USES OF PLANT GROWTH REGULATORS IN THE CONIFER NURSERY

by
C.H.A. Little [1/]

Abstract - The literature pertaining to plant growth regulators is surveyed in relation to these chemicals being used on conifers to increase the rooting of cuttings, enhance seed germination, promote or inhibit shoot and root growth, increase frost and drought resistance, improve storage and overwintering potential, and delay springtime budbreak. It is evident from this survey that although promising gains have been made in attaining some of these goals, much more developmental work is required.

The nurseryman's goal is to mass-produce, as quickly and cheaply as possible, a vigorous and well-balanced seedling that will survive and growth well after outplanting. To accomplish this goal, he must successfully manipulate a number of potent cultural tools: water, fertilizers and pesticides in the nursery, also temperature, photoperiod, light intensity and, ideally, carbon dioxide in the greenhouse. Recently, work began on developing another major tool - plant growth regulators (PGRs). The purpose of this report is, first, to identify ways in which PGRs might be gainfully used in the context of the conifer nursery, and, second, to briefly survey the pertinent development work performed to date.

A PGR is an organic compound that in minute quantities promotes, inhibits, or qualitatively affects plant growth and development. It is not a nutrient (source of carbon or mineral elements) or a pesticide (herbicide, fungicide, insecticide, soil fumigant). Naturally-occurring PGRs are usually referred to as hormones since they are synthesized in certain parts of the plant (eg. leaves, roots) then typically are translocated elsewhere affecting specific biochemical, physiological, and morphological processes in the tissues and organs with which they come in contact. Five classes of hormones presently are known: in general, three promote (auxins, gibberellins, cytokinins), one inhibits (a diverse group of substances, the best known of which is abscisic acid), while the last is the gas ethylene, which affects a wide array of growth processes. A vast literature exists pertaining to hormone biochemistry, action, and interaction (for recent reviews see Letham et al. 1978; Wareing and Phillips 1978; Moore 1979). In short, however, it is clear that endogenous hormones are involved in the regulation of cell division, cell enlargement, stem, leaf and root growth, flower formation, senesence, abscission, bud and seed dormancy, correlative growth, and stress response. This knowledge naturally prompted the idea of controlling growth and development by applying chemicals to the outside of the plant. To this end, a host of naturally-occurring and synthetic substances have been synthesized and screened for effectiveness

[1] Research Scientist, Maritimes Forest Research Centre, Canadian Forestry Service, P. O. Box 4000, Fredericton, N.B. E3B 5P7

in the context of horticulture and agriculture, and several economically-important applications have been developed involving specific ornamental, fruit, and vegetable crops (for recent reviews see Skoog 1980; Jeffcoat 1981; Morgan 1980; Nickell 1982). In contrast, the effects of PGRs on conifer species important in forestry have been very little investigated and, with the exception of employing gibberellins to promote flowering (e.g. Ross et al. 1980), no major practical uses are known.

PGR USES

(1) Vegetative Propagation

The rooting potential of conifers declines rapidly to zero with increasing tree age. This decline can be partially overcome in materials obtained from relatively young trees by treating the base of the cutting with a synthetic auxin such as indolebutyric acid (Brix 1974; Girouard 1974). Adding other PGRs to the formulation may further promote rooting (hare 1974; Smith and Thorpe 1975). Stimulating the rooting of cuttings probably is the best known application of PGRs with conifers.

(2) Seed Germination

To maximize the rate and percentage of germination, seed typically is stratified. This requirement can be partially replaced in many species, including conifers, by pretreating the seed with ethylene, gibberellin or cytokinin (Borno and Taylor 1975; Pharis and Kuo 1977; Khan and Tao 1978; Taylor and Wareing 1979). More importantly, gibberelin has been reported in increase the germination percentage of old, deteriorated seed of *Pinus caribaea* var. *hondurensis* Barr. and Golf. (Venator 1972; Bhatnagar 1980) and *Picea glehnii* Masters (Shibakusa 1980). Thus PGR pretreatment has real potential for enhancing the germination of seed that has a low viability or that naturally germinated at a slow, nonuniform rate (e.g. *Abies balsamea* (L.) Mill.).

