It is also important to remember that while these two phases are quite stable, reversion of the adult form to the juvenile can occur. With careful manipulation of the mature phase, propagators may be able to produce juvenile cuttings with a high capacity for rooting.

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INFLUENCE OF HIGH IBA CONCENTRATIONS ON ROOTING

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Abstract. Cuttings of *Acer saccharum*, *Cotoneaster acutifolius*, *Malus pumila* 'Mor Spur McIntosh', *Malus* 'Hopa', and *Taxus cuspidata* were treat-

ed (5-second dip) with 0 (control), 1,250, 2,500, 5,000, 10,000, 20,000, and 40,000 ppm indolebutyric acid (IBA) dissolved in alcohol, rooted under intermittent mist, and evaluated for percentage rooting, mean root length and mean root number *Cotoneaster acutifolius*, *Malus* 'Hopa', and *Taxus cuspidata* showed significant increases ($P = 0.01$) in rooting percentage, root length, and root number, with optimum responses in these parameters observed with IBA treatments between 10,000 and 40,000 ppm *Acer saccharum* showed a significant increase ($P = 0.05$) only in rooting percentage with maximum response occurring with the 5,000 ppm IBA treatment *Malus pumila* 'Mor Spur McIntosh' failed to root regardless of IBA treatment

The discovery in the mid-1930's that auxins were of real value in stimulating rooting of cuttings was a major milestone in the history of plant propagation (14,16). Exogenously-applied auxins and other growth regulators have been distinctly beneficial for numerous plant species, but their effects on root formation sometimes have been conflicting and, on occasions, found to be detrimental to some species, including some difficult-to-root species not ordinarily propagated by cuttings (3,14).

Ample evidence suggests that increasing age or loss of juvenility is one of the most important single factor limiting rooting ability of many difficult-to-propagate species (1,7). It has long been advised that high concentrations of growth regulators might promote rooting in these species (1). In fact, certain hard-to-root species have been successfully rooted after treatment with high concentrations of growth hormones. *Quercus robur* 'Fastigiata' cuttings rooted after treatment with 20,000 ppm indolebutyric acid (IBA) (6) Brown and Dirr (1) reported successful rooting of softwood cuttings from mature crabapple trees due to high IBA concentrations; *Malus floribunda* was most effective with 10,000-30,000 ppm IBA, and *Malus* 'Hopa', *Malus* 'Selkirk', and *Malus zumi* 'Calocarpa' with 10,000 ppm. Still (12) observed significant stimulation in rooting of cuttings from mature *Tilia* taxa with IBA treatments, especially in the range of 20,000 ppm. On the contrary, IBA concentrations of 10,000-30,000 ppm did not promote rooting of mature red oak or black walnut cuttings, although juvenile black walnut cuttings can be promoted to root by 5,000-8,000 ppm IBA treatments (11) Thus, the rooting response of species and cultivars can be expected to vary, and optimum treatment levels must be determined empirically (2,7).

Increased demand for woody landscape plants and related fruit nursery stocks have resulted in shortages of some of these planting materials. Many of these woody plants are difficult to propagate vegetatively and require a lengthy time to produce salable plants. As part of a research program, which aims to develop more effective methods and techniques for the production of woody ornamental and related fruit nursery stocks with emphasis on more difficult-to-propagate species,

this study was undertaken to study the influence of high IBA concentration on rooting of stem cuttings of selected woody species.

MATERIALS AND METHODS

Between July 10 and 13, 1979, stem cuttings of the current season's growth were removed from the following species (approximate age of source in brackets); *Acer saccharum* (20 years); *Cotoneaster acutifolius* (15 years); *Malus pumila* 'Mor Spur McIntosh' (10 years); *Malus* 'Hopa' (2 years, budded nursery stock). Length of cuttings varied between 10-15 cm depending on species. Cuttings of *Acer saccharum* were limited to two nodes. The basal portions of all cuttings were stripped of foliage. The remaining leaves on cuttings of *Acer saccharum* and *Malus pumila* 'Mor Spur McIntosh' were cut in half to reduce the surface area.

