PHYSIOLOGY OF ROOTING

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The development of roots on cuttings is a growth process. Growth is the result of the many processes occurring within the plant which are directly and indirectly affected by factors within and outside the plant. Theoretically, it should be possible to develop new roots on any part of the the plant — on stems, leaves, roots and even on flower parts and fruits; however that level of success has not been reached on a practical basis. The plant propagator is interested in the development of roots on stem cuttings and of new shoots and roots on leaf and root cuttings.

Successful root formation on stem cuttings depends upon:

1. cells capable of dividing and differentiating root initials,
2. favorable internal factors
3. favorable environmental conditions.

First, there must be cells capable of dividing and differentiating into root initials. It is quite possible that all cells of the plant, which contain a nucleus and cytoplasm, contain the necessary information needed to develop into a shoot, a root, or even an entire plant. There are three major areas of cell division in the plant: the stem tip, the root tip, and the cambium. These areas, called meristems, are undergoing cell division much of the time the plant is actively growing. In addition, all organs and tissues of the plant contain cells called parenchyma. A parenchymatous cell is only partially differentiated or specialized. They have thin cell walls, a relatively large nucleus in proportion to the size of the cell and lack the large central vacuole. Further, under proper conditions, parenchymatous cells may revert to meristematic cells, that is, cells capable of dividing. It is this widespread distribution of parenchymatous cells which enables the plant propagator to root successfully the cuttings of a wide range of species. In stem cuttings roots arise internally from parenchymatous cells near the vascular tissue.

Wound healing, graft and bud union and the initiation of shoots and roots results, at least in part, from division of these cells. Excised parts of roots and stems have been grown *in vitro* for many years. It is relatively easy to stimulate roots on these masses of callus tissue, but it is much more difficult to obtain new shoots. Bourgin and Nitsch (1) have obtained entire plants from anther cells of the stamen of tobacco. Because of the difficulty of obtaining shoots from callus masses, the emphasis has shifted in recent years to meristem cultures — the use of the apical growing

tip. Murashige (5) has recently reviewed plant propagation from tissue cultures.

Although stems commonly contain cells which should be capable for forming root initials, we know that it is not possible to root every species. Thus, we come to the second consideration: internal factors which are necessary for the division and differentiation of root initials.

Some materials that are essential for rooting are synthesized in the leaves and buds and transported down the stem through the stem tissue. To demonstrate this, it is only necessary either to remove the leaves and buds or to girdle the stem to stop the downward movement of these materials.

During the 1920's intensive studies were made of the role of the relative availability of carbohydrates and nitrogen on the vegetative and reproductive growth of plants. It was only natural that experiments would be conducted to determine the effect of these two materials on the rooting of the stem cuttings. Availability of carbohydrates were found to be essential for good rooting. A cutting which has a good supply of carbohydrates will root readily, however, if carbohydrates are low, rooting is markedly reduced. Carbohydrates are synthesized in the leaves by the process of photosynthesis.

A moderate level of nitrogen is also necessary for rooting; however if nitrogen is either very high or very low rooting is impaired. Many nitrogenous compounds are synthesized in the leaves and buds.

In the 1930's the stimulative effect of auxin, indole — acetic acid (IAA), on the rooting of cuttings was demonstrated. IAA is produced by the plant; however we now know that a number of related compounds, not produced by the plant, are also effective when applied to the base of the cutting. Two of the most widely used are indolebutyric acid and naphthaleneacetic acid. Some investigators hoped that the key to root formation had been found, but we now know that auxin is only a part of the story — for auxin may be present in adequate quantity but rooting does not occur. Again, auxin is synthesized in the leaves and buds.

More recently, Hess (3) has demonstrated that a group of components referred to as "rooting co-factors" are required for the rooting of several kinds of plants. You will recall his reports that easily rooted clones of hibiscus contain these co-factors, while the more difficult-to-root clones have reduced quantities or may be lacking in them. Additional evidence was obtained from his work with adult and juvenile forms of the English ivy. Other investigators have shown a correlation between rootability and co-factors. These co-factors are produced in the leaves.

There is also evidence that a non-mobile component, a polyphenol oxidase enzyme, may also be involved in rooting. This enzyme is present in cells which are about to divide and differentiate root primodria.

To this point, I have referred to components which are essential for root initiation. These is also evidence that there may be components actually inibiting the rooting process. Spiegel (6) has reported an inhitibor in the winter shoots of a grape hybrid. Fadl and Hartmann (2) have reported that the difficult-to-root 'Bartlett' pear has rooting inhibitors but that the easy-to-root 'Old Home' cultivar has promoters. Lee (4) studied three clones of rhododendron. Differences in levels of co-factors were correlated with the degree of the difficulty-to-root. He also found inhibitors in all clones; however he stated that these inhibitors appeared to be less responsible for the clonal differences than the level of co-factors.

We now come to the third consideration — favorable environmental conditions. Rooting of the easily-rooted species can be markedly reduced or even prevented if the cuttings are subjected to an unfavorable environment. Probably the most significant aspects of the environment are temperature, light and moisture.

We must consider the temperatures of both the air and the medium. If the air temperature is too high, excessive transpiration and respiration will occur, photosynthesis is reduced and buds of dormant cuttings may start to grow. If the air temperature is too low, the stem ceases to grow and photosynthesis and other metabolic processes are below optimum. The temperature at the base of the cutting will determine whether or not root initiation will take place. A bottom heat of 70 to 80°F is generally considered the optimum range for most plants. It is usually recommended that the air temperature should be about 10° below that of the medium.

Light is essential for the manufacture of chlorophyll, carbohydrates and auxin. Too much light, however, will raise the temperature of the leaves and result in increased rates of transpiration and respiration which may be unfavorable for rooting. With some plants, long days (14 or more hours of light daily) favors rooting and short days reduce rooting. Etiolated stem tissue — that which develops in the absence of light, will frequently root more readily than non-etiolated tissue.

Cuttings which are allowed to wilt or become too dry will not root as readily as those which are kept under good moisture regimes. Probably the most intensively studied aspects of the environment has been the control of water within the cutting. Enclosed units, both glass and polyethylene covered, are effective in increasing the moisture content of the air surrounding the cutting

and thus reduce the rate of transpiration. Careful regulation of shade and ventilation make these structures effective propagation units. The use of intermittent mist was developed in the early 1950's, largely by the members of this Society. By using mist, a wide range of plants can be propagated, utilizing very soft tissue which could not be used under the closed case conditions. Transpiration and respiration are reduced because of the cooler leaf temperatures, and high light intensities, which are permissible under mist, result in more photosynthesis and finally rooting.

Inorganic nutrients, especially nitrogen, may be deficient in cuttings made from rapidly growing stems or if the cuttings remain in the bench for an extended period of time. Applications of nutrients, either to the medium or through the mist system, can be beneficial, especially when applied after rooting has started.

We have really only begun to unravel the complex problems of why and how roots are initiated on cuttings. Certainly we must have cells which have the potential to divide and develop into the new root tip, we must have the internal components necessary to stimulate this cellular division and differentiation and we must provide an optimum environment for these complex growth processes to occur.

LITERATURE CITED

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MODERATOR FLEMER: Thank you Bill, that was a truly virtuoso performance. I will ask that all questions in this session be held until all the speakers have had a chance to present their papers. Our next speaker on the program is Carl Orndorff; he is going to discuss the scheduling of plant propagation.