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A Review :

Control of height through growth retardants in fruit trees

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In the high density plantation of fruit crops, controlling tree vigour and canopy size are important for enhancing the orchard efficiency and productivity without causing injury to plants. Out of several strategies suggested, use of rootstocks and chemical growth retardants has been found to modify growth, development and increased yield in a number fruit crops. Although dwarfing rootstocks can reduce scion vigour but because of disadvantages like high establishment and management costs and poor anchorage, associated with scions on dwarfing rootstocks, the use of growth retardants may dramatically reduce shoot growth. The response varies with chemical, rate of application, timing, cultivar and vigour.

Even though the problem of controlling tree height in fruit crops is existing from a long era, the situation has become acute and alarming because of growing demand for more fruits as a consequence of increasing population and growing knowledge about the advantages of fruits. The pressure on farmers to produce more fruits per unit area is also visible. The control of plant and organ size can be of great importance in agriculture particularly horticulture. If maximum weight, length, or diameter affects final yield, then an increase in size is desirable. On the other hand, if it would be of commercial benefit, it may be important to be able to reduce the overall size of the plant. High density orchard planting may be possible if a non-noxious plant growth regulator is used to limit vegetative growth.

Tree height can be controlled by two ways :

- Physiologically based methods.
- Horticultural or cultural practice methods.

Physiologically based technique includes use of root stocks, scion, cultivar and tree density. Horticultural control methods include irrigation methods, crop load adjustment, fertilization practices, pruning technique and chemical growth regulators.

Rootstocks, both clonal and seedling origin provide a host of advantages including controlling tree vigour. These root stocks are extensively used in apple, pear, cherry and other temperate fruits. Spur type varieties of apple, peach and sweet cherry are also available. However, these methods of controlling tree height have few disadvantages like all these measures are determined at the time of planting of an orchard. Further more, control of vegetative growth may be inadequate and not satisfactory.

Pruning technique and growth regulators are most commonly used for specific problems of excessive vegetative growth because of their quick effects, ease in application and the desired degree of control.

Chemical control of tree height in fruit trees has played a leading role in recent years which has lead to increase in yield. This can be achieved by certain growth regulators which can alter the distribution of dry matter within the plants so as to increase the economic yield and also enable the plants to adapt to adverse conditions. They can, in effect alter plants growth in a way that virtually converts it to another variety (Mehrotra and Singh, 1972)

Important terms :

Plant hormones :

These are organic compounds other than nutrients, produced by plants which at low concentrations (below 1µ molar) regulate plants physiological processes and without having biocidal effect exercise control on the growth, development, and composition of plants.

Plant growth Regulators / Plant bio-regulators / Plant bio-modifiers :

These are either plant hormones or synthetic compounds that modify plant physiological processes. They regulate growth by mimicking hormones, by influencing hormone synthesis, destruction or translocation or (possibly) by modifying hormonal action sites. Thus plant bio-regulator includes both naturally occuring plant hormone as well as synthetic chemical substances which have hormonal effects when exogenously applied to plants (Hartmann *et al.*, 1997).

Growth Inhibitors :

These are naturally occurring substances in plants which inhibit growth in both shoot and root cells. Abscisic Acid (ABA) is endogenous plant growth inhibitor. Its naturally occuring related substances are 2-trans abscisic acid, phaseic acid, 2-trans phaseic acid, and theaspirone.

Growth retardants :

A group of synthetic bioregulators: Besides the natural phytohormones, the group of bioregulators that modify a plant in its growth and developmental behaviour without including phytotoxic or malformative effects includes synthetic substances known as growth retardants. When used in appropriate concentrations, these compounds influence the plants architecture in a typical fashion, such as (a) inhibition of shoot growth (plants height, internode elongation, leaf area) with unchanged number of internodes and leaves and with intensified green leaf pigmentation and (b) maintained or slightly promoted root growth (main roots often longer and thicker). In both cases the root-shoot ratio is changed in favour of the root.