Cutting bases of each species were treated (5-second dip) with 0, 1,250, 2,500, 5,000, 10,000, 20,000, and 40,000 ppm IBA dissolved in 50% ethanol. Fifty percent ethanol served as the control. Cuttings were then stuck in a medium of 1 peatmoss: 1 perlite (v/v) in wooden boxes (44 cm long × 35 cm wide × 15 cm deep), and placed in outdoor frames under intermittent mist controlled by electronic leaf. The mist frames were shaded with lath. Captan was applied at time of sticking, followed by Captan or Benlate applied alternatively once per week.

The experimental design used was a randomized complete block with four replications and 12 cuttings per experimental treatment, except for *Acer saccharum* in which there were 10 cuttings per experimental treatment. Cuttings were evaluated for percentage rooting, mean root length, and mean root number.

On the dates, November 9, 1979 and February 19, 1980, two consecutive experiments were similarly conducted for *Taxus cuspidata* but cuttings were rooted under greenhouse conditions under intermittent mist with bottom heat of 24 ± 2°C. In experiments for *Taxus cuspidata*, six replications and 10 cuttings per experimental treatment were used. On June 21, 1980 the same experiment as described in 1979 was repeated for *Cotoneaster acutifolius*.

RESULTS AND DISCUSSION

Except for *Malus pumila* 'Mor Spur McIntosh' which failed to root regardless of IBA treatment, cuttings of the four other species rooted (Figure 1). The rooting periods (weeks) for these four species were. *Acer saccharum*, 8; *Cotoneaster acutifolius*, 5;

Malus 'Hopa', 3.5; *Taxus cuspidata*, 9. Results for *Taxus cuspidata* are shown as the average of the two experiments since data were similar for the two dates (Figure 1,2,3). On the other hand, results for *Cotoneaster acutifolius* are shown separately for experiments conducted in 1979 and in 1980 since rooting response was significantly higher ($P = 0.01$) in 1980 (Figures 1,2,3); however, the trend in rooting response of this species to increasing IBA treatments was essentially similar in both years.

