BEN SWANE: Take short cuttings — less than ½ in. in length with a heal from the inside of the plant. No hormone is required and retain the bottom leaves. Do not overpot the cuttings and place in a quick draining soil with low fertility.

MODERATOR SHUGERT: What is the "loose" yew sold by Studebaker Nursery?

DON STUDEBAKER: A selection of *Taxus cuspidata* 'Columnaris' that has a loose, upright growing habit and may have potential in shady areas.

MODERATOR SHUGERT: Question for Bill Flemer. Do you propagate your Cornus kousa var. chinensis from seed? If so, are the seedlings uniform?

BILL FLEMER: We have selected and established isolated blocks from previous seedlings. We look for broad, thick leaves and broad, thick bracts. So we do grow them from seed. It can also be propagated by cuttings but, like a number of the tree dogwoods from cuttings, we have had overwintering problems. I remember we had a block in our Allentown nursery about 9 years ago in which ⅔ were planted from seeds and ⅓ were from cuttings. Following a severe winter all the cutting plants died while all the seedlings plants lived. They were 4 to 5 feet tall at the time. The roots just died. We have had the same problem with *C. florida* 'Rubra.' The *C. kousa* var. *chinensis* grown from our isolation blocks are the way to go we feel.

ROOT REGENERATION TECHNIQUES

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INTRODUCTION

Woody plant establishment and growth are greatly affected by root loss which occurs during the transplanting process. The resulting stresses placed on the plant are a major source of problems in woody plant production and consumer usage of trees and shrubs. Root loss which occurs during digging, handling, storage and transplanting, results in reduced shoot growth for several years, branch dieback, or plant death. It also reduces the type and size of trees able to be moved and makes some species expensive to produce and unavailable in the landscape trade. The transplanting period and the first growing season following it are one of the most critical periods for survival and growth in the life of trees and shrubs.

The greatest cause of death of transplanted seedlings is water stress (8), and is directly related to root loss. Transplants undergo massive physiological shock when removed from the soil. The most damaging injury is the loss of actively growing root tips and the zone immediately behind the tips which are the areas responsible for most water uptake. The ability to form new roots, referred to as root regeneration potential, varies with the species, season, handling, and type of root system (3,9,16,20,23). Plants with low root regeneration potentials are difficult to transplant, or recover very slowly from transplanting. Plants which do not transplant readily require more expensive digging and handling procedures. Substantial amounts of post-transplant care are also required for these species

Traditional horticultural practices designed to ease transplanting stress include the use of antitranspirants, root pruning, digging plants B & B and careful selection of transplanting time. An additional technique may soon be available to the nursery and landscape industry. This technique involves the application of readily available growth regulators — auxins — to the root system of plants, which accelerate the root regeneration process. The auxins, IBA and NAA, have shown great promise in experimental root regeneration studies. These are the same growth regulators which most propagators use on a routine basis to stimulate rooting in cuttings.

Early experiments in the mid to late 1930's demonstrated the effectiveness of inserting IBA-soaked toothpicks into holes drilled in the main tap root of transplanted pecan (*Carya illinoensis*) (21). Other workers showed that root regeneration could be stimulated by soaking the root systems of several species in dilute auxin solutions (1,26,30). Research in this area essentially ceased until the mid-1970's. Since that time several research groups around the country have begun work on elucidating the process of root regeneration and have continued experimenting with auxin applications. Current research has shown that root regeneration can be stimulated in a variety of species (Table 1).

MATERIALS USED

The auxins most commonly utilized for root regeneration studies include indoleacetic acid (IAA), indolebutyric acid (IBA), and naphthaleneacetic acid (NAA). Within this group, IAA is the least effective and the most unstable in storage.

Most species respond better to IBA than to NAA and show fewer problems with phytotoxicity. Auxins are not extremely water soluble so they are first dissolved in a small amount of alcohol and then diluted with water. Alcohol concentrations of 25% or less are acceptable for quick dips and sprays (Table 3) but much lower levels should be used for soaks because alcohol is toxic to roots. A water soluble form of IBA, the potassium salt of IBA, has been used successfully on a number of species (Table 1). K-IBA can be used without alcohol but the cost ($26.50/gram) is 20 times more than IBA ($1.30/gram). Depending upon application method, size of plant, and auxin used, the cost can be expected to range from 1¢ to 30¢ per tree.

METHODS OF APPLICATION

Growth regulators can be applied to the root systems of plants in a variety of ways. One of the earliest and still most successful methods of application involves the insertion of auxin-soaked toothpicks into holes drilled in the roots. This technique allows the applicator to carefully choose the location of the auxin application to enhance root regeneration at specific sites. Application rates can be varied by changing the concentration of the auxin solution in which the toothpicks are soaked. Most workers have reported using 1000 to 3000 ppm auxin solution to deposit 1 to 4 mg of auxin per toothpick (Table 1). The major disadvantage of this method of application is the time and labor required for each tree. Despite the cost associated with this technique, Struve et. al. (24) demonstrated a substantial benefit/cost ratio in a small scale nursery study.