(3) Height Growth

Promotion Using a PGR to increase stem elongation conceivably would benefit (a) the nurseryman, by enabling seedlings of a given height to be produced in a shorter period, which would reduce production costs, and (b) the reforestation manager, by providing taller planting stock, which would increase the chance of survival in the presence of fast-growing competition.

Ideally the PGR would increase height growth without decreasing the root/shoot ratio. To do so, the PGR must affect a fundamental physiological process such as photosynthesis or root absorption so as to increase dry matter production. Otherwise the PGR can stimulate height growth only by changing the distribution of dry matter i.e. by altering seedling shape.

Stem elongation in a wide variety of conifers is increased by gibberellin (Pharis and Kuo 1977; Kossuth 1981; Heidmann 1982). Unfortunately this increase typically is associated with a reduction in lateral branching, root growth, and root/shoot ratio (Little and Loach 1975). However, in extensive experiments with container-grown Picea mariana (Mill.) B.S.P., Little (unpublished) found that spraying 1000 ppm gibberellic acid once or twice weekly for four weeks near the end of the greenhouse growing period (weeks 12 to 16) produced a taller seedling with minimal undesirable side effects at the time of outplanting, and that the increase was still evident at the end of the growing season. Treatment with gibbereilic acid did not increase the rate of photosynthesis in Abies balsamea (Little and Loach 1975).

The synthetic cytokinin 6-benzylaminopurine, especially when combined with gibberellic acid or a solution of salts, promoted height growth in Pinus palustris (Mill.) seedlings in the grass stage, when stem elongation normally is very small (Kossuth 1981). This PGR also induced the outgrwoth of fascicular buds in Pinus spp. (Cohen 1978; Kossuth 1978) and of auxiliary buds in Abies balsamea (Little, unpublished). Spraying 200 ppm benzylaminopurine on container-grown (Pinus resinosa Ait. seedlings increased the development of both fascicular and terminal buds, while decreasing needle and root growth and the root/shoot ratio (Little, unpublished). However, despite their relatively large terminal bud, treated seedlings did not elongate as much as control seedlings in the next growing season, although they did produce many more lateral branches.

Wort and Kozak (1976) reported that spraying 1-0 seedlings of Pseudotsuga menziesii (Mirb.) Franco, Pinus contorta Dougl., Picea sitchensis (Bong) Carr. and Tsuga heterophylla (Raf.) Sarg. with naphthenic acid (a complex of compounds extracted from petroleum) increased height growth measured. at the end of each of the following three growing seasons. Treatment after the start of shoot elongation gave a better response than treatment when bud development was less advanced. However a second spray applied two years after the first had no effect. Moreover, an active ingredient of naphthenic acid-cyclohexane carboxylic acid, and four closely related compounds, did not promote growth in container-grown (Picea mariana, Picea glauca (Moench) Voss, Pinus resinosa or Larix laricina (Dv. Roi) K. Koch. (Cameron, unpublished work performed at MFRC).

Triacontanol, a naturally-occurring long-chained alcohol known to increase the dry weight of several agricultural species (Ries and Wert 1982), is currently being tested for effectiveness on conifers (Cameron, unpublished).

