation.

The timing of application, with regard to season or short-term climatic conditions, may be extremely important owing to changes in penetration of the compound across the bark and upward movement in the xylem. Studies with morphactin reveal that penetration is strongly temperature dependent, with nearly 15-fold greater penetration at 90°F than at 55°F (Backhaus et al., 1980) owing to greater co-solvent action at the suberin layer or much higher de-esterification of the chlorfluorenol ester. The suberin-related response to temperature is avoided by trunk injection procedures. However, bark painting even at low

temperatures may be aided by the proper carriers and bark scoring.

Since xylem transport of growth regulators to leaves and meristematic regions is the rule, whether following injection or bark painting, most transport of the active ingredients is expected when evapotranspirational demands of the trees are highest. This demand occurs generally when temperatures and wind velocity are elevated. Water conduction occurs primarily through the early-wood xylem cells formed during the current year, since older xylem cells are largely gas-filled (Vite and Rudinsky, 1959).

It is likely that some trees or scaffold branches will be treated more than once annually to examine the possibility of cumulative growth control without the problem of overdosing. Field experience with foliar sprays and general observations by many investigators confirm the idea that multiple applications of low dosages is usually a better, although more costly, method of controlling growth than a single large dose. Should a simple technique for chemical analysis of growth regulators be developed, we will be able to examine accumulation of the compound as a function of many treatment parameters, including frequency of application.

Wood characteristics. Although pressurized injection of chemicals into the xylem seems the most positive method for targeting chemicals, there are difficulties in injecting individual trees, species, and, indeed, entire families (Sachs et al., 1977; Campana, 1977). Wood structure largely determines the relative ease of injection (Zimmerman and Brown, 1971; Chaney, 1986). Equipment advances have been rapid so that the technology of injecting relatively large volumes of aqueous or alcoholic solutions is "off-the-shelf" and readily mastered (see Sachs et al., 1977, and Brown, 1978, for specifications on early models; improved commercial equipment is now available from three companies), but in any trunk injection program the problem trees still must be identified.

For readily injected species, such as some elm, cottonwood, sycamore (Brown, 1978), apple, pear (Sachs et al., 1977), and eucalyptus, hybrid poplar (Table 2; Fig. 3) injection rates of aqueous solutions of over 100 ml/min have been achieved through 0.25 inch ports at 50-100 psi. Slow-growing specimens of these species, with much smaller diameter xylem vessels do not accept solutions as rapidly, the injection rate decreasing by 90%. In our experience pressurized injection cannot be used with coniferous species, nor with a latex-forming fig (*Ficus nitida*; Fig. 3). The injection resistance in conifers is expected on the basis of their wood structure, namely the absence of open-ended vessels typical of angiosperm wood. In angiosperm trees, there are large differences in the diameter of vessels among species, and among trees of the same species, grown under different irrigation (drought) regimes, and, hence, the relative resistance to injected fluids (Sachs et al., 1977; Chaney, 1986). The inability to inject liquids into *Ficus nitida* is not explained as yet, but latex released by drilling the injection port may plug the xylem vessels quite

Table 2. Injection rates of aqueous solutions into street and fruit trees. Pressure at 50-100 psi; single 0.25 inch injection port.

Species	Diam. (dbh, in)	Inject. rt. ml/min Water Avg	Water SD*	Isoprop Avg	Isoprop SD*
Celtis occidentalis	15.2	555	442	341	107
Eucalyptus camaldulensis	5.2	377	175	254	93
Eucalyptus globulus	5.0	97	120		
Ficus microcarpa	4.7	0		0	
Fraxinus uhdei	11.3	35	15		
Fraxinus velutina	4.5	64	35		
Ginkgo biloba	4.7	8	5	11	10
Juglans nigra	5.8	26	12		
Pinus canariensis	36.2	0		0	
Populus euramericana	6.8	252	130	284	138
Ulmus parvifolia	4.5	74	48		
Ulmus pumila	4.7	153	167		
Malus sylvestris apple	6.2	133			
Prunus armenaica "Royal Apricot"	10.0	40			
Prunus avium "Bing Cherry"	15.0				
Concave side, slow growth		13			
Convex side, fast growth		31			
Prunus domestica "Shiro Plum"	12.0	38			
Pyrus communis "Bartlett Pear"	12.0	102			
Prunus amygdalus "Nonpareil almond"	12.0	20			

*SD = standard deviation.

rapidly.

