gation of bulblets from scales, these plants could be rapidly multiplied and maintained pathogen-free.

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MODERATOR KESTER: Our next speaker is Dr. Hudson Hartmann of the University of California at Davis and Editor of the Western Region of the IPPS. He will discuss some of the factors involved in rooting hardwood cuttings. Hudson:

## SOME PHYSIOLOGICAL FACTORS INVOLVED IN PROPAGATION BY HARDWOOD CUTTINGS

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Some of our most ancient cultivated plants, as the fig, olive and grape, are ones that are readily propagated by hardwood cuttings. With these plants early man was able, when he turned to agricultural pursuits, to easily establish clones of superior types merely by inserting into the ground sticks broken from desirable seedlings, thereby producing great numbers of equally desirable plants.

Propagation by hardwood cuttings is, no doubt, the simplest and least expensive method of vegetative propagation. It would be most desirable to be able to extend this type of propagation to a much greater range of plants. It would be particularly desirable to be able to utilize hardwood cuttings in place of the more laborious layering methods now widely used in propagating clonal fruit tree rootstocks and other difficult to propagate plants. Furthermore, hardwood cutting propagation procedures lend themselves readily to mechanization practices which are more and more being utilized by the nursery industry. However, as is well known, striking differences are encountered among the various species and clones in adventitious root initiation. Some plants, as the willow, poplar and citron, have preformed root initials in the shoots of the intact plants. Cuttings made from such material quickly develop roots when placed under the proper environment. Hardwood cuttings of many other plants too, as the grape, rose or privet, will rapidly form adventitious root initials after the cuttings are prepared, with new roots forming soon after planting so that the developing buds and subsequent leaves are supplied with water to replace the water loss resulting from leaf transpiration.

Hardwood cuttings of more difficult-to-root plants may form adventitious roots after the cuttings are made and planted in the nursery row in the spring but so slowly that the opening buds and developing leaves dessicate the cuttings, causing them to die before roots can appear and begin water absorption.

Cuttings of many other kinds of plants have failed to produce adventitious roots under any circumstances and their propagation by this method has not yet been accomplished. The stem tissues of such plants may contain a high level of one or more rooting inhibitors, or they may lack a biochemical component essential to reactions which lead to critical changes in certain groups of cells that are the starting point of adventitious root initials. It is likely that the explanations for the differences in root initiation between difficult and easily-rooted plants lie in biochemical factors rather than in anatomical relationships.

There are many naturally-occurring plant regulators, as the auxins, cytokinins, gibberellins, inhibitors, vitamins and undoubtedly others. It was postulated by Skoog (30) 25 years ago from research using tissue culture techniques that cell differention and organ formation is most likely based on certain combinations and balances among these naturally—occurring growth substances. Galston and Davies (12) state that these hormonal materials are probably producing their effects by controlling the synthesis of particular enzymes, through some yet unknown mechanism concerned with nucleic acid metabolism.

Successful rooting of cuttings of some plants may not be accomplished until further basic information is developed concerning the biochemical reactions and components essential for root formation.

The most fruitful area at present for extending the practical use of hardwood cutting propagation would seem to be with those plants which will form adventitious roots but slowly and sparsely.

It is now well accepted that auxins, such as indoleacetic acid, are a required component of, perhaps, a complex of substances in the plant necessary for root initiation. Many plants have ample amounts of auxin in their tissues and do not respond to added synthetic auxin by increased root initiation. Many other plants, however, may have native auxins in such slight amounts that they will show a definite response to added auxin by increased numbers of roots forming, or by a reduced time of root development or both. In rooting hardwood cuttings of all but the easiest-to-root plants, treatment with a synthetic auxin — as indolebutyric acid — is likely to be of considerable benefit.