Early studies (1,21,26) also indicated auxins could be applied to trees by soaking the root systems in dilute solutions for periods of 24 to 48 hours Auxin concentrations of 10 to 200 ppm are typically used for a 24-hour soak application (Table 1). Shorter soaking times can be used with correspondingly higher auxin concentrations. Experience with cutting propagation suggests that the alcohol concentration required to dissolve the auxin, should be kept to a minimum to avoid toxicity during a 24 hour soak (5). Disadvantages of the soak technique include the long time required for treatment and the large volume of treatment solution required for trees larger than seedling stage.

Several other less common methods of auxin application include wrapping roots with auxin soaked string (29), applying the auxin in the form of paste (Table 1), and the use of a powder. Pastes are prepared by mixing auxin with a mixture

Table 1. Summary of effects of auxin treatments on root regeneration of woody plants

Species	Auxin	Concentration (ppm)	Method of application	Effect[1]	Reference
Acer saccharinum	IAA	10,000[2]	lanolin paste	length, number	19
A saccharum	IBA	10, 40	soak	number	26
Aleurites fordii	IBA	20	soak	dry weight	17
Carya illinoinensis	IBA	5,000	lanolin paste	dry weight, length	21
	IBA	4 mg/toothpick	toothpick	dry weight, length, number	21, 4
	IBA	5,000	wheat flour paste	length, number	21
Cercis canadensis	IBA	3,000	soak		15
Cotoneaster divaricatus	IBA	50	soak	number	1
	IAA	10	drench	number	1
Crataegus phaenopyrum	IBA	1,000, 3,000	soak, toothpick		25
Fraxinus americana	IAA	200	soak	dry weight, number	6
Juglans nigra	IBA	1,000	soak	dry weight, number, shoot growth	27
	IBA	25	soak	number	26
Liquidambar styraciflua	IBA	3,000	dip	number	10
Liriodendron tulipifera	IAA	200	soak	dry weight, number	6
	K-IBA	1,000-10,000	soak	dry weight, number, shoot growth	7
Magnolia × soulangiana	IBA	500	spray	number	Table 3
Nyssa sylvatica	IBA	3,000	toothpick string	dry weight, number	29
Oxydendrum arboreum	IBA				28
Pinus contorta	IBA, NAA	203, 19	dip	number	22
P elliottii	IBA	10	soak	length, number	18
P ponderosa	IAA	50	soak	number, increased survival	2
P taeda	IBA	20	soak	volume	14
Pistacia chinensis	K-IBA	3,000	dip	number	10
Pyrus communis	IBA	1 mg/toothpick	toothpick	number, weight	11

Table 1 Summary of effects of auxin treatments on root regeneration of woody plants (continued)

Species	Auxin	Concentration (ppm)	Method of application	Effect[1]	Reference
Quercus alba	IBA, NAA	3,000	string, toothpick	dry weight, length, number	29
Q coccinea	IBA, NAA	100, 1,000	soak, toothpick	length, number	25
	IBA	2,000	dip	number	16
Q palustris	IBA	25	soak	number	26
	IBA	2,000	dip	number	16
	IBA	1,000, 10,000	toothpick		13
Q rubra	IAA	200	soak	dry weight, number	6
	IBA, NAA	3,000	spray	number	12
Q velutina	IBA	25	soak	number	26
Thuja occidentalis	IBA	25	soak	number	26
Ulmus americana	IBA	10	soak	number	26
Viburnum dilatatum	IAA, IBA	200, 20	drench, soak	number	1

[1] Stimulatory effect on dry weight, length, number and volume of roots or shoot growth
[2] Applied to disbudded shoot meristem

of wheat flour and water, or with just lanolin, at a concentration of 5000 ppm. The paste is applied to selected places on the roots with a small tool. These methods allow for specific placement of auxin on the root system. Rooting powders can be purchased commercially, or prepared by mixing the auxins with talc. Powders are usually applied to a moist root system immediately prior to planting, much like treating cuttings prior to sticking. Concentrations of 1000 to 3000 ppm are common in powder form.

Soil drench applications of auxins have been the least successful technique reported. Chadwick (1) reported limited stimulation of root regeneration in *Cotoneaster divaricatus* (spreading cotoneaster) and *Viburnum dilatatum* (linden viburnum) with soil drench applications of IBA. Other researchers have not reported much success with soil drench applications since that time. Problems associated with soil drench applications of auxins include soil binding and inactivation, alcohol toxicity to roots, inability to get the auxin to the roots, and the large quantity of auxin required.

The most recent application technique utilizes auxin sprays. Sprays are much quicker and easier to apply and allow for more efficient utilization of auxins than other methods. Spray applications can be selective by spraying only the outside of a balled and burlapped plant, or more general by spraying the entire root system of a bare root tree. Sprays do not require any special equipment and can be applied in the field or following removal from storage. Lumis (12) reported success with 3000-ppm spray applications of IBA and NAA on landscape size red oak (*Quercus rubra*). Spray applications made to the outside edges of freshly dug root balls resulted in increased root numbers at the cut ends. Spray applications have also been used to stimulate root regeneration in *Magnolia* × *soulangiana*, saucer magnolia (Table 2).