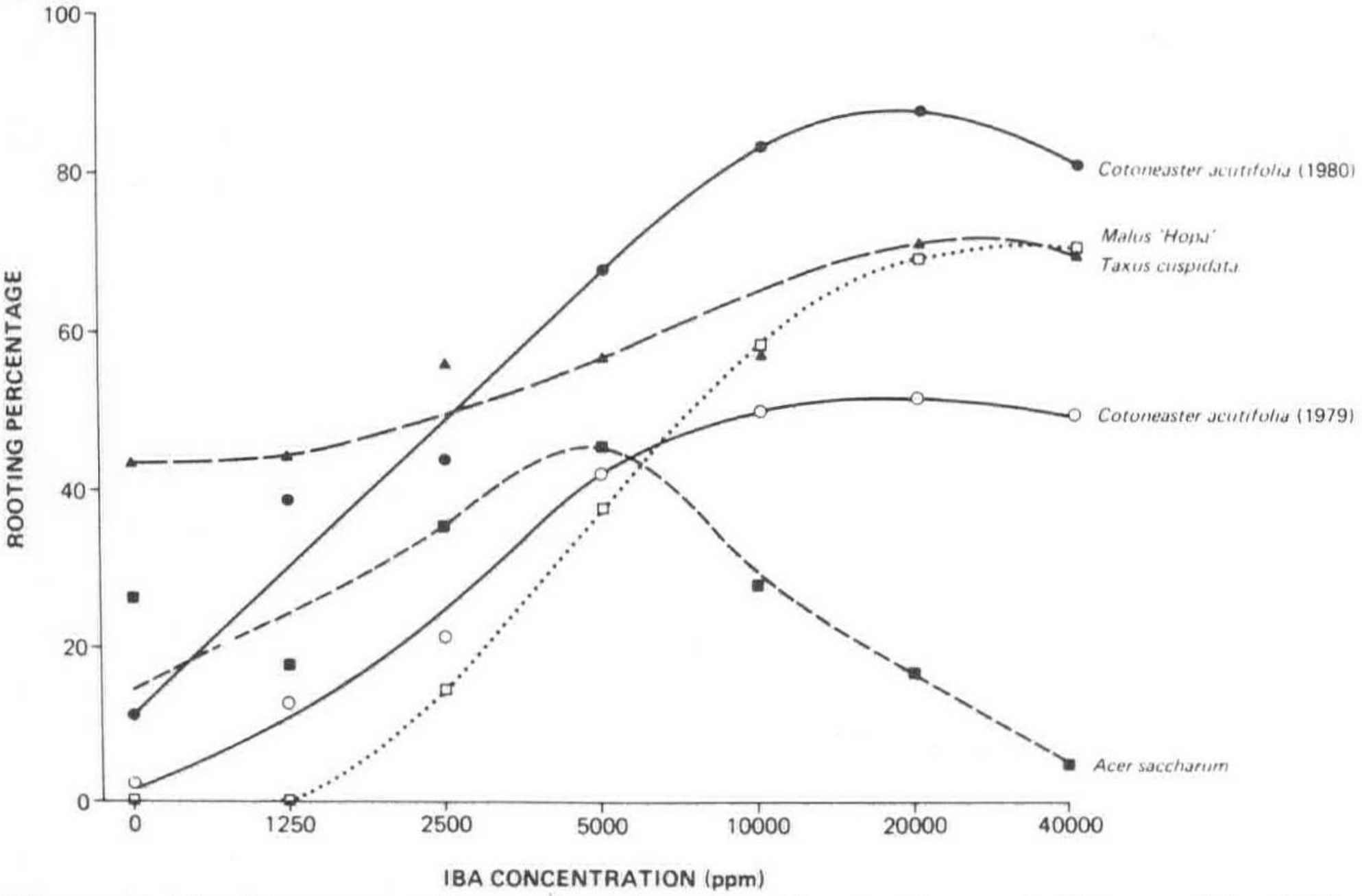

Figure 1. Rooting percentage of various woody species as influenced by IBA concentrations. LSD ($P = 0.01$): *Cotoneaster acutifolius*, 28% in 1979 and 31% in 1980; *Malus* 'Hopa', 47% *Taxus cuspidata*, 22%. LSD ($P = 0.05$); *Acer saccharum*, 22%.

Analysis of variance for rooting data of *Cotoneaster acutifolius*, *Malus* 'Hopa', and *Taxus cuspidata* showed highly significant ($P = 0.01$) and consistent increases in rooting percentage (Figure 1), root length (Figure 2), and root number (Figure 3). Percentage rooting (Figure 1) peaked or plateaued with IBA treatments of 20,000 ppm for *Cotoneaster acutifolius* (50% in 1979; 88% in 1980), 20,000 ppm for *Taxus cuspidata* (71%), and 40,000 ppm for *Malus* 'Hopa' (71%). Root length (Figure 2) peaked or plateaued with IBA treatments of 10,000 ppm for *Cotoneaster acutifolius*, 20,000 ppm for *Malus* 'Hopa', and 40,000 ppm for *Taxus cuspidata*. Root number (Figure 3) was dramatically stimulated by IBA concentrations between 10,000 and 40,000 ppm with maximum root number in all three species occurring consistently with the 40000 ppm IBA treatment. Differences in rooting percentage, root length, and root number as influenced by IBA concentrations have been reported for var-

