SESSION 6B

PLANT GROWTH REGULATORS: PHILOSOPHY, PROSPECTS AND TECHNICAL ADVANCES

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THE ROLE OF GROWTH REGULATORS IN ARABLE FARMING

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Summary. Some of the past research work on plant growth regulators in arable crops is discussed. Current uses for growth regulators in arable cropping are reviewed with the results of recent development work. Possible future applications for growth regulators in arable crops are mentioned.

Natural barriers to the development of growth regulator use in arable farming are identified and pointers to improved coordination of research input given.

Plant Growth regulators, arable crops, crop height, lodging, yield components.

INTRODUCTION

Plant growth is controlled by a complex of chemical hormones within the plant. The production of these materials within the plant will be regulated in response to major external factors such as temperature, light, water or nutrient supply. The identification of some of these materials from plants has enabled us to produce chemical analogues which provide similar responses in the plant to their natural counterparts.

Although we are still perhaps only touching the surface in our understanding of these materials and their activity a number of practical uses are already well established. Thus the development of auxin substitutes has provided the basis for the production of selective herbicides such as 24D, MCPA and CMPP. These materials interfere with the plants natural growth control mechanism causing a massive surge in uncontrolled growth eventually resulting in the plants death.

This paper will be limited to discussion of these materials which are used to achieve modifications in growth but not the destruction of the plant. Humphries (1967) defined growth regulators as "either naturally occurring or synthetic chemicals that, when applied to plants in small amounts, change the form of the plant by altering the relative properties of its component parts".

GROWTH REGULATORS IN AGRICULTURE

The manipulation of crop growth could be attractive for many reasons. Thomas (1979) identified 6 major areas where growth manipulation could be beneficial (Table 1).

Table 1

Major Aims of Manipulating Crop Growth

Aims	Some Benefits
Increased yield	- earlier crops; better land and fertiliser use.
Improved uniformity	- predictable harvest; improved marketability.
Improved quality	- better texture, taste and odour; improved storage.
Improved harvestability	- reduced losses; increased mechanisation.
Improved storage characteristics	- increased continuity of supply; reduced imports.
Modified post-harvest behaviour	- quicker turnover; less wastage.

Plant growth regulators (PGR's) have found by far their greatest application in horticultural production - notably in fruit and ornamentals but also in vegetable production (Table 2).

Table 2

FAO Production Figures and Major Growth Regulator Uses

Crop	Production 1977 (million tonnes)	No. of PGR uses (PGRWG 1977)
Cereals	1459	2
Roots and tubers	570	2
Vegetables (including sugar)	318	7
Fruit	257	16
Berries and nuts	3	2
Pulses	48	1
Ornamentals and nursery stock	-	9
General growth control	-	8

Source: Plant Growth Regulator Working Group Handbook 1977

Many of the applications in fruit production involve the use of materials which generate ethylene gas, widely used in fruit ripening. Since the effective agent is a gas which naturally occurs in ripening fruit there is little risk of any residue problems.

Growth regulators can have a major role to play in fruit thinning, or "stopping" the apical growth of vegetables, where major savings in labour can be achieved.

In arable cropping commerical use of growth regulators has been limited to two main areas, sprout suppression in stored potatoes and lodging prevention in cereals.

Most successful applications of PGR's have one thing in common - they have one clear objective. Thus the use of chlormequat has primarily been used to reduce stem length in cereals or ornamental plants; indole acetic acid is used to generate root growth in cuttings and ethephon to promote ripening in tomatoes and other fruits. All these objectives can be attained - however they may effect other yield parameters in a beneficial or adverse way.

The use of growth regulators is less reliable where the stated objective is less precise. Although auxins may be used to reduce fruit number or chlormequat to influence tiller number in cereals, there are at least two practical difficulties for the farmer in this type of use: He needs to forecast future weather conditions in order to predict the optimum configuration while the plant has the ability to compensate for these externally applied chemical "orders". Both tend to make this type of growth regulator use less reliable for the arable farmer.

GROWTH REGULATOR EFFECTS ON ARABLE CROPS

Potatoes

While sprout suppressants are now well accepted in potato storage PGR's are not normally used during the growing season.

Gibberellic acid (GA) has been shown to have a similar effect to high temperature in promoting haulm growth and suppressing tuber production, (Menzel 1980) while ABA and chlormequat had the opposite effect.

GA has also been shown to reduce dormancy in potatoes, to speed up emergence, increase the number of stems and increase the yield of the seed tuber fraction (Marinus 1978). However, higher concentrations of GA can have an inhibitory effect on tuber yields (Radwan 1976).

Increased yield of the seed potato fraction was also recorded following the application of Daminocide (Kamand 1980).

While chlormequat has been shown to reduce haulm growth and increase tuber yield effects vary with different varieties. Other work has shown that chlormequat is translocated and stored in the underground parts of potatoes. Seed tubers harvested from these plants produced temporarily dwarfed plants (Dekhuijzen 1973). Chlormequat is also able to overcome the inhibitory effect of high temperatures on tuber production (Menzel 1980). Further research is obviously needed before routine use of foliar growth regulators can be advised where a reduction in haulm may in some varieties reduce yield.

It is interesting to speculate on the areas where PGR's may find a future use in potato production. For example it may be possible to manipulate seed physiological age using a PGR without the use of expensive heating. It may be feasible to accellerate the curing process and so reduce losses in potato processing. Varieties which are known to throw few or many tubers may be manipulated by chemical regulators to improve the yield of the ware fraction. Materials with the ability to reduce stolen retention could have a major application in ware production by speeding harvest and reducing tuber damage.

SUGAR BEET

Humphries and French (1965) showed that rate of leaf production was affected by chlormequat and by GA but that dry matter production was unaffected. The conclusion was that dry matter production was more dependent on size and longevity of leaves than on total leaf number.

Jaggard (1982) identified three main areas where growth regulators might be used to increase the yield of sugar beet.

(1) to enlarge leaf area early in the growing season;
(2) to increase the conversion ratio of light energy to dry matter;
(3) to alter the distribution of dry matter within the plant so that a larger proportion is stored as extractable sucrose.

In Laboratory investigations he showed that an improved root/shoot ratio and root dry matter yield could be attained using a new material - PP333.

Unfortunately in field trials root and sugar yields were not increased. The midifying effects of climate and soil on growth regulator activity is reflected in many arable crop situations and underlines the need to test these materials in field trials as well as in the laboratory.

It would seem on present information that materials stimulating early growth of best plants, be they physical (as in transplanting - or polythene mulching) or chemical, offer the best chance of increasing root and sugar yield.

FIELD BEANS

There have perhaps been fewer successes with the use of growth regulators in legumes than in other crops. This in spite of the apparent importance of plant hormones particularly auxins in determining pod retention and seed number. The field bean is an indeterminate plant so that competition for assimilates between immature pods and continuing vegetative growth is thought to be the major factor limiting yield.

Termination of new vegetative growth either by mechanical or chemical means could enable commercial yields to be increased significantly. However, to date, suitable materials are not available for this purpose.

Developments in the breeding field to produce a determinate bean plant offer the greatest hope for yield increases in the future.

OIL SEED RAPE

In addition to yield losses from pest and disease attack, reduction in yield potential can occur through pod abortion and pod shatter. Serious lodging may further reduce yield through shading or increased disease levels, but a moderate amount of leaning may prove beneficial in reducing seed losses through wind damage.

It has been estimated that the harvest index of oil seed rape is in the order of 0.15 to 0.28 compared with cereals at .35 to .5. (Daniels 1982). It would appear therefore that there is some room for improvement in the rape crop.

Measures therefore which would reduce pod abortion, seed shedding or lodging could improve the seed yield of this crop. The above worker reduced plant height in 1980 with ethephon + mepiquat chloride while chlormequat had some influence on yield components but did not produce a yield response. Similarly ADAS trials in 1980 showed little effect on yield from the use of PGR's.

In 1981 work at Bridgets EHF (ADAS 1982) reduced crop height, increased pods per plant and seeds per pod. Yield response and yield components are shown in Table 5. Preliminary results for 1982 indicate a similar trend but a somewhat lower response than in 1981. It is suggested that better pod survival was the reason for these yield improvements in 1981. With an increase in pod number and seeds per pod, it may be expected that seed size may be reduced but differences were not significant. Further field trials results from other centres are needed before any recommendation can be made for the commercial use of growth regulator materials in oil seed rape. Materials claiming to reduce pod shatter have not reduced losses from this cause in ADAS trials.

If severe lodging can be reduced by these materials through shortening the rape straw then further yield benefits could accrue.

Table 3

Growth Regulator Use on Winter Oil Seed Rape. Results 1981 (second year)

Treatment	Yield t/ha at 92% DM	Pods per plant	Seeds per pod	Mean seed wt mg	% oil on DM
Control	2.49	117.7	13.88	5.40	42.6
mepiquat chloride	2.70	110.1	14.30	5.74	43.6
mepiquat chloride + ethephon (2.5 litre)	2.87	127.4	15.75	5.32	43.8
mepiquat chloride + ethephon (3.5 litre)	2.76	126.3	17.37	5.20	43.5
Late N	2.61	139.3	13.16	5.56	42.7
ethephon (1 litre/ha)	2.73	135.2	16.02	5.14	44.0
ethephon (1.5 litre/ha)	2.74	133.4	16.03	5.43	43.4
chlormequat (as Podquat) (Autumn)	2.62	120.8	15.35	5.37	44.0
chlormequat (as Podquat) (Spring)	2.65	129.0	15.07	5.66	43.8
SE	±0.083	±16.48	±1.423	±0.198	

Source: Results of ADAS Agriculture Service Experiments, Other Cash Crops 1981 29 Part 3 (in preparation)

CEREALS

The two main areas of growth regulator use in cereals are the use of GA in promotion of germination in barley malt production and the use of growth retardents in lodging prevention.

The use of growth regulators in cereals is well documentated and has been closely associated in the past with the use of chlormequat to prevent lodging in wheat and oats. Mean yield responses in winter wheat of 0.66 t/ha were reported on lodging sites and 0.18 t/ha in the absence of lodging by Caldicott (1978). More recently mean yield responses of 0.78 t/ha were obtained in ADAS trials in 1980 through reduction of lodging in winter wheat.

