sowing seeds into the tubes. The company is also doing considerable work on clonal selection, male and female, bud development (to produce more seed from their selected trees) and frost hardiness. Their aim is to increase the volume of timber produced by 100 percent.

It was evident that the large scale of production on many American nurseries gives them an ability to produce plants to a uniform size and high quality. Or could it be that their ability to produce plants to a uniform size and high quality enabled the companies to grow to the size that they are?

POTENTIAL EFFECTIVENESS OF GROWTH REGULANTS ON ORNAMENTALS

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A. The physiology of growth control
B. The types of chemicals with growth regulatory activity
C. Experiences with chemical control of flowering pot plants:
  i. Height retardation
  ii Production of cuttings
D. Experiences with chemical control of nursery stock:
  i Plant shaping
E. The commercial potential of growth regulator chemicals on ornamentals.

A. THE PHYSIOLOGY OF GROWTH CONTROL. The continuing advancement in the knowledge of the physiology and biochemistry of growth and developmental processes in the plant is enabling the plant scientist to explore the potential of chemical growth control with more purpose and precision and to evaluate the many biologically active compounds produced by the agricultural chemical industry. Such chemicals function by supplementing, inhibiting or interacting with the naturally occurring (endogenous) plant growth hormones. The hormone systems control not only developmental processes in plants such as germination, dormancy, flowering, and senescence but functioning within the constraints of the plant's genetic characteristics and under the influence of environmental factors they determine plant size and morphology.

The commercial production of plants in the "so-called" ornamental section of the horticultural industry involves plants of very different growth habit and a wide and physiologically complex range of genera with varying environmental response characteristics. But from the simplest seed-raised annual pot plant to the skillfully propagated exotic tree, there are fundamental chemical control systems which, with increasing experience and the correct "tools of the trade", we are able "in part" to regulate by the application of suitable synthetic chemicals.

An understanding of the types of endogenous plant hormones and their functioning in plants is helpful in the assessment of the potential of growth regulators.

Five groups of hormones are listed below. They are auxin, gibberellins, cytokinins, abscisins, and ethylene compounds. Some of their known functions are listed, but many of their functions are far from specific; frequently the physiological effect of a hormone is the result of its intercellular distribution and its relationship with other hormones at a particular site at a critical growth stage.

ENDOGENOUS PLANT HORMONES

AUXIN	Diverse functions including cell elongation, tropic movement, root differentiation, apical dominance, fruit set.
GIBBERELLINS	Stimulate cellular expansion; mediate in responses to day length and temperature; break dormancy, improve fruit set.
CYTOKININS	Promote cell division; delay senescence, stimulate growth of lateral shoots.
ABSCISINS	Growth inhibitor; involved in abscision of leaves and fruit; induced dormancy; increase cold hardiness; replace short day response.
ETHYLENE	Accelerates maturity and flowering; causes fruit ripening and abscision; causes leaf senescence; promotes lateral shoot development.

For the purpose of this paper let us take a rather simplistic view of some growth processes of horticultural importance.

Dormancy. The onset of dormancy in response to temperature or day-length seems to be correlated with changes in the level of GA. In birch, short-day conditions bring about a cessation of cambial activity within 2-3 weeks of the commencement of the short day. This change is preceded by a reduction in the level of gibberellic acid (GA). Dr. Loach at Glasshouse Crops Research Institute is investigating whether dormancy can be controlled in summer-propagated cuttings by application of GA.

Germination. This process would seem to involve the interplay of all the natural growth substances and, in some species, unspecified inhibitor substances which need to be leached from the seed before germination proceeds. The inhibition of germination of celery seed in the light by abscisic acid has been shown by Thomas (1975) to be alleviated by the application of cytokinins and to a lesser extent by gibberellic acid.

