order to prevent shifting of the work floor. However, sand size must be sufficiently uniform to allow water to circulate at a reasonable rate. Precise specifications are not currently available.

Temperature of the growing medium in containers sitting on the floor remained the same as floor temperature. The heat is transferred from the floor to the containers (Figure 3). This provides an ideal bottom heat system which has been shown effective in propagating many cuttings. In addition, the lower air temperatures experienced in this greenhouse assist in keeping the cuttings dormant throughout the rooting period. However, a good ventilation system must be provided to prevent excessive heat in late winter and early spring. Because this greenhouse is quite efficient in retaining heat during winter it also accumulates heat readily in the early spring which may stimulate unwanted soft succulent growth. Our experience to date has shown that we can maintain a low air temperature in early spring by simply drawing in cool outside air with thermostatically controlled fans.

This greenhouse is very economical to construct (materials are about $2.00/sq ft) and provides bottom heat and temperature controls more suitable for propagation than other greenhouses. Even in more northern areas, only a small amount of supplemental heat should be needed on very cold nights, reducing or eliminating the expensive fuel bills encountered in recent years.

FACTORS CONTROLLING REGENERATION FROM ROOT CUTTINGS

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Root cuttings as a method of reproducing plants are little used in today's modern nursery and probably will be used even less in the future. Modern methods, such as tissue culture appear to represent the future trend. Root cuttings, however, are applicable to a wider number of woody plants than is realized. The ability of root cuttings of many plant species to regenerate whole plants has been recognized and described in the horticultural literature over a long period of time and extensive lists of species have been compiled (7,18). Propagation through root cuttings assumed a more important role before the introduction of propagation aids such as, auxins and mist. Flemer (7) cites two principal reasons for the rarity of this method. 1. Many plants for which it is the best technique are infrequently grown

in the average nursery. 2. The inconvenience of securing root cuttings is a strong deterrent. Either the whole plant must be dug to secure appropriate root pieces or else the soil must be excavated around the plants to expose the roots. Either method is tedious, labor intensive and usually must be carried out during the fall and winter months.

Despite the difficulties involved propagation by root cuttings may be the best procedure to increase selected plants that are difficult to root or do not come true from seed. Flemer (7) has summarized the more important woody plants which can be propagated by root cuttings. The subject of propagation by root cuttings has received attention in both the *I.P.P.S Proceedings* and *The Plant Propagator*. Both publications contain information on root cutting propagation methods but research results on the factors involved in the control of adventitious root and bud formation are lacking. The position regarding the physiology of regeneration forms the basis of this presentation.

SEASONAL VARIATION OF REGENERATION

It has been documented for a number of woody plant species that regeneration from root cuttings varies strikingly with the season of the year (9,13). Seasonal differences in apple and raspberry root cuttings, for example, have demonstrated distinct "on" and "off" periods, autumn-winter and spring-summer respectively. The seasonal differences in survival of apple root cuttings resembles seasonal responses demonstrated with raspberry by Hudson (8) who correlated winter survival with starch accumulation. Robinson and Schwabe (15,16) also showed with apple that maximum accumulation of storage polysaccharides occured in autumn (November) coinciding with the highest regeneration potential and survival rate of cuttings. Cuttings of many herbaceous perennials, in contrast, regenerate readily at any time of the year.

Alteration of the seasonal variation may be possible. Marston and Village (11) demonstrated that regeneration of red raspberry from root cuttings could be achieved with plants growing in summer conditions which normally lead to poor regeneration by applying certain treatments to the shoots, 3 to 5 weeks before taking root cuttings. The best regeneration occurred from plants that had the tip half of the shoot and all axillary buds removed. Experimental results with *Populus* (5,6) indicate that polarity of auxin might account for the seasonal variation in shoot formation from roots in these plants. The results with red raspberry and *Populus* species suggests the possibility that changes in auxin levels as affected by the stage of shoot development may interact with carbohydrates and account for the seasonal variation in regeneration potential. Since

both auxin and polysaccharides exert demonstrable influences on root regeneration a suitable balance between each is probably required before the optimum potential for regeneration can be achieved.