However there have in all these trial series been occasions where yield reductions have occurred. Thus in 1979, 9 out of 14 ADAS trials gave reduced yields following the use of chlormequat on winter wheat. This may have been associated with the dry conditions during July in that year when grain filling was taking place. One of the aims of development work, therefore, must be to identify the causes of these reductions and to exclude them where possible from commercial recommendations.

Two factors have reduced the risk of lodging in winter wheats; the first is the production by plant breeders of shorter, stiffer strawed varieties and the second the introduction of fungicides with the ability to control eyespot. The justification for the use of chlormequat as a lodging preventative in winter wheat has therefore been limited. However, long strawed varieties still retain a place in commercial production and here the use of chlormequat may be justified as a straw strengthener.

There are a number of situations also where this material is used as an insurance against lodging in very high yielding short strawed wheat crops. This is an area where collaborative experimental data is decidedly lacking. The use of low rates of chlormequat is certainly cheap for the farmer to use (half rates may cost as little as £3 or £4 per hectare) but there is little evidence to suggest that they are more effective in strengthening straw or safer to the crop.

Similar yield responses to those in wheat have been obtained in winter oats and winter rye. In spring barley, however, little benefit was found from this material. Alcock (1966) showed that in wheat chlormequat is readily transported to all parts of the plant. Movement in barley however, is of a much lower order, the material remaining mainly in the treated leaf and its sheath. This difference was not due to lack of absorption but to differences in the translocation mechanisation of barley compared with wheat. The use of chlormequat on barley was not, therefore, persued in early commercial and development work.

Materials based on mepiquat chloride and ethephon, which were shown to be active in reducing straw length in barley, were introduced in 1978 and reawakened interest in the barley crop.

Yield response to these materials has been good on sites where lodging has occurred. (Table 6). Materials applied at flag leaf emergence Zadocks 37 generally providing the biggest yield response on varieties Igri and Sonja. In contrast in ADAS trials the variety Maris Otter has given greatest response to materials based on chlormequat applied before the start of jointing. Responses in the absence of lodging have been of a lower order and have frequently not been economical (Woolley 1981) although Sonja has produced some useful responses to ethephon + mepiquat chloride in the absence of lodging.

Much of the current research and development work is directed not at shortening and strengthening straw but at increasing other favourable growth parameters.

Koranteng (1982) increased yield of spring barley through the use of chlormequat by increasing mainly shoot number. He also demonstrated the ability of CCC to reduce the apical dominance of the main tiller resulting in a more even tiller size while GA had the opposite effect. Hutley Bull (1982) demonstrated the ability to simulate the effects of day length on growth of spring and winter wheat through the use of GA and CCC. Where fertile tillers or grains per ear are increased by growth regulators the cereal plant may be unable to fully supply this increased sink on all but the most fertile soils.

Table 6

IGRI Winter Barley - Response to Growth Regulators - Lodging Sites 1981

Yield Benefit Tonnes/Hectare (85% DM)

IGRI	N kg/ha	Chemical Product Control Yield t/ha	Chlormequat HELESTONE AUT	Chlormequat HELESTONE SPRING	Chlormequat CYCOCEL AUT SPRING	Chlormequat BARLEYQUAT SPRING	ethephon + mepiquat chloride TERPAL 32	ethephon + mepiquat chloride TERPAL 37	ethephon CERONE 37	ethephon CERONE 49	SED ±	CV %
ROSEMAUND	100	6.93	0.09	0.62	0.38	0.89	0.87	1.13	0.43	0.83	0.357	5.9
	150	7.23	0.27	0.15	0.33	-0.18	0.34	0.31	0.40	0.11		
BOXWORTH	165	7.09	0.03			-0.08	0.16	0.65	0.61	0.81	0.232	3.8
	205	7.08	0.02			0.24	-0.03	0.79	0.68	0.51		
NEWCASTLE	140	5.20	0.22			0.32	-0.22	0.33	0.15	0.55	0.34	6.7
	175	5.16	0.25			0.02	0.06	0.02	0.15	0.41		
BEDFORD	150	5.61		0.66	0.39	-0.01	0.91	0.66	0.04	0.32	0.207	6.0
	196	5.36		0.35	0.61	0.39	0.68	0.78	0.51	0.82		
NORFOLK AG STATION	140	6.59	0.17	0.19	0.16*	0.31	0.32	0.72	0.39	0.59	0.146	3.7
	200	6.14	0.24	0.61	0.73*	0.85	0.68	0.70	1.03	1.10		
No. of trials		(5)	(4)	(3)	(3)	(5)	(5)	(5)	(5)	(5)		
MEAN	N1	6.28	0.13	0.49	0.38	0.29	0.41	0.70	0.32	0.62		
	N2	6.19	0.19	0.37	0.56	0.26	0.35	0.52	0.55	0.59		

_____ = significant yield increase
----- = significant yield decrease
( ) = number of trials
* = material used = Titan

Source: Results of ADAS Ag Service Experiments Cereals 1981. 29 part I In preparation.

If this competition for assymilates results in a reduction in grain size the marketability of the crop could be reduced in a time of rapidly increasing grain production.

The role of hormones in the control of grain development within the ear is receiving attention particularly in Germany. The better understanding of hormonal control of plant ear and grain development is currently the source of much research. However, much of this work has yet to be developed to show commercial application in the field.

Other areas which have been suggested might have a growth regulator solution are in prevention of sprouting in the field and in straw ripening. Both could help improve harvestability.

Very high grain yields are closely associated with depth of soil, moisture availability and leaf persistance. It is perhaps in the areas of root development and leaf delayed leaf senescence that growth regulators offer the greatest hope of yield improvement. Prolonging active life with P.G.R. or fungicide can itself bring problems with delayed straw ripening and grain sprouting and suggest other avenues of P.G.R. development.

DISCUSSION

Opportunities for growth regulator use in arable farming are limited by large gaps in our understanding of plant hormone activity, by our inability to control the crop environment and by the need to provide a harvested crop free of harmful residues.

Our understanding of the role of plant hormones in controlling plant growth is still incomplete and consists largely of isolated pieces of research which fail to be completely integrated. Much of our recent research success has been in plant breeding which may reduce the need for any artificial manipulation of growth with chemical regulators.

The nature of P.G.R's is that extremely small quantities are needed to manipulate plant growth. For commercial companies to take an interest therefore the material must have an application for a major world crop or there will be no chance of recouping development costs. This is especially so where full toxicity examinations are necessary for treated food products.

There are two directions that this situation may encourage commercial companies to follow one is to withdraw resources from the P.G.R. field completely. The second is to promote new formulation of old products, perhaps applied at different timings, but with the minimum of inputs into further research.

This is a retrograde step and could do the farming and chemical industries much harm. It is to some extent the result of farmer demand for new growth regulator uses often before relevant research work is completed.

The solution to this conflict is I am sure the closer association between research, development, advisory, commercial and educational establishments. It may lead in the short term to the reduction in personal "esteem" of individual establishments or companies. It must lead to greater understanding of the role and application of P.G.R's in agriculture.

For this part of the industry to succeed finance must be forthcoming from farmers, chemical companies and government services work must be initiated - not duplicated - at educational, research, development and commercial levels. It must be well designed and carried out where possible in collaboration with other units to maximise the outturn of useful data. Communication must be active and participative by all concerned.

There are several bright stars on the horizon; the formation of the Plant Growth Regulator Group as a forum for workers in all fields of P.G.R. work: the British reawakening of ARC interest in P.G.R. work in cereals through the unit at Long Ashton. The formation of an informal group of workers to better co-ordinate the work of the universities, research and the agricultural development and advisory service; and finally the increasing interest in the chemical industry in funding research work particularly at universities - who knows where it will end?

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THE REACTION OF DIFFERENT WINTER BARLEY VARIETIES TO AN APPLICATION OF THE PLANT GROWTH REGULATOR - MEPIQUAT CHLORIDE/2-CHLORO-ETHYLPHOSPHONIC ACID

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Summary. Ten varieties of winter barley were evaluated with a plant growth regulator based on mepiquat chloride and ethylphosphonic acid (BAS 09800W) in the years 1979-1981. Prevention of lodging resulted in a yield increase of approximately 0.6 t/ha and lodging susceptibility was directly related to plant height. There was no clear relationship between yield increase and yield components. The six row varieties showed either a higher weight per thousand grains (TGW) or an increased number of grains per ear. Two row varieties of high tillering potential showed a tendency to produce a higher plant density and/or a higher TGW. Lodging reduction, grain weight, thousand grain weight, yield, yield components.

INTRODUCTION

Mepiquat chloride/ethylphosphonic acid (BAS 09800W) is applied to barley during the period of maximum stem and ear extension. During this growth phase, Zadoks GS 32-49, there is competition between the vegetative and generative parts of the plants for assimilates, nutrients and water. At this time, yield components are determined with tillers being reduced from approximately 2000 per m^2 to a number dependent on soil type and variety. In addition the supply of assimilates at this time dictates the proportion of potential grain sites in each ear, determined in the previous autumn, which actually fill. A growth regulator applied at this growth stage may therefore improve lodging resistance, and as a result indirectly the TGW and influence plant density and/or the number of grains per ear.

The objective of this work was to relate the use of BAS 09800W on a range of winter barley varieties of contrasting straw length and relate this to yield and yield components.

METHODS AND MATERIALS

The growth regulator BAS 09800W (Terpal) contains the active ingredients mepiquat chloride (305 g/l) and 2-chloro-ethylphosphonic acid (155 g/l). It was applied once annually at 2.5 l/ha in 400 l/ha of water, at a pressure of 0.25 mPa during the stem extension phase, Zadoks GS 37-39, in the years 1979-1981 inclusive.

The varieties of winter barley chosen were; the two row varieties Igri and Sonja, which exhibit good to medium standing power and large grain; the six row varieties Doris, Banteng and Dura which are tall and weak strawed; Ogra, Vogelsanger Gold, Birgit and Mammat, which have medium/weak straw, Gerbel, early maturing with stiff straw and large grain. All varieties are currently grown in Germany.