SYNTHETIC PLANT HORMONES

Group	Examples of chemicals	Trade designation
AUXINS	IAA; IBA.	Rooting hormones
	NAA: NAD; TIBA; CPA	Setting hormones
	2,4-D; 2,4,5-T	Herbicides
GIBBERELLINS	GA_3	Gibberellic acid/Berelux
	$GA_4 + GA_7$	Pro-Gibb 47.
CYTOKININS	N^6 benzyladenine (BA)	Verdan
	PBA	SD 8339
ABSCISINS	Abscisic Acid (ABA)	—
	(Morphactins)	(E Merek)

GROWTH REGULATOR CHEMICALS

Group	Examples of chemicals	trade designation
RETARDANTS	ACPC	Amo - 1618
	ACR 1158D	Alden
	Ancymidol	Arest
	Chlormequat (CCC)	Cycocel
	Chlorphonium	Phosfon
	Daminozide (SADH)	Alar/Kylar/B-Nine
	Maleic hydrazide (MH)	MH 30
BRANCH PROMOTERS	Dikegulac - sodium	Atrinal
	NC 9634	(Fisona)
	MB 25.104	(May and Baker)
	PP 528	(ICI Plant Protection)
	SD 8339	(Shell)
PRUNING AGENTS	A 820	(A M Marks)
	Aliphatic Alcohols + NAA	Tipoff
	Fatty acid esters	Off-Shoot-0
	UBI - P293	(Uniroyal)
ETHYLENE COMPOUNDS	Ethephon (CEPA)	Ethrel E.
OTHERS		
Antitranspirants	Polyvinyl resin	S -600/Clarital
	Phenylmercuric acetate (PMA)	-
	ABA	-
Defoliants	Ethephon + KI	Ethrel R.
Sprout suppressants	Tecnazene (TCNB)	Fusarex
	Chlorpropham (CIPC)	Several formulations

Fortunately, horticulturists by their interest and active involvement with trial chemicals at their latest stage of development have been able to quickly take advantage of those chemicals which finally appear on the market, but there has been and will continue to be exciting and interesting chemicals which are withdrawn because of financial limitations.

B. CHEMICALS WITH GROWTH REGULATORY ACTIVITY. The range of chemicals available and undergoing development has, in recent years, considerably expanded. There are now sufficient types of chemicals to provide an effective armoury capable of attacking many plant functions. Below are listed the various groups of chemicals, with a distinction between the synthetic plant hormones and the chemical regulant types. Several of the chemicals exist as coded samples supplied for the development and evaluation purposes with their chemical identity unrevealed. Such secrecy creates difficulties in the scientific evaluation but they are included because they will be referred to in experimental reports. The list is long but in no sense should it be assumed that these chemicals exist because they have potential use on ornamentals. The sights of the chemical companies are set on the major world food crops and, with new chemicals, unless there is such a market outlet their marketability is in doubt.

Production of cuttings. Trials in 1972 indicated that chemicals could be successfully used on poinsettias and geraniums to stimulate branching and this presented the possibility of improving cutting production from mother stock plants. With poinsettias, the cytokinin SD 8339 applied at 750 ppm increased branching by 30%.

In 1973-74 the commercial significance of ethephon treatments to the production of geranium cuttings was tested. Treatments included ethephon applied as a drench of 300 ppm and as a spray of 1200 ppm; in addition, there was a combination of ethephon to improve branching and 2 sprays of 10 ppm GA to enhance extension growth. Records of cuttings taken are shown in Table 1.

Table 1. Cutting Production — Geraniums 1973/74.

	Number of cuttings per plant				
Date	Ethephon Drench (300 ppm)	Ethephon Spray (1200 ppm)	Chlormequat	Ethephon + GA	Control
20 Dec.	9.9	11.8	8.8	12.3	10.2
6 Feb.	16.4	18.4	14.1	18.7	15.8
17 Apr.	29.8	29.5	27.2	33.4	29.5

The combined treatment was successful on the 3 cultivars and the increase in cutting production at the end of the season represented 13.3% overall, with 'Sincerity' showing a 20% increase.

C. EXPERIENCES WITH CHEMICAL CONTROL OF FLOWERING POT PLANTS.

Height retardation. Present production schedules for pot chrysanthemums and, to a lesser extent, poinsettias illustrate very well the integral part growth retardance can play in commercial horticulture and the perfection in control that can be achieved. Since the mid-60's it has become standard practice to retard the elongation on chrysanthemum shoots by using either daminozide or chlorphonium.