In attempting to root hardwood cuttings of "difficult" plants, temperature control during the root initiation period can be most useful for those kinds which will produce adventitious roots — but slowly; some method of inducing root initiation well in advance of the time of bud break and leaf development in the spring is essential. For plants which have a definite bud dormancy ("rest") condition, this characteristic can be used to good advantage. Buds of deciduous woody plants, in the fall before exposure to winter-chilling, are usually in a pronounced physiological "rest" or dormant condition. Hardwood cuttings made during the autumn, with buds in the "rest", can be treated with auxin, then held at warm (70° to 75° F.) temperatures, packed in a moist, well-aerated, relatively sterile medium — such as peat moss. They will then often develop adventitious roots quite profusely at the base of the cuttings in 2 or 3 weeks. Such treatments were shown by Chadwick (6) almost 40 years ago to be beneficial in rooting hardwood cuttings of several deciduous ornamental shrubs. Since the buds on cuttings taken in the fall are blocked from developing, probably by an unfavorable inhibitor-promoter complex, unwanted leaf production at this stage does not occur. Once there is evidence of root emergence after the auxin-warm temperature treatment, however, the cuttings must be promptly planted, if outside nursery conditions permit, or moved to cold storage (35° to 40°F.) to prevent further development of the roots, while awaiting suitable nursery conditions for planting (14). In either case, the chilling given the cuttings will lead to physiological changes in the buds, changing the inhibitor-promoter complex in favor of promoters so that the buds will start growth upon the advent of warm weather in the spring. But at that time, with cuttings handled as described, roots will have been initiated and will quickly resume growth, along with the shoots. Hardwood cuttings of some plants, however — as the peach (15) and walnut (27) — do not seem to tolerate any disturbance of even quite incipient roots. Fall-planting directly in place in the soil where they are to grow, once they have been made and treated with auxin, seems to be the most successful procedure, utilizing the warmth of the soil in the autumn to obtain the necessary temperature levels to stimulate rooting.

Warm storage plus auxin treatment procedures, such as these, have been perfected by various researchers to successfully root hardwood cuttings of the pear (2, 16, 17, 18, 35), plum (14, 16, 21), peach (15, 29) and apple (21).

Warm temperature treatments following auxin application, as described above, when given the entire cuttings, resulted in good root initiation with some plants, such as 'Old Home' pear, but have given poor results, in some instances, when used with other clones, for example the 'Bartlett' pear (18). To root 'Bartlett' pear it was found necessary to increase the temperature at the base of the cutting to stimulate root activity while simultaneously chilling the buds on the upper portion of the cuttings. Subsequently, Fadl and Hartmann (11) determined that in the 'Bartlett' pear, rooting inhibitors produced in the buds depessed root initiation, but chilling the buds, or bud removal, reduced inhibitor production and increased rooting.

This practice of applying heat to the bases of hardwood cuttings, while the tops are maintained at a lower temperature, has also been used in the successful rooting of apples in England (24, 25) California (19) Italy (13) and apples and cherries in Michigan (5). Such procedures probably involve the same physiological principles used in the old practice of storing cuttings out-of-doors, buried in pits upside down vertically to warm the bases of the cuttings while keeping the buds cool.

The presence of rooting inhibitors was noted by Spiegel (31) in grape cuttings over 15 years ago. These inhibitors could be leached out with water, and when subsequently recovered, caused reduced rooting if applied to cuttings of easily-rooted grape clones. Buds seem to be a source of such rooting inhibitors, the production being related to bud activity. In hardwood cuttings of 'Old Home' pear (10), for example, the presence of buds promoted rooting when they were in a non-dormant stage, etiher in early fall or late winter. But if the buds were in a physiologically dormant condition in early winter, their presence on the cuttings inhibited rooting. Bud removal increased rooting. In Fadl's (9) studies with pears, such an effect of bud removal was related to the absence of the bud itself and not just to a possible wound stimulus arising from cutting out of the bud, as was noted by Howard (26) in rooting plum and apple hardwood cuttings.

Apparently, too, certain root-promoting factors — other than auxins — exist in hardwood cuttings — in greater amounts at some periods of the year than at others, and in greater quantities in some clones than in others (1, 7, 11, 36). There is evidence that these factors are phenolic compounds, which probably interact enzymatically with applied or native auxins to form substances responsible for triggering differentiation of groups of cells, leading to adventitious root formation (4, 1, 22, 23). An increase in the activity of such native rooting factors was noted by Challenger, *et al.* (7) when temperatures were elevated at the base of 'E.M. 26' apple cuttings during pre-planting warm storage periods, which may, in part, account for the beneficial rooting effects of such temperature control treatments.