Crop height was assessed at flowering on five random samples per plot and lodging just prior to harvest using a 0-100 scale (0% = no lodging, 100% = completely lodged). The number of ears per m^2 was estimated immediately prior to harvest, using 8 random samples taken from a 1 m row in each plot. TGW was determined on sub samples taken at harvest and the number of grains per ear calculated from the final yield and other components of yield. Plots were 12.5 m^2 in area, replicated 4 times and on a split plot design.

Results

Plant height, lodging and yield. The height of all winter barley varieties was reduced by BAS 09800W and as a result resistance to lodging was significantly improved. Variation in weather between the three years resulted in effects on stem extension differing between years; in 1979 the reduction in straw length was less than in other years.

Table 1

Mean plant height (cm), lodging score (0-100%) and yield t/ha after application

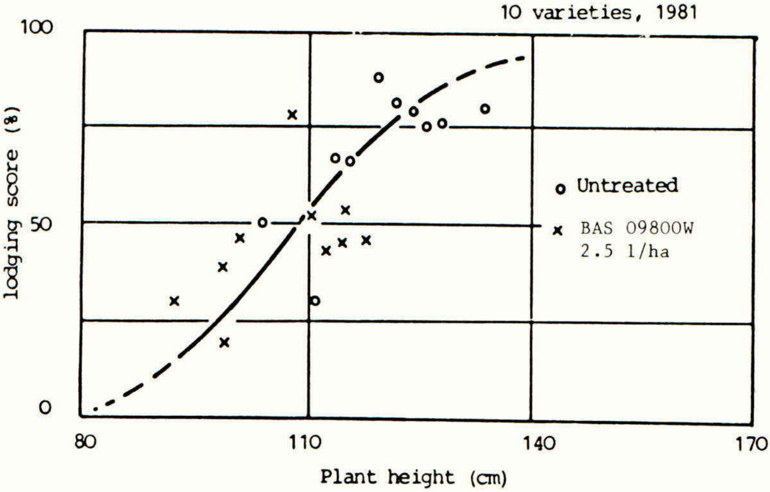
	Plant Height		Lodging Score		10 varieties Yield	
Year	Control	BAS 09800W	Control	BAS 09800W	Control	BAS 09800W
1979	120	110 +	47	19 +	6.50	7.01 +
1980	122	104 +	57	19 +	8.83	9.60 +
1981	120	107 +	66	44 +	6.12	6.59 +

+) statistic significant at $p \leq 5\%$

Resistance to lodging was related to shorter and thicker stems and also to increased yield, but without any varietal interaction. Plant height was directly related to the lodging score (Fig. 1) and it is assumed that the shortening effect of BAS 09800W is more important than effects on stem thickening, which was not measured here but is known from previous work (Behrendt et al 1978).

Figure 1

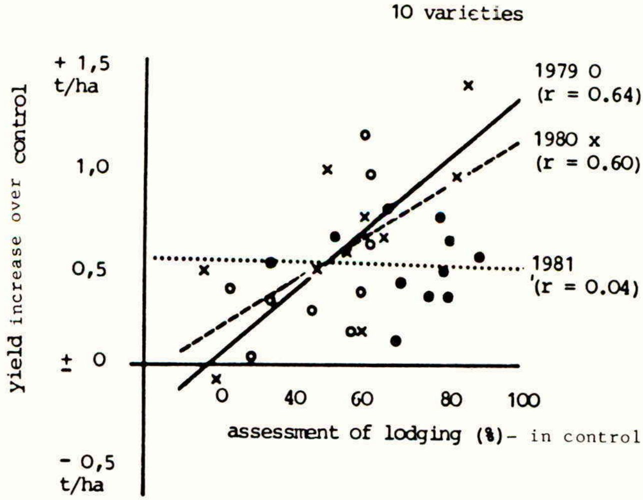
Assessment of lodging of winter barley varieties as a function of plant height



The effect of BAS 09800W on yield increases with the severity of lodging. In all years, except 1981 when mean lodging even after treatment was high (Table 1) there was a positive correlation. Even in 1981, the application of BAS 09800W increased yield by 0.47 t/ha (Table 1). This poses the question, which factors are responsible for the yield increase? Is it factors associated with the prevention of yield loss or increased activity positively influencing yield by improving TGW, or grain set.

Figure 2

Yield response to BAS 09800W of winter barley varieties affected by different degrees of lodging



Effects on Grain

If we assume the yield increase to be associated with reduced losses, then an increase in ear weight can be expected. The correlation between lodging and TGW (Fig. 3) was not significant (r = 1979 - 0.15, 1980 + 0.36, 1981 + 0.51. The relationship was not a sensitive index of grain filling relative to lodging.

Figure 3

The effect of BAS 09800W on the 1000 grain weight of winter barley varieties with different degrees of lodging

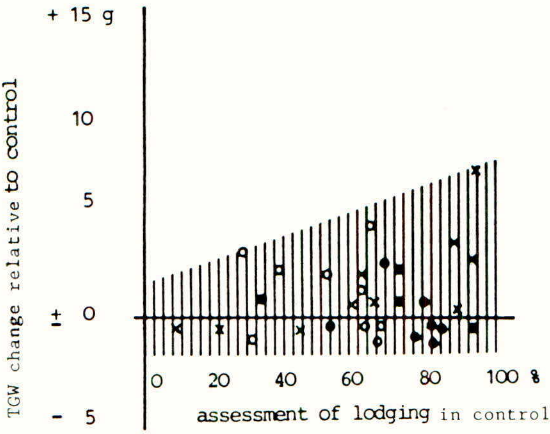


Table 2

The effect of BAS 09800W on TGW (g); mean of 10 varieties

TWG (g)		
year	control	BAS 09800W
o 1979	41.5	42.5 +
× 1980	35.5	36.6 +
• 1981	37.7	37.8

significant at p ≦ 5 %

In figure 2 a yield increase was recorded at low lodging pressure while in 1981 there was a yield response unrelated to lodging.

It is necessary therefore to examine relationships between yield components.

Table 3

The effect of BAS 09800W on the number of mean ears/m^2, grains/ear and thousand grain weight - mean of 3 varieties*

	Ears/m^2		Grains/ear		TGW	
Year	Control	BAS 09800W	Control	BAS 09800W	Control	BAS 09800W
1979	519	512	42.1	42.4	31.3	33.7 +
1980	753	781	38.9	40.4 +	30.3	31.8 +
1981	526	553	39.2	41.7 +	30.9	32.9 +
$\bar{x}$	599	615	40.1	41.5	30.8	32.8 +

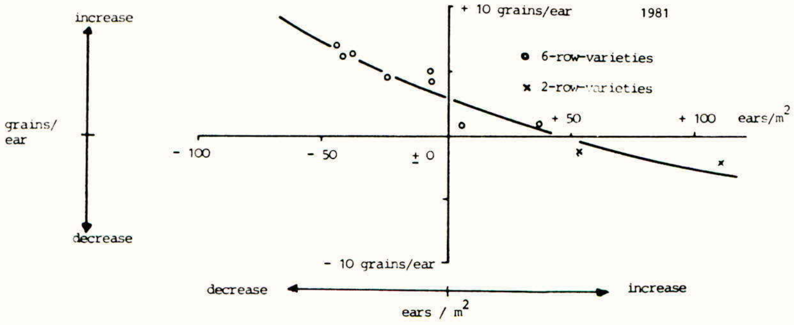
+ significance at $p \leq 5\%$.

Measurement on three selected varieties (Doris, Dura, Sonja) (Table 3) showed significant effects of BAS 09800W on TGW and the number of grains per ear. There was a tendency for the number of ears/m^2 averaged for the three varieties (Table 3) to be higher. 2 and 6 row varieties reacted differently (Fig. 4). In 1981 the above components of yield were estimated for all varieties.

* Only 3 varieties assessed for logistical reasons.

Figure 4

The relationship between the differences (treated - control) in ears m^2 and grains/ear due to BAS 09800W



DISCUSSION

Lodging reduces grain yield by reducing TGW and associated grain size. In view of the relationship between yield and lodging it is to be expected that the yield increases achieved as a result of the application of growth regulators would be associated with an improved TGW (Behrendt et al 1978; Stanca et al 1979; Knittel et al 1981; Herbert 1981).

There must also be other physiological effects associated with reduced dominance in main tillers. These may be associated with improved penetration and distribution of sunlight in the canopy of the shorter plants. This would enhance assimilation by the lower leaves and the growth of dominant tillers, especially in varieties with a high tillering capacity. With increasing tiller numbers the average number of grains per ear decreased although the number of grains per m^2 increased. In 6 row varieties the reduction in straw length coupled with an alteration in the distribution of assimilates may be responsible for a better grain set.

In conclusion, the application of BAS 09800W increased the number of grains per m^2 and where lodging occurred, produced an improved thousand grain weight.

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DIMETHIPIN: A UNIQUE PLANT MATURITY REGULATOR FOR RICE AND SUNFLOWER

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Summary. Dimethipin is a unique plant maturity regulator that has been tested extensively on a variety of crops since 1972. In addition to its activity as a cotton and grape defoliant and potato haulm desiccant, dimethipin also accelerates certain maturation processes in sunflower and rice. Dimethipin applied late season to sunflower and rice foliage at 0.28 to 0.56 kg a.i./ha will reduce the seed moisture content at harvest time, allowing for a predictably earlier harvest and/or a controlled field drying with consequent reductions in artificial drying costs. No significant adverse yield or quality reductions have been noted when dimethipin was applied at an appropriate stage of plant maturity. Dimethipin, plant growth regulator, maturation regulator, seed moisture reduction, crop maturity, sunflower, rice.

INTRODUCTION

'Harvade^{R}' is the registered tradename for the unique synthetic plant growth regulant dimethipin* (2,3-dihydro-5,6-dimethyl-1,4-dithiin 1,1,4,4-tetraoxide). Dimethipin has been tested extensively since 1972 on cotton and grape as a defoliant, on potato for haulm desiccation, and most recently on sunflower and rice as a maturity accelerant. Numerous reports have been published concerning dimethipin as a cotton defoliant (Ames *et al*., 1974; Hegman 1982; Neidermyer *et al*., 1974 and Sarpe *et al*., 1975), a grape vine defoliant (Costa and Intrieri, 1981) and a potato haulm desiccant (Bell *et al*., 1974; Cremaschi and Vender, 1977; and Neidermyer *et al*., 1974). This paper contains the first public discussion of the activity of dimethipin for reducing the preharvest moisture content in sunflower and rice seed in the field.