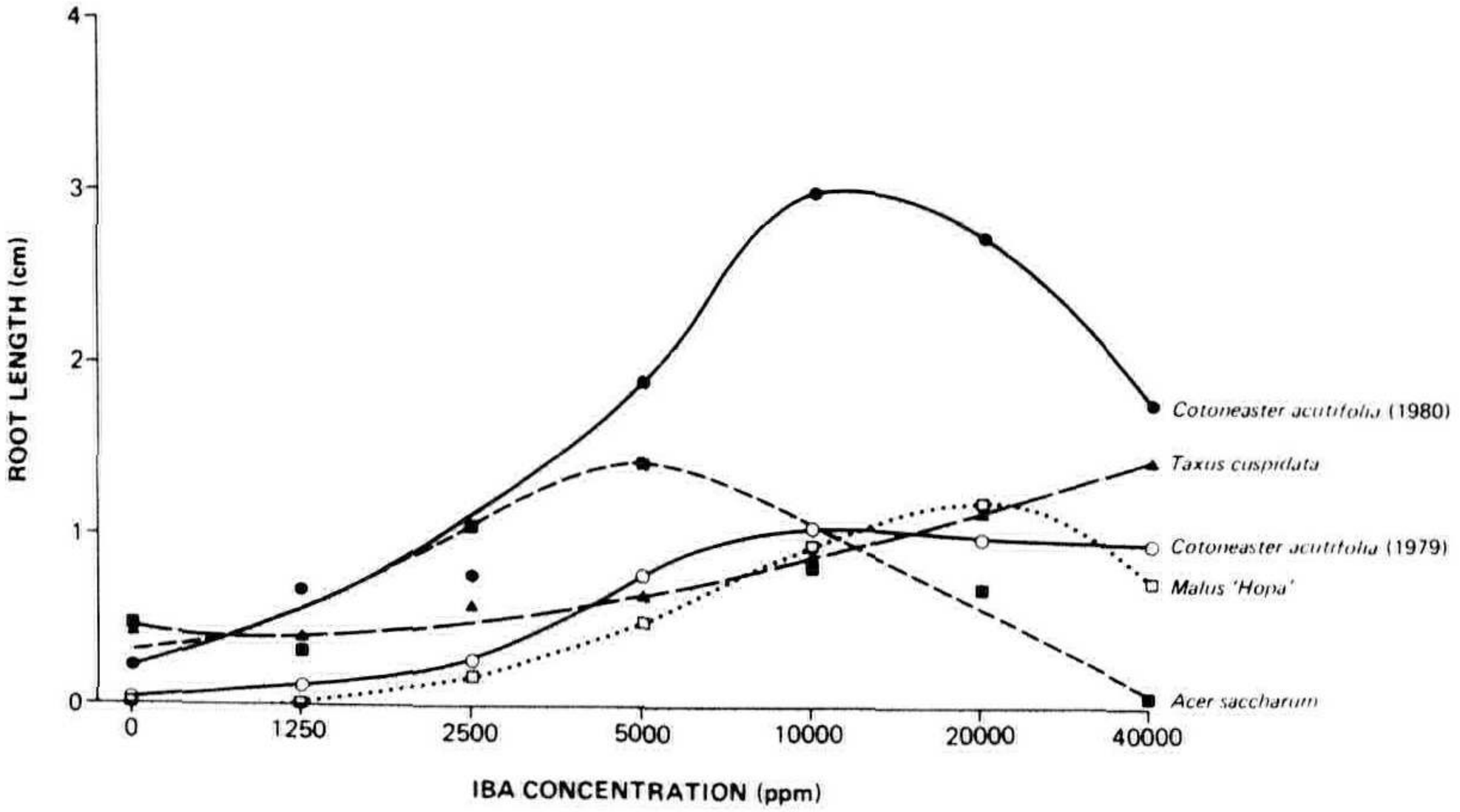

Figure 2. Root length of various woody species as influenced by IBA concentrations. LSD ($P = 0.01$): *Cotoneaster acutifolius*, 0.81 cm in 1979 and 1.32 cm in 1980; *Malus* 'Hopa', 0.91 cm; *Taxus cuspidata*, 0.81 cm. Root length was not significantly different for *Acer saccharum*.