AUXINS

The presence of auxin has been demonstrated conclusively in roots. Auxin is also transported within roots from root base to root apex, that is, in an acropetal direction and the transport is polarized. A strong polarity of bud and root initiation occurs with more shoots formed towards the basal end, i.e. nearest the crown, and more roots formed towards the apical end of the root segment (1, 2,10,14,19). The polar transport of auxin within root pieces may, therefore, be an important mechanism controlling the distribution of adventitious roots and buds (5,6,16).

In general exogenous applications of auxins suppress bud development and stimulate root initiation on root cuttings, further supporting the important role of auxin in root regeneration (1,2,4,10,19).

CYTOKININS

Cytokinin treatments increase bud numbers, increase the bud producing region and counteract auxin inhibition (2,3,12). Exogenous cytokinin applications also inhibit root formation when applied to the distal end. The kinin induced buds in many instances exhibit a different developmental origin. Often the cytokinin stimulates callus formation on the proximal end of the root cutting with resulting development of shoot primordia in the callus (2,12,19).

In conclusion, the diverging behavior of the ends of root cuttings with regard to organ production has been interpreted as the result of different hormonal regimes at organ forming sites in the root segment. Exogenously applied auxin and cytokinin can profoundly influence the regeneration of root cuttings. Auxins in general stimulate roots and inhibit bud initiation (16) while cytokinins stimulate bud and inhibit root formation. Both groups of hormonal substances need further critical study on woody plants in order to explore their possible use in commercial propagation through root cuttings.

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CHARLIE PARKERSON: You mentioned increasing bud production on root pieces by treatment with cytokinin, are these segments predisposed to bud formation?

CHARLIE HEUSER: No, in those cases a callus is first formed and the bud arises from the callus. In root segments where cytokinins are not needed for bud development, the buds often arise from the pericycle or other tissue, so the origin of the buds is quite different.

JOHN WILDE: In the 1930's and 1940's, while working at Cornell University we did a survey of over 200 species concerning propagation by root cuttings. One of the things that we observed was there there was no development of adventitious buds unless true secondary wood existed in the segments — the buds always develop from the secondary tissue. Another interesting observation was that if hypocotyledonous buds were present on seedlings grown from these species the plant could almost always be propagated by either underground stems (stolons) or root segments.

Most of the legumes can be grown from root cuttings and the easiest way for the small nurseryman to do this is to grow them *in situ* by driving a sharp shovel into the ground in concentric circles around the plant. By this method you can produce 5-6 liners of legumes such as *Gymnocladus* and *Gleditsia*.

CHARLIE HEUSER: You are right, a great many plants can be produced by root cuttings and the article by Stoutemeyer contains a considerable list of these.

PROPAGATION OF WOODY PLANTS BY ROOT CUTTINGS

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Asides from growing by seed, the next oldest method of propagation of woody plants is by root cuttings or root sprouts. Early settlers of America brought woody plants from Europe by this method and used this method of transporting them as they moved westward in settlement of their new homelands.

Very little can be found in the literature on plant propagation concerning the use of root cuttings for woody plants. L.H. Bailey in *The Nursery Manual*, published in 1920, devotes three paragraphs to the subject. His primary discussion is of the bramble fruits, horseradish and certain tropical foliage plants. He states, with no elaboration, that fruit trees may be grown from root cuttings. Bailey also states that true root cuttings possess no buds whatsoever. This would seem subject to question. (Possibly I should have entitled this presentation "root sprouts" rather than "root cuttings".)

James S. Wells in his *Plant Propagation Practices*, published in 1957, devotes two paragraphs to root cuttings. He outlines briefly a method of making root cuttings, but does not state what materials may be grown by this method.

Today, aside from the growers of herbaceous perennial plants, very few growers extensively use the root cutting