Table 2. Effect of spray applications of indolebutyric acid on root regeneration of *Magnolia* × *soulangiana* seedlings [1]

IBA concentration (ppm)	Average number of regenerated roots	Root system quality[2]
0	36 5 b[3]	3 7 ab[4]
500	67 1 a	4 7 a
1000	38 7 b	3 6 ab
2000	24 3 c	2.0 bc
4000	1 3 d	1.1 c
8000	0 0 d	1 0 c

[1] 15 plants per treatment
[2] Quality ratings 5 for excellent, 2 for alive but poor, 1 for dead
[3] Mean separation by Duncan's Multiple Range Test, 5% level
[4] Mean separation by Scheffe's test, 5% level

A number of generalizations can be made from the numerous root regeneration studies that have been conducted. Progress made in the area of root regeneration is summarized in the following paragraphs.

1) Natural root regeneration varies with the season. Root regeneration is at a maximum at bud break and declines over the summer with an increased capacity in fall (3,9,16,20,23). This is the basis for spring versus fall transplanting for some species.

2) Root regeneration is greatly affected by the physiology of the plant at digging time, storage conditions and stresses during and following transplanting (3). Auxin treatments are no substitute for maintaining healthy, vigorous plants that are properly stored and handled (3). Prevention of water stress during the entire process is extremely important.

3) Auxin treatments can increase the number of regenerated roots. The dry weight or total mass of a root system is not necessarily increased when root number increases. Often the density of the root system is increased by a stimulation of a large number of small roots. This increase in fibrous roots can be a major improvement for a plant with a coarse root system. While some plants respond to auxin treatments by increasing root numbers and mass (Table 1), there may be no increases in root length with auxin treatments.

4) The concentration of auxin required for root regeneration differs with species (Table 1). A typical range for IBA would be 1000 to 3000 ppm for a quick dip or spray and 20 to 50 ppm for a 24-hour soak. Some species are quite sensitive as evidenced by stimulation of root regeneration in *Magnolia* × *soulangiana* with spray concentrations of 500 ppm IBA and inhibition at 1000 ppm and above (Table 2). Careful consideration should also be given to the concentration of alcohol used to solubilize auxins. Ethanol concentrations above 25% inhibit root regeneration in *Magnolia* × *soulangiana* (Table 3). Much lower levels of alcohol should be used for 24-hour soaks.

5) Younger plants are generally more responsive than older plants (21). Most root regeneration studies have used seedlings for ease of experimental handling. Auxin applications however, have been effective on large plants (12). Older plants will respond to auxin but the response of most species as affected by age is largely unknown.

6) Root regeneration techniques are successful on difficult- and easy-to-transplant species (Table 1). Much emphasis has been placed on root regeneration in species with low root regeneration potentials; however, some of the greatest benefits

may be gained by auxin use in species that are considered to be easy-to-transplant. Additional work is needed to determine effects and benefits with other species.

7) The main objectives of root regeneration are not limited to increasing the number of roots, their length, or the mass of the root system. Treatments should result in increased transplant survival and accelerated shoot growth of plants following transplanting. Work by Fowells (2), Gossard (4), Turner and Moser (27) and Kelly and Moser (7) has demonstrated increase survival rates and shoot growth stimulation.

Table 3. Effects of spray applications of ethanol on root regeneration of *Magnolia* × *soulangiana* seedlings [1]

Ethanol concentration (%)	Average number of regenerated roots per plant
0 0	34 3 a[2]
12 5	36 7 a
25 0	36 5 a
50 0	28 4 b
70 0	24 5 b

[1] 15 plants per treatment
[2] Mean separation by Duncan's Multiple Range Test, 5%

FUTURE OF ROOT REGENERATION STUDIES

Certainly not all root regeneration studies have produced successful results. Some experiments show no response, or even significant inhibition of root regeneration with auxin treatment. Positive results can sometimes be hard to reproduce from year to year or on related species within the same year. Many of these problems can be attributed to our lack of knowledge concerning the effect of previous environments in which the plant was grown or stored (20). We know small differences in timing or handling procedures of cuttings can make a great difference in rooting. Similarities could exist in root regeneration.

Inconsistent results from growth regulator applications also indicate a lack of knowledge about internal plant hormone control of the process of root regeneration. A basic understanding of the role of hormones in plant development is essential to future improvement of woody plant production and usage. Much work remains in this area.

Root regeneration techniques have been successful on many species, resulting in increased root system density and size. Most woody species, however, have not been evaluated for response to auxin treatments. Research is needed to determined which species will benefit most from these techniques.

Additional refinements in timing, rates, and methods of application could bring greater responses and more consistent results. Field nursery trials need to be conducted to determine large scale results and the economic benefits of these treatments. Results from these types of studies should make root regeneration techniques a helpful tool to accelerate nursery production and establishment of trees into landscapes. Root regeneration techniques should improve the transplantability of large trees and facilitate establishment of trees in difficult urban areas. It is hoped that these procedures will result in lower cost, higher quality trees for the public, and an increased diversity of available plant materials.

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