By chemically lowering the seed moisture content of rice and sunflower in the field, two important harvesting advantages are theoretically possible: (1) a controlled schedule harvest may be undertaken, which allows optimum utilization of mechanical and human resources, and (2) the cost of artificial drying may be reduced, because the crop can be dried more thoroughly and more quickly in the field. The trials conducted thus far indicate that dimethipin application can result in good moisture reduction in both sunflower and rice seed without loss in quality and yield.

*Common name (ANSI; ISO-proposed). Other designation: UBI-N252.

METHODS and MATERIALS

In each of the trials below, dimethipin was formulated in a 600 g/l flowable concentrate.

1) SUNFLOWER - EFFECT ON SEED MOISTURE (Table I)
Dimethipin and paraquat were diluted in water and applied to the foliage by airplane to one hectare plot in 50 l/ha approximately 28 days before estimated harvest. Replicated seed heads were harvested at random within the treated plot. The seed heads were thrashed and the seed tested (capacitance meter) for moisture content at 0, 14, 21 and 28 days after treatment (DAT).

2) SUNFLOWER - EFFECT ON SEED MOISTURE AND OIL CONTENT (Table II)
Dimethipin was diluted in water and applied at a volume of 300 l/ha to replicated plots with a ground spray applicator approximately 28 days before harvest. Sample heads were harvested from each of the replicates and thrashed and tested for moisture (capacitance) and oil content, as indicated in Table II.

3) RICE - EFFECT ON SEED MOISTURE, YIELD, AND MILLING QUALITY (Figure I & Table III)
Dimethipin was diluted in water and applied with a small plot sprayer to the foliage of rice plants in 45 ca plots replicated four times in a randomized complete block design. For comparison, the standard chemical treatment was sodium chlorate in a commercial formulation. Seed heads were harvested from one centare blocks in each replicate at 0, 5, 10, and 16 days after treatment. These samples were thrashed and tested for percent seed moisture. Subsequently, the samples were air dried to 12 to 14 percent seed moisture and milled in a McGill sample mill. Head rice percentages were obtained by removing the broken kernels from the total mill fraction with a Satake separator.

RESULTS

Sunflower: The dimethipin and paraquat treatments caused a reduction in seed moisture at all testing dates. The paraquat treatment, however, took on moisture during and after the rains. Both chemical treatments would have allowed a 7 day earlier harvest if no rainfall occurred. Due to the rainfall, harvest of the paraquat treated plots would have been delayed to after that of dimethipin.

Table I

SUNFLOWER - EFFECT ON SEED MOISTURE (%)

Treatment	Dosage (kg a.i./ha)	Days After Treatment 0	14	21[a]	28
Untreated	-	35	29.5	18.7	15.5
Dimethipin	0.56	35	15.7	10.4	9.3
Paraquat	0.28	35	15.7	11.9	13.5

[a]Intermittent rainfall at 16 through 23 DAT. cv: Dalgren 809

This trial was established to determine whether dimethipin could reduce oil content if applied earlier than physiological maturity. The data suggest that it is feasible to apply dimethipin at up to 52% seed moisture and obtain an 8-10% moisture reduction without drastically reducing the oil content of the seed.

Table II

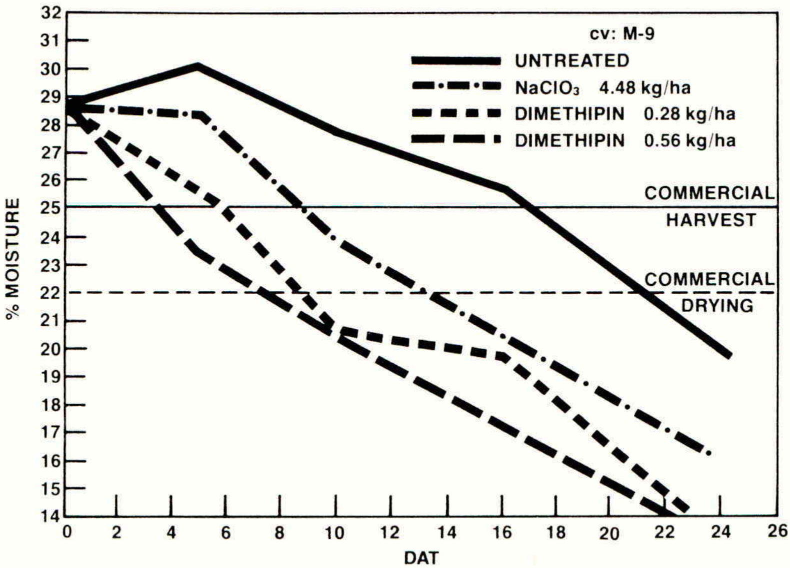
SUNFLOWER - EFFECT ON SEED MOISTURE AND OIL CONTENT

cv: Hybred 907E

Treatment	Dosage (kg a.i./ha)	Days After Treatment 0	5	12	20	% Oil Content At Harvest
Untreated	-	52	41.2	30.4	15.7	32.8
Dimethipin	0.5	52	39.0	10.7	7.9	32.3

Rice: Dimethipin and sodium chlorate both reduced seed moisture faster than occurred in untreated plots. In typical rice culture, harvest could have begun (at 22 to 26 percent moisture) about 12 days sooner in dimethipin treated plots than in the untreated and 4 to 6 days sooner than those treated with chlorate.

Figure I
RICE—EFFECT ON SEED MOISTURE (%)



Although both dimethipin and sodium chlorate slightly depressed grain yield from these plots, these reductions were not statistically significant ($p = 0.05$). Likewise, the milling data indicated that dimethipin had no effect on total mill yield or head rice percentage.

Table III

RICE - EFFECT ON MILLING QUALITY AND YIELD

cv.: M9

Treatments	Dosage (kg a.i./ha)	Milling Quality % Head Rice	Milling Quality % Total Rice	Rough Rice Yield MT/ha
Untreated	-	60	65	10.2
Dimethipin	0.28	60	64	9.3
Dimethipin	0.56	60	66	9.7
Sodium Chlorate	4.48	59	64	9.6

DISCUSSION

All evidence accumulated to date strongly indicates that dimethipin enhances maturity in all the species mentioned above: cotton, potato, grape, sunflower and rice. This enhancement in cotton and grape is manifested when the leaves abscind in a green, turgid condition, after the rapid development of a well-defined abscission zone at the petiole base. The evidence of maturation enhancement on potato is a slow "natural-like" senescence of the haulm without the rupturing of cell walls, good skin set on the tubers, reduced incidence of vascular ring spot and (perhaps) late bulking-up of the crop. The accelerated maturation of sunflower and rice takes form in a reduction in seed moisture without gross tissue destruction. The sunflower and rice phenomena are described in greater detail below:

Sunflower: If dimethipin is applied when the sunflower seed moisture is 40-50%, no visual sign of maturation will likely occur for at least 5 days. At this point, those leaves that are still green will begin to yellow. The bracts also start to become lighter in color. In contrast, paraquat treated tissues turn brown immediately after treatment. The bracts are light to dark brown and an eventual shrinking of the entire head is often noticeable.

Since the gross morphological effects of dimethipin application are gradual and subtle, the best evidence that dimethipin treatment is actually working to accelerate maturity on sunflower is to measure the seed moisture decline curve. Five to seven days after treatment, the seed moisture of treated heads is reduced by at least 3% when compared with untreated controls. Seed moisture will continue to consistently decline until harvest. In contrast, the moisture content of a paraquat treated head may be similarly reduced, but also may fluctuate significantly depending on rainfall after treatment. The difference between the two chemicals may be that the dimethipin treated head is slowly catabolizing, whereas the tissue from a paraquat treatment is moribund and is more or less acting simply as a sponge for exogenous moisture.

In sunflower culture, the seed are harvestable at a moisture content as high as 20 to 25% (Schuler *et al.*, 1978). In most of our trials, a satisfactory harvest moisture was obtained 7-10 days earlier with dimethipin treatment than when untreated. Such response is desirable since it should allow the grower to have greater control over the harvest, allowing him to schedule his harvest for greatest ease and efficiency. Furthermore, preliminary projections indicate that dimethipin could be used to increase the field drying potential of the crop and to reduce the requirement for artificial drying by 33 to 50%.

Rice: The visual effects of dimethipin on rice foliage are similar to those of sunflower. In contrast to sunflower, however, the seed head (panicle) soon turns completely brown while the foliage often remains a pale yellow. Since the plant is not harshly desiccated, the stem strength is maintained to resist preharvest lodging. Desiccants such as sodium chlorate, while also reducing seed moisture, frequently do so at the expense of stem weakening or brittleness and subsequent lodging.

Research trials indicate that dimethipin applied at 0.28 - 0.56 kg a.i./ha can result in commercial harvest at the usual 22 to 26% moisture (Steffe *et al.*, 1980) approximately 4 to 10 days earlier than in untreated fields. As with sunflower, no reduction in yield or quality have been noted when dimethipin was applied at the proper stage of plant maturity.

In areas where precipitation during the harvest season is a common occurrence, such as in tropical areas or in the Mississippi Delta region of the U.S., the potential benefit of dimethipin on scheduling is significant. Use of dimethipin could make possible better harvest scheduling, so as to take advantage of favorable weather and to increase use efficiency of harvest, drying, storage, and shipping equipment and facilities. In addition, use of dimethipin may also permit more extensive field drying of the crop, reducing the need for expensive artificial grain drying without significantly altering crop quality.

The physical and toxicological properties of dimethipin have been reported elsewhere (Ames *et al.*, 1974 and Hegman, 1981). All indications are that dimethipin is safe to handle and apply late in the season on crops such as rice and sunflower.

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SOME FURTHER RESULTS ON EGYT 2250

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Summary. EGYT 2250 was applied pre and post-emergence in field trials of corn, pea, tomato and sunflower, post-emergence to greenhouse red pepper, lettuce and cucumber, and as a seed dressing to rice. In the field trials growth and cropping were increased at certain rates within the range 1.4 - 7.2 kg/ha. Yields of the greenhouse crops were generally increased, especially of cucumber. Seed dressing improved plant growth. PGR, rice, corn, sunflower, red pepper, tomato, pea, cucumber, lettuce.