Cultivars such as the vigorous Anne types require 2 foliar applications of daminozide at 2,500 ppm or 750 g/c.m. chlorphonium mixed with the potting compost. Work has continued to find chemicals with improved activity and ancymidol was shown to be very effective in trials at the Lee Valley EHS in 1972. Satisfactory height control was achieved with either a drench of 5 ppm or 2 foliar sprays of 100 ppm ancymidol. Dr. Menhenett has found that the retardant Alden, produced by Magg, effectively dwarfed chrysanthemums when applied as a foliar spray at 100 or 275 ppm whereas the compost drench was effective at 10 mg a.i.

Chlormequat is very much part of the standard programme for height control of the Christmas poinsettia crop, either as a repeated foliar application of 1,250 ppm or a compost drench of 2,500 ppm. Work at the Lee Valley EHS showed that an ethephon drench (300 ppm) produced short plants without reduce the size of the bracts. Again, with this crop, ancymidol was extremely active at only 10 ppm.

The introduction of the seed-raised F_1 hybrids of pelargoniums highlighted the advantage in shaping the plant with retardants such as chlormequat, chlorphonium, or ancymidol with the consequential improvement in number of lateral shoots and flower numbers.

Height of Asiatic hybrid lilies can be controlled by compost drenches with chlormequat, ethephon, or ancymidol. Work at LVEHS and GCRI in 1972 reported that ancymidol was effective without reducing flower number.

There has been sufficient experience with the traditional retardant on the main lines of flowering pot plant for reliable recommendations of chemical and of rate of usage to be made. These are summarized below:

RECOMMENDATIONS FOR POT PLANTS

		Daminozide	Chlormequat	Chlorphonium	Ethephon	Ancymidol
Chrysanthemums	Sp.*	2 × 2500 ppm		—	—	200 ppm
	D	—	—	80 ppm	—	5 ppm
	I	—	—	750 g/m^3	—	—
Poinsettias	Sp.	—	3 × 1250 ppm	2	1200 ppm	?
	D	—	2500 ppm	—	300 ppm	10 ppm
Lilies	Sp.	—	—	—	?	?
	D	—	25,000 ppm	?	250 ppm	5 ppm
Pelargoniums	Sp.	—	—	—	—	—
	D	—	2,500	125 ppm	300	50
	I	—	—	1200 g/m	—	—

* Sp. = Foliar Spray D = Compost Drench I = Compost incorporation

In 1975, Cathey published a comprehensive report on the response of 88 species to 5 different growth retardants. In addition to flowering pot plants he included foliage plants, bedding plants, shrubs and trees. The number of species responding to each of the chemicals is shown below:

RESPONSE OF ORNAMENTALS TO RETARDANTS (CATHEY 1975)

Chemical	Year of introduction	Number	Species response
ACPC	1949	5	6
Chlorphonium	1958	12	13
Chlormequat	1960	21	24
Daminizide	1962	44	50
Ancymidol	1970	68	77

Of the 5 chemicals, the newest, ancymidol retarded 77% of those plants tested and showed the widest response spectrum. Daminozide was effective on 50% of the species. Only species of chrysanthemum, rhododendron, phaseolus and salvia responded to all 5 chemicals. None of the conifers, including cypress, juniper, redwood, and yew showed any visual response to the chemicals. Members of the rose family were another group with limited sensitivity to growth retardant type chemicals.

Rooting. Root differentiation was shown by Thimann and Went (1934) to be stimulated by auxin and now the application of a "rooting hormone" has become part of standard horticultural practice. In the propagation of plants from cuttings the presence and proportion of leaves and flower parts on treated cuttings can greatly influence rooting effectiveness, indicating that auxin is not exclusively responsible for root differentiation. The cytokinins may have a regulatory function.

Extension growth. Both auxin and the gibberellins participate in the growth of plant shoots and stems and promote cellular elongation so producing internode extension. It has been demonstrated that the application of GA will stimulate such growth. In tree species vigorous shoots are characterised by a higher auxin content. Retardation of extension growth can be achieved by the application of synthetic chemicals which interfere with the synthesis of auxin or gibberellin.