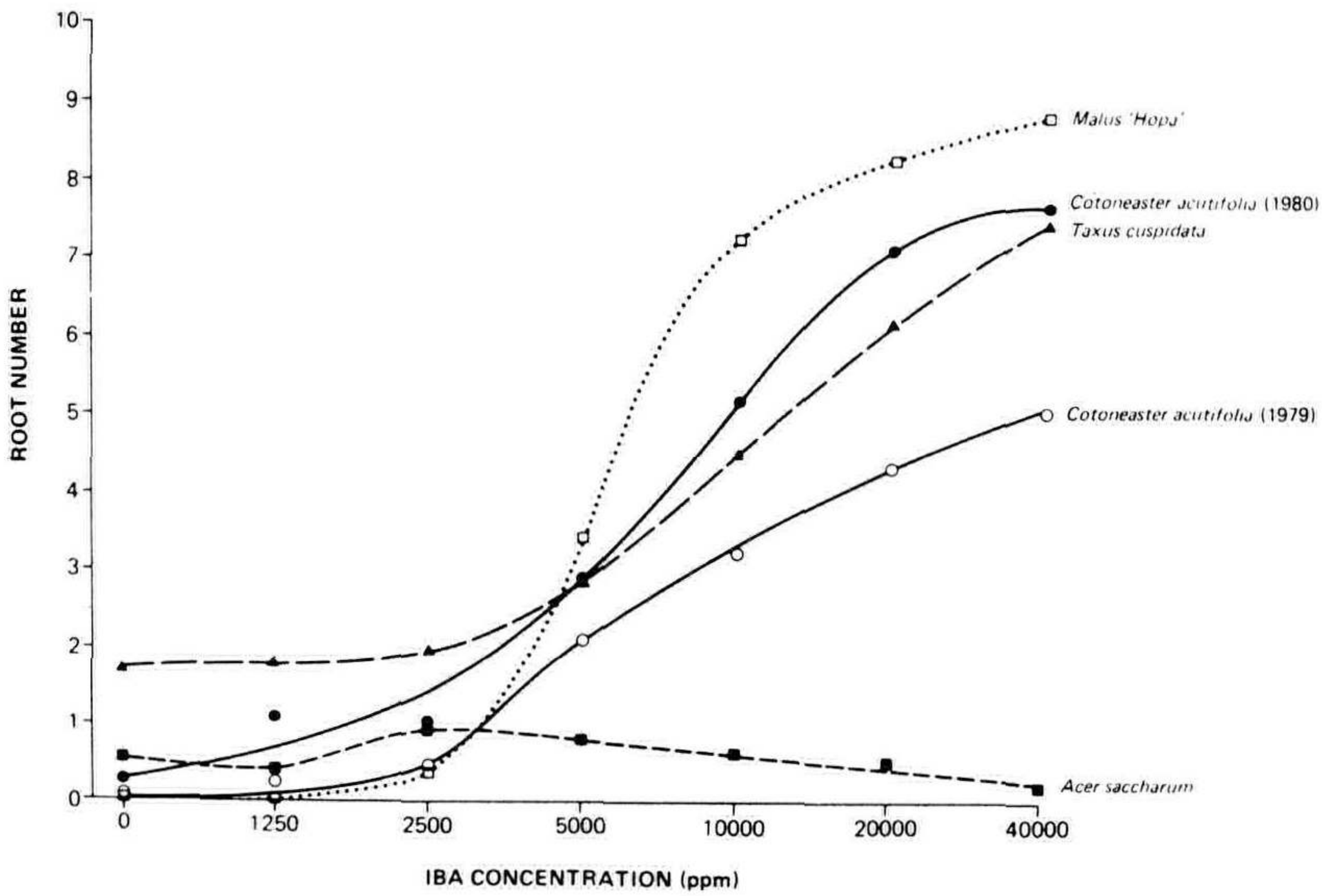

Figure 3. Root number of various woody species as influenced by IBA concentrations. LSD (P=0.01): *Cotoneaster acutifolius*, 3.5 in 1979 and 1.8 in 1980. *Malus* 'Hopa', 7.2; *Taxus cuspidata*, 3.6. Root number was not significantly different for *Acer saccharum*.

ious crabapple taxa (2) and for juvenile oak (11).

Acer saccharum showed significant increase ($P = 0.05$) only in rooting percentage, which peaked at 45% with IBA treatment of 5,000 ppm (Figure 1).

It is perhaps worth noting that further tests with IBA

during the winter of 1981 in a commercial nursery, in which *Taxus* × *media* 'Hicksii' cuttings were rooted in a greenhouse without intermittent mist but supplied with bottom heat, confirmed the results of this study (Figure 1.2,3). In another experiment conducted in 1980, cuttings of *Malus pumila* 'Mor Spur McIntosh', treated with all combinations of IBA at 2,500, 5,000, and 10,000 ppm and ethephon (2-chloroethyl phosphonic acid) at 0, 500, 1,000, and 1,500 ppm, also failed to root Many cuttings developed callus in the fall and several developed roots the following spring, after being allowed to overwinter in the mist frame. However, there was no discernible relationship of rooting with growth regulator treatments. Ethephon alone, or in conjunction with other auxins, has been shown to stimulate rooting ability of various species (4,5,13).