INTRODUCTION

In 1980, the PGR EGYT 2250 (heptoparcil), ± -2-propargyloximino-1,7,7-trimethyl-bicyclo-2,2,1-heptane) was reported as a seed dressing for corn and sunflower and as a pre-emergence application for tomato and red pepper. Growth promoting effects were observed in both the vegetative and generative stages (Kis-Tamas et al, 1980).

This paper presents new results of the effects of EGYT 2250 (50% EC formulation) applied pre and post-emergence and as a seed dressing.

Results on efficacy, toxicity, spectrum of activity, mode of action, application and phytotoxicity have been submitted for registration.

METHODS AND MATERIALS

In all applications the formulation EGYT 2250 50 EC (a 50% w/w emulsifiable concentrate) was used. All rates given in the text are of active ingredient. Seed dressing: A combined seed dressing of EGYT 2250 and two fungicides benomyl and mancozeb was applied to rice seeds. The seed was treated by placing into a dragee-pan, rotating the pan and wetting the seeds with an aqueous solution of a binding agent plus an aqueous emulsion of EGYT 2250 at rates of 50-300g/2L of emulsion/100 kg of seed. The seed was dried in an air current at Tmax 40°C.

Pre-emergence and post-emergence applications: Applications were made using either a hand precision sprayer at pressures of 2-4 kg/cm² or a Van der Weij type logarithmic sprayer which varied the application rate between 0.1 and 10 kg/ha at a pressure of 2 kg/cm². Spray volumes were 250-600L/ha. In all trials there were four replicates.

Field trials: Pre and post-emergence applications were made to corn, peas, tomato and sunflower. Sowing or planting took place on the 12th May and the post-emergence treatments were applied to 40 m² plots, using the Van der Weij sprayer, on the 23rd June. Soil type was a clay loam. Compared with EGYT 2250 treatments were plots treated with the liquid nutrient Wuxal^R Schering AG (9%N. 9% P_2O_5, 7% K_2O + Fe,Mn,B,Cu,Zn,Co,Mo and vitamin B_1).

Greenhouse trials: Small plot trials of post-emergence treatements were conducted under plastic tents, in 1981:-

Red Pepper'Fehrer ozon' (a Hungarian type paprika). Seed was sown on the 14th March and treatments applied thirteen days later to 1m² plots. Application rates were 0.10, 0.25, and 0.75 kg/ha applied at a volume of 300L/ha. The soil was a sandy loam.

Lettuce 'Lucia'. Up to three applications at rates of 0.10, 0.25 and 0.50 kg/ha were made as described in table 1.

Table 1.

The dates of application of EGYT 2250 to lettuce

No. of applications	Date applied
1	7th April
2	7th, 13th April
3	7th, 13th and 23rd April

The plants were harvested 27-28 days after the first application, from 2m² plots, 108 plants per plot. The growing medium was a 1:1 mixture of peat and perlite.

Cucumber 'Budai felhosszu' (Hungarian type). Plants, in 2m² plots, were sprayed twice (14th and 24th May) during the flowering period. The soil was a clay loam.

RESULTS

Table 2.

The effects of pre-emergence applications of EGYT 2250 on four field crops

Rate kg/ha	Corn ear yield	Peas fresh weight	Peas pods number	Peas pods weight	Tomato fruit yield	Sunflower ear yield	
8.9	108	100	100	100	104	95	% of control
7.2	113	100	107	97	103	98	
5.7	117	101	108	99	103	91	
4.5	118	100	101	107	109	99	
3.6	127	96	100	100	115	98	
2.8	128	100	106	105	124	96	
2.25	129	100	118	118	123	96	
1.8	136	101	117	117	114	93	
1.4	129	105	110	96	108	100	
1.15	110	100	100	101	103	100	

Pre-emergence treatments gave increases in corn ear yield at 1.4-3.6 kg/ha, in pea pod number and weight at 1.4-2.25 kg/ha, and in tomato yield at 1.4-4.5 kg/ha, and in tomato yield at 1.4-4.5 kg/ha (table 2).

Post-emergence treatments (table 3) gave increases in pea pod number and weight at 1.4-4.5 kg/ha, in tomato yield at 3.6-7.2 kg/ha, and in sunflower ear yield at 2.8-5.7 kg/ha. Rates of application above 4.5 kg/ha were usually either ineffective or less effective than lower rates. The relative effectiveness of pre and post-emergence applications varied between crops; ear yield increased more by pre-emergence application in corn and by post-emergence application in sunflower.

Table 3.

The effects of post-emergence applications of EGYT 2250 on four field crops

Rate kg/ha	Corn ear yield	Peas fresh weight	Peas pods number	Peas pods weight	Tomato fruit yield	Sunflower ear yield
8.9	101	97	100	100	103	100
7.2	104	97	106	107	124	110
5.7	110	103	106	107	124	111
4.5	107	104	127	117	112	115
3.6	107	114	126	127	127	117
2.8	110	127	121	124	104	118
2.25	108	126	114	114	108	104
1.8	115	122	113	114	114	103
1.4	108	100	114	100	108	100
1.15	101	100	114	100	110	100

% of control

Table 4.

Comparison of the effects of EGYT 2250 and Wuxal

Rate kg/ha	Corn ear yield g Pre-em EGYT	Corn ear yield g Pre-em WUXAL	Peas pods weight g Pre-em EGYT	Peas pods weight g Pre-em WUXAL	Sunflower 1000 seed weight g Pre-em EGYT	Sunflower 1000 seed weight g Pre-em WUXAL
8.9	751	733	460	460	75.0	75.0
7.2	783	723	492	467	82.0	75.0
5.7	810	697	496	469	83.6	75.7
4.5	817	711	464	459	86.5	74.8
3.6	878	737	460	460	87.8	75.0
2.8	887	715	486	471	88.7	78.0
2.25	894	742	543	479	77.5	76.1
1.8	943	671	538	487	77.1	76.5
1.4	830	757	502	467	75.0	75.0
1.15	761	731	460	470	75.0	75.0
LSD	5.30		2.67		2.93	
P	0.05		0.05		0.05	

EGYT 2250 increased yields relative to the Wuxal treatment in almost all cases, but especially with pre-emergence applications to corn. Differences were greatest in the ranges 1.4-5.7 kg/ha for corn, 1.4-2.25 kg.ha for peas and 2.5-7.2 kg/ha for sunflower.

Table 5.

Effect of EGYT 2250 on fruiting of red pepper.

Rate kg/ha	Fruit yield kg/m^2	% of control
0	10.9	100
0.1	10.75	98
0.25	12.05	110
0.75	13.25	121

Rates of 0.25 and 0.75 kg/ha increased fruit yields of red pepper by 100% and 21% respectively.

Table 6.

Effect of multiple applications of EGYT 2250 to lettuce

Rate kg/ha	Number of applications	Yield g/plant	% of control
0	-	92.5	100
0.1	1	99.0	107
	2	116.9	126.3
	3	132.5	143.2
0.25	1	109.0	117.8
	2	115.3	124.6
	3	94.6	102.2
0.5	1	97.2	104.9
	2	102.1	110.0
	3	100.8	108.9

Multiple applications of the 0.1 kg/ha rate gave the greatest increases in lettuce yields (table 6), although single and double applications of the 0.25 kg/ha rate were also effective. Applications at 0.5 kg/ha were generally less effective than the lower rates.

Table 7.

Effect of EGYT 2250 on cucumber yield. kg.

Harvesting dates	Control	Rate 0.5kg/ha	1.5kg/ha	2.5kg/ha
28.05	0.11	1.36	0.18	0.31
01.05	0.35	0.74	0.41	0.51
04.06	0.13	0.39	1.16	0.34
11.06	0.28	0.44	1.27	0.46
18.06	0.00	0.84	0.85	0.43
22.06	1.12	0.00	0.82	0.73
29.06	0.00	0.31	0.26	0.33
05.07	0.00	0.64	0.33	0.41
09.07	0.54	0.16	0.36	0.66
22.07	0.00	0.09	0.10	0.30
13.08	0.3	0.00	0.11	0.56
	2.83	4.97	5.85	5.04
% of control	100	175	206	178
L.S.D.		0.37	2.26	1.60
P		0.05	0.05	0.05

Both total and early yields are greatly increased over the range of rates used (table 7) with increases greatest, on average, at the 1.5 kg/ha rate.

Table 8.

Effect of a seed dressing of EGYT 2250 on the germination, height and fresh weight of rice plants.

Treatment	Rate kg/t	Germination %	Height %	Fresh-weight % of control
Untreated	0.0	100	100	100
benomyl + mancozeb	0.5 0.8	96	107	111
benomyl + mancozeb + EGYT 2250	0.5 0.8 1.0	97	137	217
benomyl + mancozeb + EGYT 2250	0.5 0.8 3.0	101	123	209

EGYT 2250 applied as a seed dressing at 1 or 3kg/t of rice seed, in combination with benomyl and mancozeb increased both the height and fresh weight of plants, and had no effect on germination.

DISCUSSION

These new results are similar to those previously obtained with different crop/application combinations (Kis-Tamas, 1980). EGYT 2250 is effective on a range of crops, applied either pre-emergence, post-emergence or as a seed dressing, and can increase both growth and cropping. It is envisaged that pre-emergence treatments could be combined with pre-emergence weed control.

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AN INTEGRATED APPROACH TO THE CHEMICAL CONTROL OF FRUIT TREE GROWTH AND CROPPING

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Improvement of regularity of production of quality fruits and the development of improved systems of production, are major research objectives reflecting the needs of the modern fruit industry. Clearly, good husbandry must form the basis of improved methods of fruit growing but plant growth regulators have an important part to play both in improving productivity of existing plantings and in the development of more efficient systems.

The trend towards higher density planting in fruit growing has highlighted the need for new methods to control tree growth and cropping. Ideally, fruit trees should fill their allotted space as rapidly as possible, thus giving high cropping potential from an early stage in the life of the orchard. The level of cropping during the early years is important because the success of many modern planting systems depends upon early cash returns to off-set the high capital cost of orchard establishment.