Apical dominance. Axillary bud development is suppressed by auxin which is synthesised in the terminal apex of the shoot. Removal of the site of synthesis by pinching or pruning techniques releases the control over the growth of lateral shoots, at least temporarily. Usually the growth of a limited number of laterals from axils towards the top of the shoot occurs and these, in turn, regulate the development of laterals further down. The angle at which branches grow in tree species is also auxin-controlled and branches are known to grow more vertically if the apex is removed. Cytokinins move from the root system and are considered to have a stimulatory effect on branch production. This function of endogenous cytokinins has been exploited recently by the use of a range of synthetic chemicals to promote branching.

D. EXPERIENCES WITH CHEMICAL CONTROL OF NURSERY STOCK. With pot plants the main requirement is to control height; with container nursery stock the objective in the use of growth regulant chemicals is to improve the overall shape of the plant, in particular to encourage controlled growth of lateral shoots, to stimulate bud initiation and to reduce production time and labour input. The amount of experimental work with growth regulants on hardy ornamentals in the UK is sparse and of scattered origin. Work by Sachs and Maire (1967) in USA indicated that maleic hydrazide and daminozide were effective as retardants on pyracantha and cotoneaster species. In the early 1970's there was work with TIBA, PBA, and ethephon; the latter two chemicals were found to promote branching of roses. Further work was done with ethephon and formulation was marketed for use in glasshouse roses to improve basal branching. Another area of work was with the chemical pruning agents based on fatty acid derivatives. These emulsions, when applied to plants with buds at a critical stage of development, killed the meristematic tissue. This work resulted in the development of Off-Shoot-0 and Cathey in 1970 published a detailed list of species response and optimum dosage rates.

Bud Initiation. Work by Margaret Scott has been in progress by Efford EHS for the past 4 years on the combined use of high nitrogen and phosphate, with chlormequat treatment, to promote budding in camellias. Two compost drenches of 3000 ppm chlormequat applied during June and July ensured maximum budding in most seasons. Treatments on rhododendrons has been more variable in effect.

Shaping (*Pruning/Pinching*). In 1974 Scott reported on a trial where 2 branch promoters, SD 8339 and NC 9634, had been applied to 1-year-old plants of *Ilex aquifolium*. The application of 5000 ppm NC 9634 in June increased the number of shoots per plant by 50%. At this time this chemical was being extensively tested as a means of improving feathering of maiden fruit trees. Dr. Quinlan reported that at East Malling Research Station that feathering had been increased on 'Comice', 'Bramley' and 'Discovery'. Encouraging results were also obtained on 'Bramley' with the experimental chemicals PP 528, UBI-P 293 and Atrinal. An indication of the longer term potential of trees chemically shaped is obtained from the records taken at East Malling with some trees of 'Bramley Seedling' treated in the nursery in 1971 with the treatments repeated in the orchard in 1972 and 1973. Table 2 shows that in their second cropping year the hand-pruned trees produced fewer flower clusters and fewer fruits than the sprayed trees.

Table 2. EMRS — 1975 Results From Tree Shaping Experiment

	Hand Pruned	NC9634	Off-Shoot-0
Flower clusters per tree	46.8	100.3	88.2
Number of fruits per tree	26.2	44.9	53.5
Crop wt (kg) per tree	5.12	8.60	10.72

As well as the possibility of stimulating lateral growth, Dr. Quinlan's work has shown that unwanted side-shoots can be controlled with the chemicals A 820 and Tipoff applied in May. This work on fruit was encouraging and the results suggested that possibly container-grown nursery stock could be effectively shaped by using this relatively new group of branch promoter chemicals and pruning agents.

Another interesting chemical is under development by Maag of Switzerland. The activity of this compound, dikegulac-sodium (Atrinal) was described in "Nature" (13 November 1975). More recently a comprehensive list of recommended usages has been issued and indicates the potential of this chemical for shaping hardy ornamentals.