Inhibition A potential major use for PGRs is preventing shoot and root overgrowth in containers and nursery beds, such as when transplanting is unavoidably delayed or when fast-growing species are being produced. Ideally the inhibition of shoot growth would be temporary, so that bud development on the current-year shoots, hence shoot elongation in the following year, would not be decreased. This application requires a PGR that will inhibit the activity of the subapical meristem and thus decrease shoot elongation without disrupting the function of the apical meristem, which would inhibit leaf and bud development and reduce apical dominance. Several such chemicals (AMO-1618, phosfon, chiormequat, daminozide, ancymidol and ethylene-generator ethephon), referred to as growth retardants, have been discovered and are used routinely to curtail shoot elongation in many ornamental species (Sachs and Hackett 1972; Cathey 1975). Various other chemicals are also known to inhibit shoot growth, but these PGRs (maleic hydrazide, chlorflurenol, ethylhydrogen propylphosphonate) set by killing buds or severely disrputing apical meristem function (Sachs and Hackett 1972). Many growth retardants and inhibitors have been shown to be active on conifers. For example, Weston et al. (1980) surveyed the effects of 13 such PGRs applied to container-grown Picea glauca and Pinus contorta var. latifolia Engelm. seedlings over an eight-week growing period. Some (daminozide, ancymidol) decreased height growth without affecting shoot or root dry weight, others (chlorflurenol) inhibited shoot height and dry weight, while still others (mefluidide, ethylhydrogen propyiphosphonate) reduced growth everywhere in the seedling. AMO-1618, daminozide and chlormequat decreased shoot and root growth in Picea abies Karst. seedlings growth in nutrient solution. (Dunberg and Eliasson 1972). Pharis et al. (1967) reported that height growth was inhibited by daminozide, phosfon and AMO-1618 in Cupressus arizonica Greene, by daminozide and AMO-1618 in Sequoia sempervirens D. Don Endl., and by daminozide and phosfon in Pinus coulteri D. Don. Of the nine PGRs applied to 7- and 8-year-old plantings of Pinus elliotti Engelm. and P. taeda L., only mefluidide reduced shoot elongation without significant associated injury (Hare 1982). Growth retardants and inhibitors have also been used successfully to retard stem elongation in a variety of ornamental conifers (Sachs and Hackett 1972; Cathey 1975; Sachs et al. 1975; Hield 1979).

(4) Stress Resistance

It is well known that photoperiod, temperature, mineral nutrition, and water can be manipulated to increase resistance to frost and drought. However weeks are required to attain the desired hardiness state, and, moreover, the appropriate manipulation often cannot be done in practice. Because hardiness and growth rate generally are negatively correlated, growth retardant and inhibitor PGRs have been extensively tested in the attempt to increase stress resistance rapidly and at will, but the results obtained to date are disappointing.

Frost The successful storage of semen and blood at low temperature suggests that chemicals referred to as cryoprotectants (e.g. glycerol, ethylene glycol, dimethylsulfoxide) might be used to increase frost resistance immediately and at any stage of the annual growth cycle (Howell and Dennis 1981). Such chemicals actually are not PGRs, but are mentioned because they hold such potential. Cryoprotectants have not been tested on conifers, but have been observed to increase frost hardiness in. some fruit-tree species (Levitt 1980a; Howell and Dennis 1981).

PGRs found to be marginally effective in increasing frost hardiness in studies involving agricultural and horticultural species include daminozide, chlormequat, abscisic acid, maleic hydrazide, AMO-1618, ancymidol and ethephon (Levitt 1980a; Howell and Dennis 1981). Daminozide increased hardiness slightly in young roots in Taxus cuspidata Sieb. and Zucc. (Mityga and Lanphear 1971) but not in Taxus X media Rehd. cv. Densiformis (Harrington et al. 1977). Van den Driessche (1970) tested four PGRs on Pseudotsuga menziesii seedlings, but none proved effective.

Drought Post-planting survival and growth would be increased in many instances if dessication could be reduced. Conceivably, PGRs might be employed in two ways:

(1) the PGR could be used to decrease water stress indirectly through increasing the root/shoot ratio, either by promoting root development so as to increase water uptake, or by inhibiting shoot growth so as to reduce the transpiration capacity (Levitt 1980b). Root initiation and growth were promoted by auxin in Pseudotsuga menziesii (Loewenstein et al. 1968), Pinus ponderosa Laws. (Coffman and Loewenstein 1973) and Pinus contorta (Selby and Seaby (Yamaji and Tomioka 1980), by ethephon in Pinus contorta (Weston et al. 1980) and Pseudotsuga menziesii (Graham and Linderman 1981), and by phosfon in Pinus contorta (Weston et al. 1980). Weston et al. (1980) found that several growth retardants and inhibitors increased the root/shoot ratio in Pinus contorta and Picea glauca seedlings, chlorflurenol being the most effective. Chlormequat reduced water loss and inhibited shoot and needle growth in Pinus elliottii seedlings (Asher 1963), while ethephon decreased the transpiration capacity of Pinus taeda seedling by hastening the abscission of 1-year-old needles (Griffing and Ursic 1977). Post-planting survival was not assessed in any of the above-mentioned studies. However, Bacon and Hawkins (1977) reported that spraying daminozide on Pinus caribaea Mor. seedlings in the nursery had no effect on height growth, but did increase survival after outplanting up to 10%.