As trees fill the available space, the control of inter-tree competition becomes an important objective. Although pruning and dwarfing rootstocks may be used to contain tree growth, these methods are often inadequate, pointing to the need for an effective and safe chemical control method.

An additional problem facing the fruit grower is year-to-year variability in cropping. A major factor contributing to this variability is variation in the level of fruit set.

Fruit set and retention are under hormonal control suggesting exogenous application of appropriate growth regulators to be a logical approach to the control of fruit numbers.

Although there are many examples of the use of growth regulators to control growth and cropping of fruit trees, these treatments have tended to be used in isolation. Recent developments indicate potential use for more integrated growth regulator systems in the management of fruit trees.

FORMING THE YOUNG TREE

The quality of trees used to plant an orchard is a major factor determining not only the rate at which the orchard becomes established but also the level of productivity in the early years (van Oosten, 1978). The main criterion of quality which the grower recognises in a nursery tree is the presence of branches (feathers) at a height which makes them suitable to form the initial branch framework of the orchard tree.

Branching of nursery trees may be influenced by a number of factors such as the virus status of the tree and the standard of nursery management but an over-riding influence is the cultivar; many cultivars of several tree fruit crops consistently fail to branch adequately in the nursery or produce branches which are poorly positioned so that they are unsuitable for forming the primary branch framework when the tree is transferred to the orchard.

1. Branch induction in the nursery

Several research workers have demonstrated that branching of young trees may be stimulated by treatment with growth regulators such as mixtures of gibberellins and cytokinins (Williams and Billingsley, 1970), maleic hydrazide (Baldini et al., 1973) and long-chain fatty acid esters (Quinlan and Preston, 1973). Auxin transport inhibitors also stimulate branch production and one of these, n-propyl 3-t-butylphenoxyacetate (M&B 25-105) is commercially available in the U.K. for use on young apples and pears (Quinlan, 1980). Examples of the effect of this branching agent in improving the quality of nursery trees are shown in table 1.

Table 1

Chemical induction of branching in nursery trees. Number and total length (cm) of branches produced following June spray treatment with 3×10^{-3} M n-propyl 3-t-butylphenoxyacetate

		Untreated		Treated	
		No.	Length	No.	Length
Apples:	Spartan on MM106	0.5	21	3.9	159
	Bramley on MM106	2.6	29	6.9	296
	Crispin on M26	3.2	45	9.3	254
Pear:	Conference on QA	0	-	9.1	268

Branches thus produced provide sites for the production of flowers and crop in the early years (Table 2).

Table 2

Influence of a nursery treatment with the branching agent n-propyl 3-t-butylphenoxyacetate on subsequent flowering and cropping. Spartan apple on MM106

Nursery treatment	Total length of branches at planting (cm)	Fruit crop 3rd yr Flower clusters per tree	Crop (kg)	Mean fruit wt(g)
Untreated	7	25.7	6.6	140.6[a]
Treated	162	50.3	11.1	133.6[a]

(In this and subsequent tables, differences within columns are significant at the 5% level except those with the same letter)

2. Removal or retardation of the growth of unwanted branches in the nursery

The height at which branches are produced by the nursery tree is important. Although many cultivars naturally branch freely, branches are often produced too near the base of the tree. These low branches must be removed when the tree is planted in the orchard because they interfere with orchard management operations such as herbicide application. The basal branches are usually the largest ones and their removal represents a loss of potential fruiting points.

If incipient low branches are removed by hand from nursery trees during early summer, more and longer branches are produced in the upper part of the tree (Preston, 1968). Similarly, application to the lower part of the tree of a non-translocated growth retardant such as n-secondary-butyl-4-tertiary-butyl-2, 6-dinitroaniline results in the production of more usable branches and more precocious and prolific flowering and cropping (Table 3). Although no chemical is yet commercially available for this purpose the potential benefits are clear.

Table 3

Growth retardant* application during June to unwanted low branches on nursery trees of Cox's Orange Pippin on M26. Influence on production of useful branches (above 55 cm height) in the nursery and flowering and crop in the second orchard year

Treatment to lower 55 cm of nursery tree	Branch production above 55 cm No.	Total length (cm)	2nd orchard year No. flower clusters	Crop (kg)
Untreated	12.1	434	41.6	3.91
Growth retardant*	14.6	647	70.5	7.03

*n-secondary-butyl-4-tertiary-butyl-2, 6 dinitroaniline

Growth regulators therefore offer considerable potential for improving nursery tree quality which, in turn, greatly influences early orchard productivity.

GROWTH REGULATOR USE ON ORCHARD TREES

1. Induction of early cropping

In the past, when trees were more widely-spaced, they were encouraged to grow strongly in the early years, by heavy pruning, which tended to delay the onset of cropping. As orchard densities increased there was a need for much earlier cropping, to help check tree growth and to enable the grower to recoup as early as possible the high capital costs of orchard establishment. Although the use of dwarfing or semi-dwarfing rootstocks tends to induce precocity, young trees often crop poorly due either to inadequate flower production or to poor fruit set as a result of competition from vegetative growth (Quinlan and Preston, 1971). Growth regulators can be used to overcome these deficiencies. For example, treatment of young trees with daminozide (succinic acid-2-2-dimethylhydrazide) may improve flower production and fruit set (Luckwill, 1978). Chemical branching agents may also be used on young trees to increase the number of fruiting points (Quinlan and Preston, 1978); when applied to Bramley's Seedling apple during June in the second and third years, branching agents substantially increase flowering and cropping in the fourth year (Table 4).

Table 4

Comparison of effects of hand pruning and chemical branching treatments on growth and cropping of Bramley's Seedling apple

	Total no. shoots/tree (2nd and 3rd years)	4th year No. flower clusters	4th year Crop (kg)
Hand pruned	110.6	68	9.5
Chemically branched*	163.5	158	18.5

*4 x 10^{-3}M n-propyl 3-t-butylphenoxyacetate applied during June in the second and third years.

2. Chemical control of tree growth

The need for a growth regulator to control the growth of cropping trees is well established. In addition to controlling excessive shoot growth which might otherwise adversely affect fruit set and retention, its use to control inter-tree competition would be a valuable aid to orchard management. Beneficial effects would also include reduced shading within the tree, thereby improving fruit quality and flower bud formation (Jackson, 1975) and a reduction in the amount of hand pruning necessary.

Use of NAA paints on pruning cuts can greatly reduce shoot regrowth after pruning (Blanco and Jackson, 1982) and so contribute to general control but overall control by a chemical spray treatment would have additional advantages.

At the present time overall growth retarding chemicals are used to only a limited extent in U.K. orchards. Although not yet recommended for use on cropping trees in this country, chlormequat ((2-chloroethyl) trimethylammonium chloride) has been used in several European countries to control the growth of pear trees to improve regularity of cropping and to reduce the amount of hand pruning necessary.

No suitable overall growth retardant is commercially available for use on apples and stone fruits. The use of daminozide for controlling the growth of cropping apple trees is limited because of undesirable effects on fruit size, when applied early in the season during the period of most shoot growth; in addition, longer-term fruit storage quality may be adversely affected by this growth regulator, particularly in the case of Cox's Orange Pippin.

The absence of an adequate range of size-controlling rootstocks for plums and cherries, coupled with the lack of effective chemical methods to control shoot growth has made the problem of tree size control a major factor contributing to the decline in acreage under these crops over recent decades. However, recent developments give cause for optimism. Although still at the experimental stage a range of new growth retardants offer great potential for the control of the growth of orchard trees. When tested on a range of fruit crops, long-lasting control of tree growth has been obtained with little or no adverse effects on the growth of fruits of most cultivars tested.

The most widely tested member of this group of triazole-type growth regulators is the coded material PP333 (2RS,3RS)-1-(4-chlorophenyl)-4,4-dimethyl-2-(IH-1,2,4-triazol-1-yl)pentan-3-ol (paclobutrazol, BSI proposed common name, May 1982). Table 5 shows an example of its effects on the growth and cropping of strongly-growing 4-year-old Bramley's Seedling apple. When sprayed to the point of run-off at three weeks after full bloom, paclobutrazol reduced shoot growth by 58% without significantly reducing fruit growth. When applied to young cherry trees this growth retardant was twice as effective in reducing shoot growth when compared with application of the equivalent amount of daminozide (Quinlan, 1981).

Whereas the trees treated with daminozide grew more strongly than the controls in the year following treatment, those sprayed with paclobutrazol continued to grow more slowly than the untreated trees.

Table 5

Effect of spray application of 6.8 x 10^{-3}M paclobutrazol, 3 weeks after full bloom, on growth and cropping of Bramley's Seedling apples on M9

	Crop		Shoot growth	
	kg	Mean fruit wt (g)	Total (m)	Mean length (cm)
Untreated	6.74[a]	327[a]	38.7	29.8
Paclobutrazol	6.54[a]	316[a]	16.2	15.0

Paclobutrazol is readily taken up by the root system of trees. When applied at full bloom to the soil surface around the bases of young cherry trees this growth regulator caused a 60% reduction in the amount of shoot growth produced during the season (Table 6). This soil treatment was as effective as treatment with the equivalent amount of chemical applied to the foliage.

Table 6

Comparison of soil and foliar application of paclobutrazol to young cherry trees. Sweet cherry Bigarreau Gaucher on F12/1

	Shoot growth	
	Total (m)	Mean length (cm)
Untreated	32.7	54.8
Paclobutrazol: 1.2 g/tree, soil application (full bloom)	13.3[a]	25.0
1.2 g/tree, foliar application (3 weeks after F.B.)	12.2[a]	23.8

The most effective time of soil application to control the growth of apple and other fruits has yet to be determined but this method could be a very useful alternative to foliar application, particularly for large trees, the tops of which are easily missed by a spray.

In addition to affecting tree growth paclobutrazol also frequently stimulates flower production which in turn may affect cropping levels. The triazole growth retardants are now being extensively tested in orchard trials. Although these trials are centred on the control of growth of conventionally grown trees, others are designed to test potential uses in new, novel systems, such as the control of growth of scions on their own roots.