Root formation in cuttings is a complex phenomenon influenced by numerous factors such as physiological condition; genetic origin of donor plants; climatic effects or season in which cuttings are taken; treatment with growth regulators, nutrients, or other chemicals; misting frequency and composition; and temperature of the rooting medium (7)

High hormonal concentrations have proven to be a significant factor in the successful rooting of stem cuttings of various ornamental crabapples and a limited number of other difficult-to-root woody species as reported in this (Figure 1,2,3) and other studies (1,2,6,12). This contrasts with the difficulty in rooting stem cuttings of *Malus pumila* 'Mor Spur McIntosh' (this study), other commercial fruiting apples, and apple rootstocks (2,9,10) and certain other woody species tested in this way (11). This evidence seems to emphasize our present uncertainty in the use of growth regulators and also our lack of understanding of the sequence of rooting events which allows growth regulators to be used effectively (3,8).

Unlike easily rooted species, such as the willows, which possess preformed root primordia in their stems, root primordia must be biochemically induced in many species (8). Difficult-to-root tissues may lack the necessary active enzymes or substrates to induce a meristematic state and thus the initiation of root primordia (8).

Evidence further suggests that, like other growth processes, each step of the rooting process is controlled by delicate balances of growth hormones, both promoter and inhibitor types, in conjunction with other rooting cofactors and complexing enzymes (15,16). Thus according to Cameron and Rook (3), it seems unlikely that a single application of one growth regulator applied against the background of natural growth regulators that vary in composition with age of the plant, time

of year, and an integrated series of events will give consistent results.

Brown and Dirr (1) and Burd and Dirr (2) indicated that high concentrations of IBA between 20,000 and 30,000 ppm often resulted in defoliation, significant injury or death in crabapple taxa. In the present study, it was noted that the basal portions of cuttings treated with 20,000 and 40,000 ppm IBA also tended to be injured by these high concentrations. However, in the three species that responded positively to high IBA concentrations (Figures 1,2,3), more prolific rooting nevertheless occurred above the injured portion, as exemplified by cuttings of *Cotoneaster acutifolus* (Figure 4). At these high concentrations, IBA dissolved in 50% ethanol will usually form a precipitate after several days of storage in the refrigerator (4°C). The precipitate will clear easily after standing for several minutes in luke-warm water with occasional shaking. Dissolution of the IBA in 95% ethanol will prevent this problem.