(2) the PGR could be used to decrease water loss directly, either by inducing stomatal closure so as to reduce transpiration, or by coating the root system with a protective material. A number of chemicals act as antitranspirants, in particular the PGR abscisic acid and various non-PGR film-forming materials (Kozlowski and Davies 1975; Das and Raghavendra 1979). Unfortunately antitranspirants inhibit photosynthesis as well as transpiration, hence generally reduce growth (McClurkin 1974; Davies and Kozlowski 1975; Little 1975). Nevertheless, antitranspirants can be useful when environmental conditions act to severely dessicate the transplanted seedling and survival is more important than maximum growth (Gale et al. 1966; Stoeckeler 1966). Similarly, survival in the presence of poor planting conditions often is increased by employing root dips that contain such non-PGR materials as clay or starch-based polymer gel (Bacon et al. 1979; Goodwin 1982; Whitmore 1982).

(5) Storage and Overwintering

Successful storage of refrigerated lifted stock, and overwintering of field stock, necessitates that the seedlings be fully dormant (hardy) at the start of the storage and winter periods (Garber and Mexal 1980; Roberts and Miskra 1980; Venn 1980). Occasionally however, the seedlings are not dormant when they have to be lifted or when they are hit by an early frost, and. serious losses result. Thus hastening dormancy, and thereby also incidentally extending the fall lifting Period, represents another major potential use of PGRs. Many attempts have been made to impose bud dormancy in deciduous tree species using abscisic acid, but overall this PGR was not effective (Saunders 1978). More promising is Cheung's (1975) finding that ethephon induced the formation of dormant buds in container-growth Tsuga heterophylla (Rafn.) Sarg., although four other inhibiting-type PGRs were inactive.

PGRs may also find practical application in reducing physiological deterioration during overwintering and cold storage. This deterioration is attributable mainly to dessication in overwintering field stock, resutling in "winterkill", or to dessication and the depletion of reserve carbohydrates in refrigerated seedlings. Antitranspirants have been observed to protect overwintering seedlings from dessication injury under some enviromental conditions (Turner and Roo 1974; Ward 1981; Rossow 1982), but have not proved useful in protecting cold-stored stock (Hocking and Nyland 1971). Zaerr and Lavender (1980) reported that exposing autumn-lifted Pseudotsuga menziesii to 5 ppm ethylene during cold storage markedly improved post-planting survival and growth. On the other hand, Hinesley and Saltveit (1980) found that treating spring-lifted Abies fraseri (Pursh) Poir. seedlings with 17.5 ppm ethylene during refrigeration inhibited height growth after outplanting.

(6) Budbreak

By delaying springtime bud flusing in the field, frost damage could be avoided and the lifting period could be extended. Many PGRs have been screened for effectiveness in postponing budbreak in horticultural species, but no active chemical, except possibly for ethylene, has been found (Howell and Dennis 1981). Similarly, no real success has been obtained with conifers. Budbreak was retarded slightly by abscisic acid in Abies balsamea (Little and Eidt 1968) and Picea glauca (Haissig and King 1970), and by maleic hydrazide in Pseudotsuga rnenziesii (Van Lear et al. 1970). However, budbreak was not postponed in Pseudotsuga menziesii by daminozide (Krueger and Tsuda 1968), nor in Abies balsamea by any of the nine PGRs tested (Eidt and Little 1972).

FACTORS AFFECTING RESPONSE

A plant's response to a particular PGR reflects its ability to absorb, translocate, and metabolize that PGR. These processes are affected by the following factors: species, stage of development (eg. seedling dormant or actively-growing; current-year needles immature or mature), method of application (foliar spray, soil drench, injection, bark bandding), dosage (concentration x volume), formulation (kind and concentration of additives), frequency of application, and environmental conditions at and following the time of application (e.g. weather, soil moisture) (for detailed discussion see Sachs and Hackett 1972; Cathey 1975). The multiplicity of these factors and their interactions explains not only why the literature pertaining to PGR effects contains many conflicting results, but also why the response to a particular PGR under a given set of circumstances cannot be predicted with assurance. Since specific recommendations for use cannot be given, and misapplication could. kill the crop, prudence dictates that every PGR be pretested in a small trial under local operational conditions before large-scale application.

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