Trials were conducted in 1976 by the ADAS Plant Physiology Unit, in conjunction with Horticultural Advisers in Worcester and at Luddington EHS to compare the three types of growth regulants (retardants, branch promoters, and pruning agents) with manual pruning on a range of nursery stock subjects, with the objective of improving plant shape. The treatments applied are shown below:

NURSERY STOCK TRIAL — 1976. Treatments:

Type	Chemical	Concentration (ppm a.i.)
1. Retardant	Daminozide	5,000
2. Branch Promoters	Atrinal	1,000
3. Branch Promoters	Atrinal	4,000
4. Branch Promoters	NC 9634	2,000
5. Branch Promoters	NC 9634	5,000
6A Pruning Agent	Off-Shoot-0	42,000
6B Pruning Agent	UBI - P293	20,000
7. —	Hand Pinched	—
8. —	Control (Untreated)	—

Treatments were applied as foliar sprays on 13 and 26 May to cuttings rooted in autumn, 1975, and grown on in polythene tunnels. The preliminary results of these trials are very interesting; of the three types of regulants, the retardant daminozide has not been effective, and the pruning agents have given variable results, but the branch promoters stimulated branching in at least 7 subjects. Growth asessments were made 8-10 weeks after application. The results for *Forsythia* and *Cornus* are shown in Table 3.

Table 3. Use of Growth Regulants for Shaping Nursery Stock. 1976.

	1. Daminozide 5000 ppm	2. Atrinal 1000 ppm	3. Atrinal 4000 ppm	4. NC9634 2000 ppm	5. NC9634 5000 ppm	6. Off-Shoot-O 4.2%	7. Hand Pinching	8. Control
Forsythia 'Lynwood'								
Shoot number	3.1	8.2	13.0	7.7	7.8	3.2	5.2	2.7
Height, cm	53.4	35.8	29.5	42.9	32.7	48.5	47.3	54.5
Cornus stolonifera 'Flaviramea'								
Shoot number	4.1	12.8	15.4	6.1	8.1	—	6.9	3.4
Height, cm	42.0	29.5	31.8	51.3	48.1	—	40.6	47.8

Atrinal stimulated most branching, with a substantial decrease in overall height of the plant, but there was some interveinal yellowing of the terminal leaves. NC9634 also improved branching. Other subjects showed an improvement in shape at this stage of growth, including *Euonymus fortunei* 'Gracilis' (*E.f. radicans* 'Vareigata'), *Prunus laurocerasus* and *Weigela florida*. Further assessments will be made during the season in order to ascertain whether there are any permanent side effects, foliage markings, or retardation of growth which affect plant quality. The early indications are that Atrinal is an exciting chemical which, with the necessary refinement to timing and rate of application, has the potential to produce the required response. It seems likely that this compound will appear on the UK market as a regulant for retarding and thickening hedgerows in late 1976 and so its marketability would seem assured, thus justifying more detailed trial work.

E. POTENTIAL EFFECTIVENESS OF GROWTH REGULATOR CHEMICALS. Production of Belgian Indica hybrid azaleas is an example of effective use of growth regulant chemicals; the shaping of the plants is achieved by chemicals such as Off-Shoot-0 or Atrinal and bud initiation is encouraged by the retardant Daminozide. There is even recent work which suggests that the cold treatment required to break bud dormancy can be replaced by GA treatment. Such precision is possible with a crop that is produced under very controlled environmental conditions. There is concern that such a reliable effectiveness can be generally achievable on nursery stock. Growing techniques show much variation, e.g. type of cutting material, propagation schedules, compost, nutrition, whether grown under polythene or in the open, whether grown fast or slow. These factors are critical to the plant in its response to exogenously applied chemicals and can effect the uptake and mobility of the chemical.

I am optimistic that on those species where these chemicals are shown to be of real advantage, production systems will be planned for maximum plant response.

Certainly the range of chemicals under development gives the plant scientist flexibility in chemical control. The newest group of branch promoters including NC 9634 and dikegulac-sodium has exciting possibilities. It would seem from the trials to date that the objectives in using growth regulators are now within reach. It is as well to end by restating those objectives for containerised nursery stocks:

1. To improve plant quality
2. To produce a good quality plant more quickly
3. To replace labour intensive cultural procedures for plant shaping with chemical control techniques to reduce production costs.

These objectives are as important to the "cheap" lines produced in quantity as they are to the exotic plant. Chemical control should be used only if these objectives can be reliably achieved at reasonable cost.