Injection formulations for Clipper and Prunit will contain high concentrations of methanol or some similar solvent for the active ingredients. Comparisons of injection rates for aqueous and alcoholic solutions revealed no statistically significant differences in the three species tested.

Distribution of growth regulators. Distribution of compounds differs following bark-banding or injection. Injected materials are more localized or do not move to the tissues desired (Campana, 1977; Chaney, 1986; Sachs et al., 1975, 1977).

Sectorial ascents of injected dyes, first reported by Vite (1959) and Vite and Rudinsky (1959; Fig. 4) for coniferous species has been verified in other species as well (Sachs et al., 1977; see also Chaney, 1986). Earlier studies on trunk-injected dyes, tetracycline and daminozide (Alar, from Uniroyal) in several deciduous fruit tree species (Sachs et al., 1974; Sachs et al., 1977) revealed that upward movement was primarily sectorial with a 40 to 60° arc spread about 1 to 2 m above the injection site (Sachs et al., 1977; Fig. 4). Distribution of compounds to scaffold branches depended upon the site of injection in relation to the intended branch. All injected compounds moved more rapidly into secondary and tertiary branches that were aligned in the orthostichy above the point of the chemical's original entry into the scaffold. The pattern of distribution will depend strongly on the degree of interlocking of xylem vessels and the grain of the wood (Chaney, 1986; Fig. 3).

Compounds that are bark applied move into the xylem across a broad band and have a better chance of distribution to all primary, secondary, and tertiary branches.

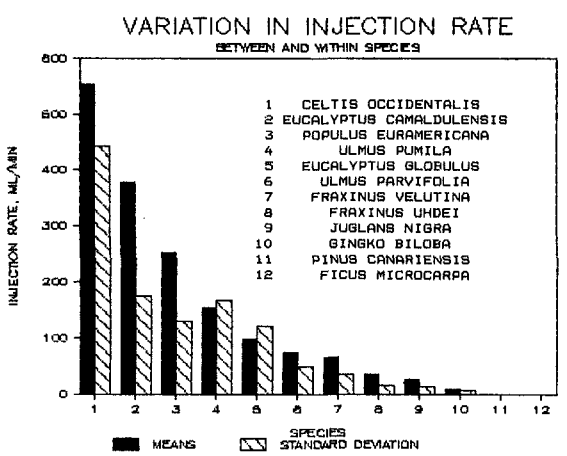

Figure 3. Variation in injection rate of aqueous solutions within and among species. Injection pressure 50-100 psi; single 0.25 inch port; tapered friction fit injector. Additional data in Table 2.

Expected Advances

Dosages recommended. Use of labeled growth regulators is valuable for studies with isolated bark slices. Bark penetration and metabolism of the compounds can be followed as a function of formulation and bark type, in much the same manner that has been done with the morphactins (Neumann et al., 1977; Backhaus et al., 1980) and daminozide (Sachs and Mock, 1975). Using a technique developed by Backhaus et al. (1980), bark pieces are lifted from the candidate tree species, placed between gasketed water tight chambers, and the inner chamber analyzed for movement of the label across the bark. The inner chamber is sampled periodically for radioactivity, thereby permitting calculation of a diffusion rate for a growth regulator as a function of bark type and/or formulation. This device proved very effective for testing penetration of chlorfluorenol across walnut and pine bark (Table 1).

Investigations of this kind can be pursued in large trees as well if simple chemical techniques adapted to high performance liquid chromatographic separation and detection methods for the candidate growth regulators are developed for a variety of tree species (see Sachs et al., 1974; Sachs et al., 1977, for studies with daminozide). In this way the distribution of the chemical within the tree itself can be determined.