Apart from the morphological effects of growth retardants a whole series of physiological alterations have been reported that are often seen in connection with an optimized yield formation in various crops. These changes include:–

– Retardation of senescence with enhanced concentration of chlorophyll, protein and mineral elements in the plants tissue.
– Stimulated translocation of assimilates to the seeds.
– Promoted flowering and modified sex expression.
– Reduction of water consumption.
– Improved resistance to environmental stress conditions, eg. cold, heat, drought and fungal infections.
– Improved nutrient uptake from the soil.

Because of these specific properties plant growth retardants have found widespread use in agricultural and horticultural practice. The economically most important applications are:-

– Improving the lodging resistance and canopy structure of crop plants (Cereals, Oil seed rape).
– Reducing the vegetative growth in favour of the generative (Peanuts, Cotton, Orchard tree, Ornamental plants).
– Controlling growth of trees, bushes, hedges and amenity grasses to save trimming costs.

New types of plant growth retardants and their use

Chemical Class	Chemical Name	Common Name	Trade Name	use Growth regulation
Imidazole	1-(2, 6-diethylphenyl)-Imidazole-5-arboxamide	Hoechst	-	Cereals, oilseed rape.
Triazole	b-(cyclohexy (methylene)-a-(1, 1-dimethlethyl) -1H-1, 2, 4-triazole-1-ethanol	Triapenthenol (Bayer)	Baronet	Oil seed rape, rice. (antilodging) ornamental plants.
	(E)-1-(P-chloroprene) -4, 4-dimethyl-2-(1, 2, 4-triazol-1- y1)-1-penten-3-ol.	Uniconazole-P	Sumagic	Prunit Trees, bushes, grasses (antilodging)
	(2RS,3RS)-1-(4-Chlorop-henyl) 4-4-dimethyl-2-1,2,4-triazole-1-yl) 1-Penten-3-ol.	Paclobutrazol PP333	Cultar Bonzi	Orchard trees, ornamental plants,tree bushes.
	1-Phenoxy-3-(1H-1,2,4-triazol-1-yl)4-hydroxy-5,5-dimethyl hexane	BAS 111	—	Oil seed rape.
4-Pyridine	4-Chloro-2(a-hydroxy-benzyl) isonicotinanilide	anabenfide CGR-811 (Chugai)	Seritard	Rice (antilodging)
Pyrimidine	a(1-methylethyl)-a-[4-(trifluro-methyloxy)-Phenyl]-5Pyrimidine-methanol.	Flurprimidol (Elanco)	Cutless	Orchard trees, Ornamental plants.
Norbornano-diazetine	5-(4-Chlorophenyl)-3,4,5,9, 10-Pentaaza-tetra-cyclo-4,5 1, 0^2,6,0^8,11-dodeca-3,9-diene.	tetcyclacis	Kenbyo	Rice Seedling.

Source : Grossmann (1990)

– Improving the quality of seedlings for mechanical transplantation.

Plant height control mechanism :

There are at least 3 basic methods as how plant height is controlled by chemicals.

– By killing the terminal buds or branches or severely inhibiting apical meristematic activity.
– By inhibiting internode elongation without disrupting apical meristematic function.
– Reduced apical control.

Terminal bud destruction :

Some of the most effective inhibitors, maleic hydrazide (MH), triidobenzoic acid(TIBA) fatty acids, ethylene and ethylene releasing compounds such as ethephon and ethyl hydrogen propyl phosphate act by killing the terminal bud or by causing severe disruption in apical meristematic functions(Sach and Hackett,1972). In some species ethylene, TIBA, Napthylpthalamic acid (NPA) and others have been shown to inhibit polar auxin transport. Hence the inhibition of stem elongation observed may reflect reduced auxin level in tissues below the apical meristem, too. These compounds usually alter geotropic responses, cause auxiliary bud break, or induce early leaf abscission as well as reduced stem elongation.