Van der Lek pointed out (33) many years ago the influence of buds on the rooting of hardwood cuttings. As previously mentioned, this influence is likely due, at least in part, to the production of rooting promoters or inhibitors, or both, varying according to the activity of the buds at different times of the year. However, this effect of buds on rooting and possible explanations for such effects is complicated by the fact that active buds utilize stored foods for growth and are in competition with metabolic processes involved in root initiation (2). Warm storage periods, following auxin application, which have been shown to promote rooting, also increases the respiration rate of the cutting's tissues and, if prolonged, can deplete stored food reserves.

In considering the propagation of plants by hardwood cuttings, a clear distinction must be made between the internal mechanisms involved in root initiation and in the survival of the cuttings in the nursery. For example, profuse rooting can often be obtained in the laboratory with auxin-treated cuttings enclosed in plastic bags (28) or set in containers of a sterile medium under precisely controlled conditions of temperature and humidity. Similar cuttings set in the nursery where they may be obliged to contend with unfavorable weather conditions, fungal attacks, or less than ideal soil situations often succumb even though roots may have been initiated.

There seems to be rather convincing evidence from various studies (32, 34) that fungicide applications, particularly Captan, is of real benefit in protecting cuttings from fungus attack in the nursery, which apparently is its primary benefit, rather than a direct stimulus of root initiation (20). It is probable that more widespread use of such fungicidal treatments is justified and would be helpful, particularly in years of wet springs and in heavy soils.

Ciampi and Gellini (8) and Beakbane (3) have proposed, to account for the variability in rooting among clones, that the ability of stems to produce adventitious roots is related to the anatomical structure of the primary phloem. In supporting this theory it is pointed out that difficult-to-root cuttings, as those of 'Conference' and 'Bartlett' pears, have an almost contінous cylinder of mature, thick-walled fiber cells encircling the secondary phloem, whereas in easily-rooted cuttings, as 'E.M. V', E.M. XI' and 'E.M. XIII' apples, this sclerenchyma ring is not continuous, and would permit the emergence of roots formed inside the ring. However, while such anatomical relationships may influence root development, it is unlikely that they are primary factors in root initiation. 'Bartlett' pear cuttings, for example, even with an almost continuous schlerenchyma ring can be rooted in fairly high percentages with the proper procedures (18). Studies by Sachs, *et al.* (29) with olive, cherry and pear stem cuttings failed to show any clear relationship between continuity of a schlerenchyma ring and rooting ability.

There are, of course, many other factors which can influence the success attained in hardwood cutting propagation, such as the source and type of cutting material, the concentration of auxin used, weather, and soil conditions of the nursery site. It is certainly advisable for each propagator to do some experimenting with the variable factors at his disposal under the fixed conditions with which he must work and with the particular clones he is attempting to propagate.

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MODERATOR KESTER: Thank you, Hudson. I will now present some results we have obtained in rooting hardwood cuttings of peach/almond hybrid clones.

## ROOT INITIATION IN HARDWOOD CUTTINGS OF PEACH-ALMOND HYBRID CLONES

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This report summarizes results of experiments carried out during the fall and winter, 1968-69, as part of a program to select clonal rootstocks for stone fruits (*Prunus*), with emphasis on peach x almond, $F_1$ hybrids. Earlier, we found that cuttings of almond clones were impossible to root; peach was relatively easy-to-root and hybrids of peach and almond (P-A) were intermediate, with a range among clones from easy to difficult (3, 4). Hansen (1) has selected P-A clones that are nematode resistant and Hansen and Hartmann (2) reported good survival of hardwood cuttings of P-A clones if taken in the fall or early winter, treated with IBA and Captan, then planted directly into the nursery.

The purpose of the experiments reported here was to evaluate rooting of different *Prunus* clones. To do this we wanted to develop a screening procedure whereby we could accurately and easily evaluate the genetic ability of individual