Special reference to bark painting. Development of solvent/carrier systems that promote transport of compounds across the bark to the xylem without damaging the bark (cambial layer in particular) is of primary concern to bark painting technology. Since a number of bark-treated trees have suffered considerable damage (up to death of the tree) from some formulations designed for morphactins, one goal of current research is to exclude what are judged to be the most toxic ad-

ditives, diesel oil and toluene, and yet promote movement of the compounds across the bark. Recent studies suggest that high concentrations of the chlorfluorenols may in themselves be toxic to the cambium; hence, concentration of the active ingredient may be varied.

All formulations, to be effective, must contain some suberin cosolvent. Formulations (such as polyethylene glycol, crop oils and a wide range of surfactants/wetting agents) that were judged initially to be less effective or more costly in our initial studies will be reexamined.

In view of the significance of formulation technology to the success of a bark banding program, a rapid technique for evaluating toxic effects to tissues following bark applications is a necessary aid. Triphenyl tetrazolium chloride (TTC) is used widely to detect dehydrogenase activity of plant tissues; the colorless TTC is reduced to a bright red insoluble pigment (formazan) that is readily detected by microscopic examination of tissues and can be measured quantitatively after extraction in acetone (Norton, 1985). The cambial layer of bark is the main, and perhaps

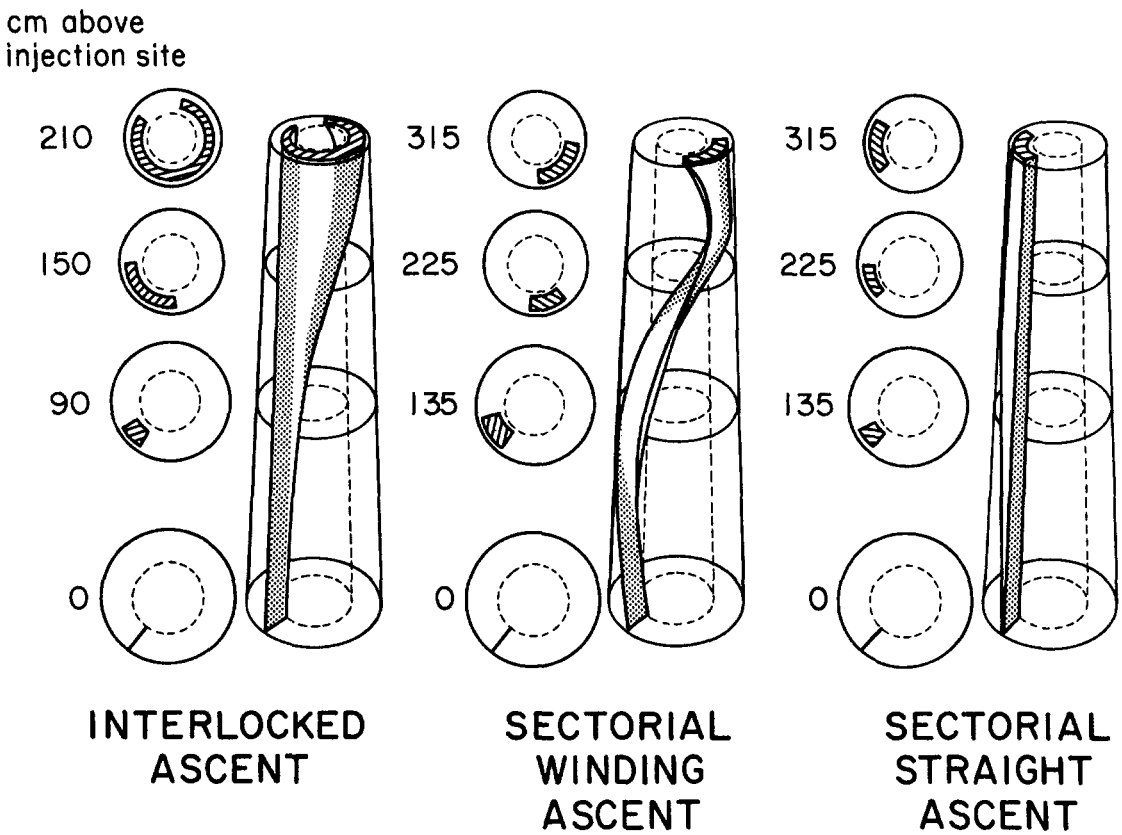

Figure 4. Diagrammatic representation of dye movement upwards from site of trunk injection (low pressure, less than 4 psi) showing 3 different patterns of xylem transport and dye dispersion (adapted from Vite, 1959). With high pressure injection movement is down and up; see Sachs et al. (1977). Interlocked ascent is the pattern desired for the most favorable distribution of injected chemicals in the upper canopy of trees, but the most commonly observed pattern by Sachs et al. (1977) following high pressure injection was "sectorial straight." Since entry is from the entire tree circumference, sectorial patterns are not important considerations for explaining distribution of chemicals entering the xylem following bark painting.