Internode elongation inhibition :

The effect of retardants on stem growth occurs on the subapical region of the shoot tip where cell division and, to a lesser extent, cell elongation is inhibited. Thus, internodes of retardant-treated plants are shorter primarily because they possess fewer cells. Many growth retardants like succinic acid, 2, 2-dimethyl hydrazide (SADH) and 2-chloroethyl trimethyl amonium chloride (CCC or chlormequat) act by inhibiting a specific step in the synthesis of naturally-occuring gibberellins, which is necessary for the maintenance of subapical meristem activity. When such retardants are used, it is possible to reverse the inhibitory effect in intact plants by the application of an appropriate dose of GA_3 (Nickell, 1994).

Reduced Apical Control :

Reduction in plants height can also be achieved by stimulating the growth of auxiliary buds and branches which will compete for minerals, nutrients, hormones and other metabolites thus reducing the growth of main stem. In general, branched plants are shorter than those with a single axis. Application of 6-benzylamino purine and Gibberellin A_{4+7} (Forshey, 1982) and Promalin (6-benzlamino purine plus gibberellins $A_4 + A_7$) (Miller, 1983) increased spur and lateral shoot development. The cytokinins apparently promote growth directly in the auxiliary buds rather than by inhibiting terminal meristematic activity or by inhibiting auxin transport.

Mode of action :

Paclobutrazol :

Among some newer compounds, or new uses for old compounds on different crops, one of the first which should be mentioned is paclobutrazol. This material has been referred to in the literature for quite some time as PP-333. It is growth retardant which, when applied to the soil around the base of apple trees, controls the shoot growth for several seasons with little effect on fruit size. However, the yield of treated trees under some conditions can be increased because of the increased amount of sunlight which now can get to the fruiting spurs. By reducing excessive terminal growth of the shoots, tree efficiency is increased. The explanation is that many plants produce more leaves than are needed for maximum photosynthesis in those leaves beneath them which are shaded. It is apparently absorbed through leaves, stems and roots and is translocated through the xylem (Liyembani and Taylor, 1989). The mode of action of paclobutrazol has been revealed as the consequence of inhibition in the biosynthesis of elongation growth promoting hormone gibberellins, known to be synthesized following isoprenoid pathway. The isoprenoid pathway besides synthesizing gibberellins, also partially regulate the synthesis of other important endogenous hormones such as abscisic acid (ABA) and cytokinins. Considering that the plant growth is regulated by interaction among endogenous hormones and the levels of one hormone influence the level of others, the growth inhibitory response of paclobutrazol could better be explained by changes in the levels of different hormones rather than single hormone (Murti *et al*., 2001). It can be applied to fruits trees by soil drench, truck soil-line pour, trunk injection and foliar sprays (Liyembani and Taylor, 1989).

Maleic Hydrazide (MH) :

It is a systematic plant growth inhibitor which has been shown to inhibit cell division. Some workers have shown that transportation, respiration, and photosynthesis are inhibited by MH.

Chlormequat :

The mechanism of action of the plant growth retardants including chlormequat has been related to inhibition of synthesis or action of gibberellin.

The growth retardant effects obtained with diaminozide are also similar in many respects to those found with chlormequat.

Morphactines :

Further classes of growth retardant are the morphactines that do not only inhibit elongation but stop the apical dominance altering the shape of the plants drastically due to the development of numerous lateral shoots that cause a bushy look. Furthermore, geotropism and phototropism are influenced as well as the development of carpels and stamina. Morphactines obstruct the mitotic activity of meristematic tissues and do thus change the orientation of the mitotic spindle thus inhibiting the usually strictly followed polarity typical for plants. This disturbance is caused by a far-reaching, morphactine- induced stop of auxin transport. The effects of morphactine are normally irreversible.