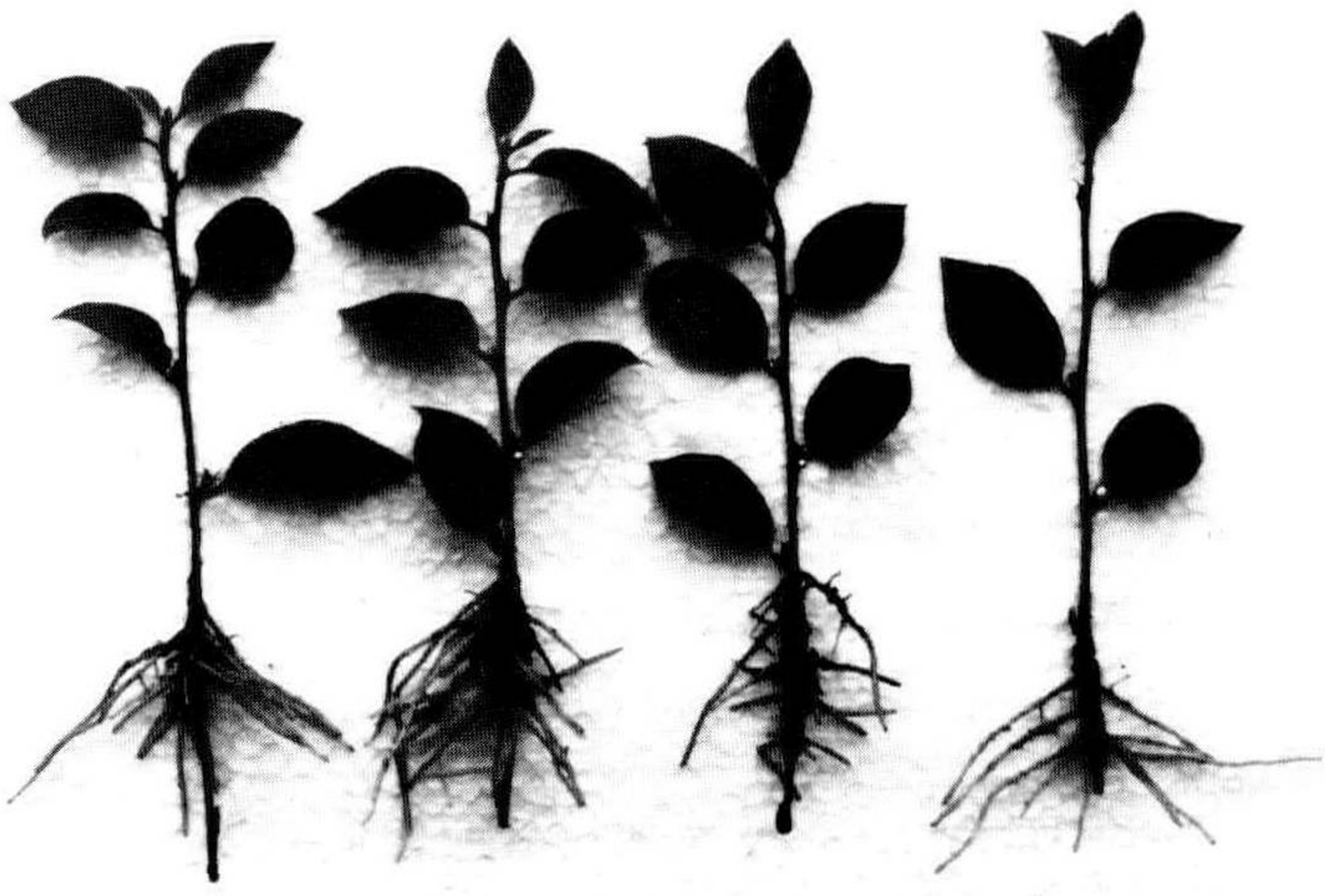

Figure 4. Prolific rooting occurs above basal portion of *Cotoneaster acutifolius* injured by high concentrations of IBA.

The results of this study, together with those of other researchers (1,2,6,12), indicate the favorable use of high IBA concentrations for stimulating rooting of certain difficult-to-root species. Further extension of this finding to other species and also use of other growth regulators in a similar way may be the key to rooting of many more difficult-to-root species.

Acknowledgements. This work was supported by a grant from the Conseil des recherches et services agricoles du Quebec. The technical assistance of Tedros Mikael, Eng-Chung Pua, and Juan E. Gonzales is acknowledged.

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JOERG LEISS: What was your growth response after heavy hormone treatment? Did the heavy hormone treatment suppress growth?

CALVIN CHONG: I did not do a formal growing-on study. However we did pot a few cuttings and did not see any detrimental effects.

CARMINE RAGONESE: Please explain how to make a 20,000 ppm solution?

CALVIN CHONG: A 20,000 ppm solution is equal to 20 grams per liter or 20,000 milligrams per liter.

WILLIAM WOLFF: I have tried varying hormone strengths with a number of *Acer* species. The conclusion we came to was that high IBA concentrations act as growth inhibitors.

ADJUSTING NURSERY PRACTICES FOR PRODUCTION OF MYCORRHIZAL SEEDLINGS DURING PROPAGATION

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During the past few years, there has been a growing interest in mycorrhizal research. There are many reports citing the possible benefits mycorrhizal fungi may afford nursery crops, such as increased nutrient uptake, growth, disease resistance, cold hardiness, drought tolerance, rooting of cuttings, and fertilizer conservation. Information pertaining to these benefits has been thoroughly discussed in previous Proceedings (8,19,20) as well as for other horticultural and forestry crops (25,47).

A major requirement in developing uses for mycorrhizal fungi in the nursery industry will be to determine cost-efficient methods of producing plants infected with specific mycorrhizal fungi and no others. We feel that one of the most efficient methods of producing mycorrhizal plants will be through the inoculation of seedlings at time of propagation. During propagation, the amount of mycorrhizal inoculum required is minimal, and regulation of environmental conditions and/or cultural practices can be closely monitored and controlled.

The primary objective of this paper is to place in perspective some of the current information pertaining to mycorrhizal formation so that the propagator has a better understanding of how to develop techniques for the production of specifically infected mycorrhizal seedlings. This objective will be accomplished in three steps: first, through a review of mycorrhizal occurrences and chief characteristics; second, through a brief discussion of plant-fungus interactions and mycorrhizal formation; and third, through a discussion of how production practices may have to be adjusted and/or new ones developed to inoculate and grow mycorrhizal seedlings economically.