sole, tissue responding rapidly to the TTC test. Bark tissue, including the cambial layer, treated with a toxic substance, such as some of the chlorfluorenol formulations in use, produce formazan in greater amounts than untreated bark. The data in Fig. 5 show the amounts of formazan formed in the bark of *Eucalyptus gunnii* as a function of treatment with solutions known to inhibit certain respiratory activity (cyanide and azide) as well as a chlorfluorenol formulation (Maintain), and the diesel oil-toluene carrier system. Some new formulations, containing a crop oil, isopropyl alcohol, and a surfactant, cause much less dye reduction in bark tissues, suggesting that they are less phytotoxic. Since these formulations when mixed with 0.5 to 1.0% active growth regulator inhibit growth of treated trees, we appear to be close to resolving one of the problems encountered with bark painting. Determining the optimum formulation for each growth regulator and type of bark treated is a much more difficult problem.

Longitudinal knife scores should do a minimum of permanent damage to the bark and yet greatly increase movement of the compound across the bark; development of a rapid method of scoring the bark just before, or at the same time as chemical application should be included in any bark-banding program.

In earlier studies with bark-applied morphactins, extensions to backpack spray nozzles, with two nozzles per application wand, permitted more rapid treatment of scaffold branches and improved growth control of the entire tree probably as a result of better distribution of the morphactin to tertiary branches.

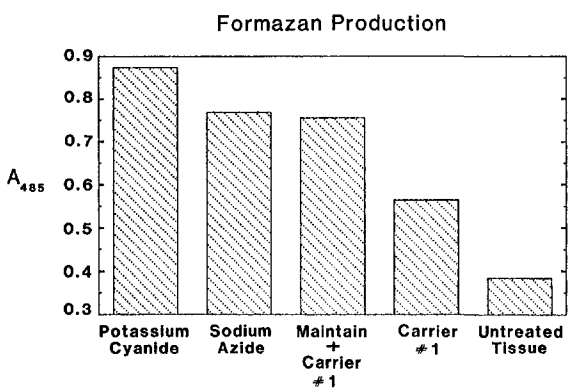

Figure 5. Formazan formulation in bark tissues of Eucalyptus gunnii as a function of treatment with 2.5% Maintain and carrier systems for Maintain; 0.5% potassium cyanide and 0.5% sodium azide treatments are included to show near maximum promotion of dye formation induced by known metabolic toxins. Note that Maintain increases dye formation over that due to the carrier system alone, suggesting that the chlorfluorenol esters or the solvent system in Maintain is somewhat toxic to bark tissues at the 2.5% dilution applied.

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USE OF TREE GROWTH REGULATORS AT SOUTHERN CALIFORNIA EDISON[1]

by C. J. Pilkerton

To create a mental image of the unique line clearing aspects of Southern California Edison, visualize the following: (1) A service territory of 50,000 square miles, topography ranging from the Pacific Ocean to the alpine mountain ranges of the High Sierras, low desert regions of Palm Springs to inland agricultural valleys of the San Joaquin. Climatic zones of frost-free subtropical areas with year-around growing conditions to severe low temperature areas with a growing period of two to three months. (2) Our trimming cycle is 12-18 months, with some of our fast growing tropical species being trimmed every six months. With these line clearing problems, you can appreciate that Southern California Edison is enthusiastic about the potential help that the growth regulators might offer.

Our company started a tree growth retardant program in February, 1977; at which time 2500 Athel trees were foliar sprayed by Arbor Tree Company in the Palm Springs District with Maintain CF125. The project was a success as

1. Presented at the annual conference of the International Society of Arboriculture in San Antonio in August 1986.