Dikegulac :

[2, 3:4,6-bis-0-(1-methylethylidene)-a- L-xylo-2-hexulofuranosonic acid]

It is one of the potential plant growth regulators which has been studied extensively on ornamentals and to a limited extent on fruit crops and has been shown to dwarf their size. Dikegulac elicits various responses from different plant organs. When applied to leaves, Dikegulac translocates via the phloem to active meristematic area within 2 days, where DNA synthesis is inhibited. High concentrations destroy terminal buds and auxiliary outgrowth below affected terminal commences almost simultaneously and abruptly stops. It has been shown that foliar application of dikegulac at 2000, 4000 and 6000 ppm at 2^{nd} leaf 'June Gold' peach reduced tree size and increased auxiliary branching (Arnold *et al*., 1983) .Most recently a new class of potent plant growth retardants was found, which derives from a cyclohexanetrione structure. They are suggested to block primarily the 3b-hydroxylation step in the conversion of GA_{20} to GA_1 which is catalyzed by a 2-Oxoglutarate-dependent dioxygenase. As a side effect, inhibition of anthocyanin formation was observed (Grossmann, 1990).

Use of growth retardents in different fruit crops :

Mango :

Murti *et al*. (2001) studied the cumulative effects of three annual soil drenching treatments of paclobutrazol (5 and 10a. i.g/ tree) given to the mango cv Alphonso during months of Aug-Sept and the results revealed reduction in tree heights, mean shoot length and number of dormant shoots and enhancement in flowering. Between the treatments, 10g /tree paclobutrazol treatment was more effective in altering the vigour determining morphological characters. Flowering intensity did not differ much between the two treatments.

Cultar was used to induce flowering in mango cv Langra during off year. It was appiled in both on and off years and effects were more pronounced in off year than on year. The soil application of cultar @ 5g a.i/tree was most effective in inducing more number of flowering shoots and improved fruit set and fruit retention during the off year. Highest fruit yield during off year was recorded under soil application of cultar @5g a.i / tree followed by 10g a.i /tree, the yield being 54.26 and 52.27 kg /tree, respectively (Hoda *et al*., 2001).

Litchi :

Application of cultar (paclobutrazol) significantly reduced shoot growth as compared to the control which resulted in profuse flowering, higher sex ratio, increased fruit set and yield of 'Rose Scented' litchi. The TSS content of litchi fruits was higher in cultar treated trees. Higher dose of cultar (5ml /m^2 plant spread) proved better than the lower dose of 3ml /m_2 plant spread in controlling vegetative flush and increasing flowering and yield. Similarly, cultar application 90days before bud break was found to be more effective than its application 60days before bud break. Paclobutrazol thus holds promise in increasing flowering, fruits set, yield and quality of fruits (Ahmad *et al*., 2000).

Grapes :

Significant reduction in shoot length was observed with three sprays of Maleic Hydrazide (MH 500 ppm at 5 leaf stage followed by 1000 ppm at leaf stage and 1500 ppm at 15 leaf stage) when compared to control. Shoot length was not significantly reduced by any of the 2-chloroethyl trimethyl ammonium chloride (CCC) treatments. None of the treatments reduced the internodal length measured between 5^{th} and 6^{th} ; 10^{th} and 11^{th}; and 15^{th} and 16^{th} nodes significantly when compared to control. However application of CCC at 5 leaf stage was more effective than other treatments in reducing the internodal length between 5^{th} and 6^{th}; 10^{th} and 11^{th}; and between 15^{th} and 16^{th} nodes. Maleic hydrazide (MH) seemed to be more effictive than CCC in increasing the cane diameter in Thompson Seedless grape (Shikhamany and Reddy, 1989).

Pear :

Cultar :

Jain and Bist (1997) reported trunk soil line pour application of cultar(PP333) @ 0.025-1.2g a.i cm^{-1} trunk diameter(TD) at late fall stage in Jan.1994 and again in 1995 controlled vegetative growth, enhanced productivity and fruit quality in 10-11 year old Gola pear (*Pyrus Pyrifolia* (Burm.) Nakai) trees growing in subtropical plains of U.P. Cultar @ 0.3g a.i. cm^{-1} TD lowered the growth to half to one third with more than 1.35 times increase in yield.