CHEMICAL INDUCTION OF FRUIT SET

Fruit development is largely under the control of hormones produced by the fertilized ovules and young seeds within the ovary.

Environmental conditions adversely affecting pollination or ovule development often have major effects on yield.

There are many examples of the use of hormone treatment of flowers or fruitlets to improve fruit set when environmental conditions are unfavourable. Of the temperate fruits, pears tend to be the most responsive but fruit set of apples, plums and cherries may also be improved by hormone treatment. The main component of fruit setting hormone mixtures has usually been gibberellic acid (GA_3). Some crops such as Conference pear (Luckwill, 1960) and Bramley apple (Modlibowska, 1972) set better following treatment with GA_3 alone, but other apple cultivars (Goldwin, 1981), cherries (Goldwin and Webster, 1978; Webster et al. 1979) and plums (Webster and Goldwin, 1978) respond better to mixtures containing GA_3 with a cytokinin and/or an auxin.

Although the chemical induction of fruit set has important practical implications a problem limiting the more widespread use of fruit setting hormones is variability in response. The level of response varies from species to species, and within a species, is influenced by factors such as cultivar (Webster et al., 1979), rootstock (Blasco et al, 1982) and flower quality (Goldwin, 1981). The underlying reasons for this variability in response are still largely unknown.

FRUIT THINNING

Fruit thinning is carried out for several purposes. Young trees are often thinned to prevent over-cropping which might otherwise check tree growth too severely, but the most frequent use of chemical thinners is on more mature trees to control fruit quality. Over-cropping of mature trees results in the production of fruits which are too small to be commercially acceptable. An additional purpose for fruit thinning is to ensure adequate flowering the following year. It is generally accepted that gibberellins produced in the seeds inhibit flower bud formation so that the presence of a large number of fruits on the tree tends to limit the number of flowers produced during the following season. Thus, the need for regularity of cropping and high fruit quality makes fruit thinning an essential part of orchard management practice.

The benefits of thinning fruits by hand are well established but this method is too costly to have widespread use. Many chemicals have been shown to thin blossoms and/or fruitlets but most have produced variable results under U.K. conditions. Although regarded as not always consistent in effect, the insecticide carbaryl is the most reliable material available for the range of apple cultivars grown in this country (Knight and Jackson, 1980).

CONCLUSIONS

It is clear that growth regulator treatments applied in the nursery to improve maiden tree quality can result in large beneficial effects on orchard establishment and on cropping in the early years. Consequently, application of a branching agent to nursery trees of poorly branching cultivars is becoming an integral part of orchard planning and preparation.

Although the planting of good quality trees favours early cropping, supplementary treatment with a growth regulator such as daminozide is often beneficial in ensuring adequate flower production by the young tree. These treatments are becoming widely used in young apple orchards but there is a need for suitable treatments to improve precocity of other fruit crops, particularly stone fruits.

It is generally recognised that fruit set and retention may be adversely affected by competition for available substrates between the developing fruits and other growth centres in the tree. Chemical treatments which limit tree growth would be expected to favour crop production. When growth retardants are used to control tree growth these often increase both flower production and fruit set; this is particularly the case with the new triazole growth regulators. In these circumstances it is therefore important to regulate the level of cropping in order to maintain fruit size and quality, by the use of fruit thinning agents when fruit set is excessive.

Cropping levels are often adversely affected by poor weather during blossoming. As progress is made with fruit setting hormone treatments to counteract this constraint to cropping, these treatments may play an important role in reducing year-to-year variability in cropping which is the major problem facing the British fruit grower.

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PRE-HARVEST DEFOLIATION OF GRAPES (V. Vinifera L.) INDUCED BY CHEMICALS

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Summary. Experiments on pre-harvest defoliation were performed on some grape cultivars using a) 2-chloroethyl-phosphonic acid at 500 and 1500 ppm on cv "Montuni" and at 1500 ppm on cv "Lambrusco Graspa Rossa" and b) 2,3,dihidro-5,6-dimethyl-1,4-dithiin 1,1,4,4-tetraoxide at 350 ppm on cvs "Montuni" "Lambrusco Graspa Rossa", "Lambrusco Salamino", "Sangiovese", "Cabernet Franc", "Raboso Veronese", "Trebbiano toscano", "Trebbiano romagnolo", "Verduzzo" and "Verdicchio" and at 650 ppm on cvs "Montuni" and "Lambrusco Graspa Rossa". Ethephon at 500 ppm did not induce defoliation and did not effect the Berry Removal Force, while at 1500 ppm induced defoliation up to 85% and caused berries and clusters drop up to 30%. Dimethipin gave better results: at 350 ppm did not change the B.R.F. and caused defoliation from 55% up to 98% depending upon the varieties; at 650 ppm increased defoliation occurred but a certain degree of fruit drop was also recorded (up to 18%). Cultivars, berry and cluster drop, dosage, ripening, dimethipin, harvesting.

INTRODUCTION

During mechanical harvesting of grapes many leaves are detached by the vibratory action of the shakers, which normally act on the fruiting area at a very high frequency (300-400 impacts/min).

The amount of leaf drop, which in some grape cultivar has been recorded at high levels (Vendemmia Nord-Sud, 1977) can give rise to different problems, by reducing the conveyor belt efficiency, by limiting the speed of the operation and by increasing the juice losses through the air stream of the aspirators used for leaf removal.

Side by side with the optimization of the grape training systems and harvesters, a possible attempt to overcome these problems can be represented by the use of chemicals which may induce pre-harvest defoliation; among these chemicals, Ethephon has been used by many Authors and its efficiency has been explored on several grape cultivars (Eynard et alii, 1974; Weaver and Pool, 1969; Weaver and Pool, 1971 ; El-Banna and Weaver, 1979; Lane and Flora, 1979).

Recently, promising results on pre-harvest defoliation of various crop, especially cotton, have also been obtained by a new chemical, originally coded N-252, which has been released by Uniroyal Company under the commercial name of Harvade (dimethipin).

In order to compare the Ethephon and dimethipin effects under the environmental conditions of the Po Valley area, experiments on pre-harvest defoliation of some wine grape cultivars have been conducted since 1977 with the aim of also evaluating the effects on berry and cluster drop as well as on ripening.

METHODS AND MATERIALS

Experiments were performed using Ethephon (2-chloroethylphosphonic acid) and dimethipin (2,3 dihydro-5,6-dimethyl-1,4 dithiin 1,1,4,4-tetraoxide), both applied on the vine fruiting area two weeks before the expected harvest date.

Ethephon was applied at 500 and 1500 ppm on the cv "Montuni" and at 1500 ppm on the cv "Lambrusco Graspa Rossa".

Dimethipin was applied at 350 and 650 ppm on both cultivars, Geneva Double Curtain trained, using UBI 1126 at 5 g/l of water as surfactant.

After treatments the defoliation rate and the B.R.F. were monitored: at harvest, berries and/or clusters drop, total production and juice soluble solids were also checked.

Defoliation was periodically evaluated counting the retained leaves on tagged fruiting shoots positioned in the treated area. On clusters of the same shoots, the B.R.F. evolution was checked using a "CARPO" model dinamometer.

The total fruit losses were recorded collecting berries and cluster from the soil which had been covered with a plastic film since spraying.

Juice soluble solids were checked by refractometer.

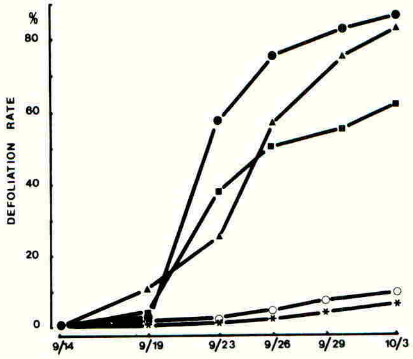
Additional varieties, hedgerow trained ("Sangiovese", "Cabernet Franc", "Raboso veronese", "Lambrusco Salamino", "Trebbiano toscano", "Trebbiano romagnolo", "Verduzzo", and "Verdicchio") were also treated with dimethipin at only 350 ppm, to evaluate leaf abscission as previously described.

RESULTS

On cultivar "Montuni", Ethephon at 500 ppm had minimal effect on defoliation, while at 1500 ppm the leaf drop reached about 85% at harvesting time (fig. 1). Dimethipin effects on defoliation were related to the spray concentration, ranging from 60% to 90% in vines sprayed at 350 ppm and 650 ppm respectively (fig. 1).

Fig. 1

Defoliation rate on the cv "Montuni": * = control; ■ = dimethipin 350 ppm; ● = dimethipin 650 ppm; ○ = Ethephon 500 ppm; ▲ = Ethephon 1500 ppm



As far as B.R.F. is concerned, dimethipin at both concentrations and Ethephon at 500 ppm had little effect, reducing the B.R.F. by up to 10% as compared with the untreated vines (fig. 2). Ethephon at 1500 ppm was however very effective, reducing the B.R.F. up to 80% at harvest time (fig. 2). Consequently, different levels of fruit drop were recorded, ranging from 4 to 8% on vines dimethipin treated (350 and 650 ppm respectively) up to 30% on Ethephon treated vines at 1500 ppm (fig. 3).The total production (including fruit drop) and grape quality were practically unaffected by the chemicals (fig. 3).

Fig. 2

Effect of treatments on the reduction of Berry Removal Force on the cv "Montuni"; * = control; ■ = dimethipin 350 ppm; ● = dimethipin 650 ppm; ○ = Ethephon 500 ppm; ▲ = Ethephon 1500 ppm

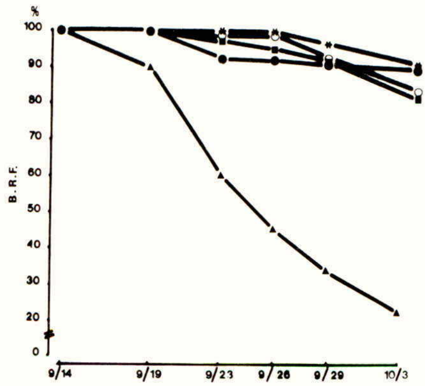
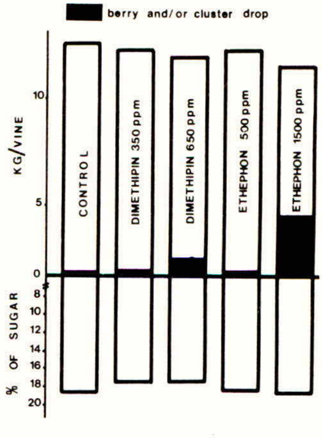


Fig. 3

Yield, losses on the ground and percent of sugar on the cv "Montuni"



On treated vines of "Lambrusco Graspa Rossa" the defoliation and the B.R.F. showed the same trend as reported on cv "Montuni", but the effect on B.R.F. reduction was generally higher (fig. 4 and fig. 5). Consequently, the fruit pre-harvest drop was increased from 10% to 20% with dimethipin and up to 35% with Ethephon(fig.6).