Huang *et al.* (1989) investigated the influence of soil applied PP333 (paclobutrazol) technical and PP333 suspension or wettable powder on the growth of some Asian pears. Both the treatments of paclobutrazol supressed shoot growth, mean number and mean length of the shoot internodes, drastically reducing shoot thickness and promoted lateral shoot growth causing slender, horizontally spread shoots.Young 'Clapp's Favorite' pear trees (*Pyrus communis* L.) recieved soil applied paclobutrazol at 6g.a.i per tree in Nov.1983, or foliar sprays of daminozide at 2000ppm or 2 sprays of chlormequat at 1600 ppm in June 1984. Terminal growth was reduced by daminozide and chlormequat the year of treatment and suppressed by chlormequat and increased by paclobutrazol the following year (Embree *et al.,* 1987).

Peach :

Dikegulac :

Arnold *et al.* (1983) reported that tree height and width decreased and lateral branching increased with increasing concentration of dikegulac.

Paclobutrazol and ethephon :

Cultivar 'Crimson Gold' nectarine trees (*Prunus Persica* (L) Batsch) were treated with paclobutrazol (PP333) as a trunk drench and fruits were thinned either by hand or by a spray with ethephon. No Interactions between PP333 and ethephon were found .Vegetative growth was reduced by PP333, both in terms of terminal shoot length and relative trunk girth increment (Blanco, 1990).

Cherry :

Daminozide and ethephon :

In a study to determine possible effects of combinations of ethephon and daminozide on growth, daminozide significantly reduced average terminal growth at 2000 and 4000 ppm. Ethephon significantly reduced growth only the first year of application (Facteau and Rowe, 1979).

Paclobutrazol :

Jacyna *et al.* (1989) concluded that paclobutrazol significantly decreased tree height, canopy diameter, mean shoot length and mean internode length in 'Bing' sweet cherry in the year of application. The paclobutrazol + Promalin gave a most promising result with the branching effect of Promalin and the greater spur promotion of paclobutrazol. The internode-shortening effect of paclobutrazol reduced the length of shoots with the combined treatment, and it would be expected that these short shoots might also produce many flowers.

Apple :

Paclobutrazol and daminozide :

Soil applications of paclobutrazol (PP333) had no effect on vegetative growth of 'Red Delicious' apple, but both PP333 sprays reduced shoot length. There was no significant difference between the single and sequential paclobutrazol sprays. The growth of the daminozide-treated trees was not significantly different from that of those sequentially sprayed with paclobutrazol (Jones *et al.*, 1988). Sterrett (1985) studied the effect of paclobutrazol injected into one-year old trees of 'Golden-Delicious' apple, to evaluate growth inhibition response. The dose of 500µg of ^{14}C-paclobutrazol resulted in significant inhibition of shoot growth after 27days after injection.

Avacado :

Wolstenholme *et al.* (1990) reported that both foliar sprays of paclobutrazol (PP333) and fruiting reduced the length of the spring flush, with the former having the stronger dwarfing effect in both cultivars of avacado. On average, fruiting and non-fruiting shoots were about 40-42% shorter than controls after spraying.

Strawberry :

Investigations carried out on strawberry with certain growth regulators revealed that all the concentrations of both growth retardants *viz.* PP333 and cycocel remarkably reduced crown height, leaf number and leaf area. However, magnitude of inhibition was more at higher concentration. Maximum inhibition of leaf area was 34 per cent in cycocel (1000ppm) treated plants as compared to control (Thakur *et al.,* 1991).

Conclusion :

The use of growth retardants have an important impact on the economic production of fruit crops by incorporating more trees in a given area of land because of their reduced tree height, canopy size and spread. This has resulted in increase in the fruit yield at the expense of only cost of chemical and its cost of application. Thus, the increase in final production is at no extra purchasing of land, no extra tilling of land, no addition of extra fertilizers, no extra weed control or other pest control measures. However, judicious use of growth retardants which have been properly registered and experimented with no harmful effects on humans and environment are only to be allowed for commercial use in agriculture.

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