Fig. 4

Defoliation rate on cv "Lambrusco Graspa Rossa": ✱ = control; ■ = dimethipin 350 ppm; ● = dimethipin 650 ppm; ▲ = Ethephon 1500 ppm

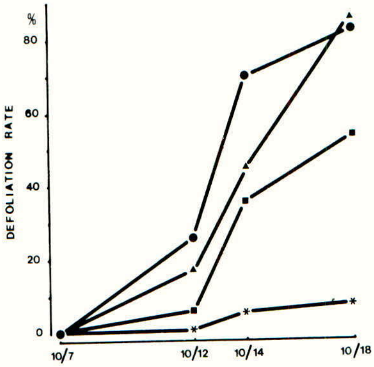
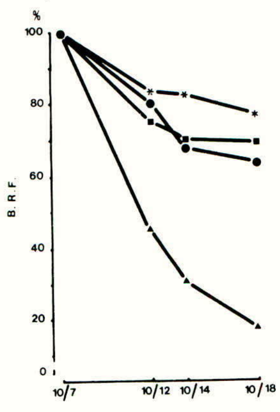


Fig. 5

Effect of treatments on the reduction of Berry Removal Force on the cv "Lambrusco Graspa Rossa": ✱ = control; ■ = dimethipin 350 ppm; ● = dimethipin 650 ppm; ▲ = Ethephon 1500 ppm



As on cv. "Montuni", the total production and grape quality on cv. "Lambrusco Graspa Rossa" were not affected (fig. 6).

The evaluation of dimethipin effect on the defoliation of other grape cultivars demonstrated that this chemical applied at 350 ppm caused a satisfactory rate of leaf drop, ranging from 75% up to 98% depending on the varieties (fig. 7).

Fig. 6

Yield, losses on the ground and percent of sugar on the cv "Lambrusco Graspa Rossa"

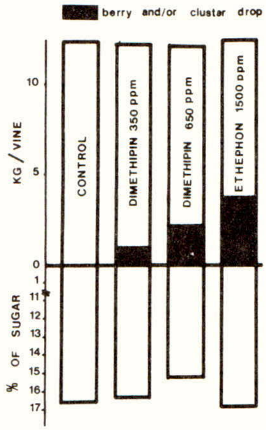
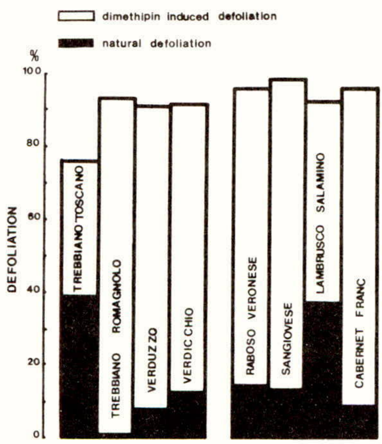


Fig. 7

Defoliation rate on several grape cvs dimethipin treated at 350 ppm



DISCUSSION

The results of these preliminary trials on some wine grape cultivars growing in to Po Valley area indicate that a) Ethephon at lower dosage was ineffective, while at higher concentration had a strong effect on both leaf and berry drop; b) dimethipin at lower and higher dosage induced leaf abscission on all the tested cultivars, with little or no effects on the B.R.F. and on the fruit drop; c) Ethephon and dimethipin had no effects on grape production and ripening.

These results of Ethephon treatments only partially agree with those of previous trials carried out in different environmental conditions and grapevine varieties. On the other hand the variability of the Ethephon effects on grapes is very well known. According to some Authors, Ethephon at only 100-500 ppm improved ripening on cvs. "Barlinka", "Thompson" and "Black Corint" (Blommaert et alii 1974; El-Banna and Weaver, 1978; Singh et alii, 1977), while at 1000 ppm or more lowered the juice soluble solids on cvs "Zinfandel", "Grenache" and "Barbera" or was completely ineffective (Weaver and Montgomery, 1974; Eynard et alii, 1970). At higher concentration (1000-2000 ppm) Ethephon caused berry and/or leaf drop on varieties like "Barbera", "Ciliegiolo", "Bonarda", "Freisa" and "Concord" (Eynard et alii, 1970; Cahoon, 1974) but ineffective on cvs "Merlot" and "Cabernet Franc" (Cargnello, 1977).

As far as the dimethipin is concerned, the results generally agree with those of previous work (Iannini and Lavezzi, 1980) and the effects of this chemical on grape defoliation without affecting the fruit drop and ripening seems of value, improving the speed and the efficiency of the mechanical harvesters on the vigorous vines of the Po Valley area; nevertheless further investigations are needed to carefully verify the chemical residues on the berry juice and the possible side effects on vines, especially relative to long term treatments.

In addition, since few references are currently available on dimethipin application on vines, experiments in other environmental conditions and on a larger number of grape cultivars are also necessary.

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PROSPECTS FOR MANIPULATING TREE ROOT SYSTEMS USING PLANT GROWTH REGULATORS: SOME PRELIMINARY RESULTS

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Summary. Tree root systems are often sub-optimal in their exploitation of soil resources. Possibilities for using PGRs to modify tree root systems, so as to improve performance under specific conditions, are discussed. A range of PGRs were tested for their effects on the root growth and shoot/root ratio of micropropagated M.25 rootstocks. Some, for example paclobutrazol (PP333), affected both. Studies using observation tubes showed that the balance of short to long roots and root diameter were also altered. Probably as a consequence of the root system changes both the concentrations of major nutrients, e.g. N, P, K, and the total amounts in leaves were altered. Effects varied between nutrient elements and chemicals.

The application of paclobutrazol and a related compound reduced both transpiration and water flux through the root system. This should confer a measure of drought resistance. As a result of transpiration and root system effects paclobutrazol reduced the competition for water between fruit trees and inter-row grass. Apple, root growth, mineral nutrition, paclobutrazol.

INTRODUCTION

Plant growth regulators (PGRs), as foliar sprays, have been used in both arable and fruit crops (Sampson *et al*., 1980, Quinlan, 1981) to control shoot growth, to encourage partitioning of assimilates into grain or fruit or to affect the architecture of the shoot system but only rarely to influence the root system. PGRs applied to the shoot system may however affect the root system; e.g. Popou *et al*. (1979) found that foliar chlormequat which reduced shoot growth also reduced root growth. The absence of attempts to manipulate root systems may have been due to limited perceptions of the functioning of the root system, particularly under field conditions, or to the lack of chemicals either with soil activity or capable of downward translocation, or to both of these.

A better understanding of the root system, the development of chemicals with soil activity, e.g. paclobutrazol ((2RS, 3RS)-1-(4-chlorophenyl)-4, 4-dimethyl-2-(1*H*-1, 2, 4 triazol-1-yl) pentan-3-ol), and the presence of much of the tree root system close to the soil surface as a result of herbicide-based soil management (Atkinson, 1980), make possible the application of PGRs to tree root systems in soil.

Is there a need to modify root systems, of trees or other species, in the orchard situation? Three examples illustrate situations where the naturally-developed root system is sub-optimal and how it might be modified:-

1) Most fruit trees are grown in herbicide strips with grassed inter-rows. Goode (1956) showed that a long grass sward used 10-12.5 cm water compared with the 7.5-8.7 cm used by a mown sward. The difference was due to root distribution below 50 cm depth. Frequent mowing of orchard grass is needed to conserve water but is expensive. A PGR treatment to modify the grass root system, as with mowing, and reduce water use to a similar or to an even greater extent would be valuable.

2) At least in the early years of an orchard most apple trees are staked. Staking adds a cost of £0.67-0.84, depending on length, at 1982 prices, to the cost of the tree, £1.65, and so adds up to £994 ha^{-1}, depending on planting density to the costs of orchard establishment. This is needed because of poor anchorage which is related to both root thickness and distribution.

3) The density of fruit tree roots in the soil (Atkinson, 1980), 1-10 cm cm^{-2}, is low compared to other species, e.g. grasses and cereals 200-4000 cm cm^{-2} (Newman, 1969). As a result fruit trees can suffer from stress, leaf water potentials <-2.0 MPa, even when in moist soil (Atkinson, 1981). This could be changed by an alteration in the balance of root length to leaf area.

Root systems can be characterized in many ways, e.g. total length or mass, root length related to the shoot system, distribution in the soil, the frequency distribution of root diameter and the balance of short and long roots. The potential to manipulate some of these features with PGRs is discussed in this paper.

METHOD AND MATERIAL

Experiment 1. M.25 rootstocks were produced by micropropagation (Jones *et al.*, 1977) and used when about 4 months old. They were planted in a sand/loam mix in observation chambers made from 30 cm lengths of 10 cm diameter plastic guttering and high-density polythene which served as a window to allow the observation of root growth. Plants were grown in a Conviron S10 growth chamber which provided a temperature of 20°C day, 17°C night, a day length of 16 hours and a light intensity of 250 Wm^{-2} at stem tip height. Observation windows were covered during growth to exclude light.

The following treatments were applied: 1) control, water only; 2) indoylacetic acid, 75 µg $plant^{-1}$; 3) TIBA, 150 µg; 4) GA_3, 300 µg; 5) Benzyladenine, 100 µg; 6) chlormequat, 750 µg; 7) paclobutrazol, (1-(4-chlorophenyl)4, 4-dimethyl-2-(1*H*-1, 2, 4-triazol-1-yl) pentan-3-ol), 390 µg; 8) 1-(4-chlorophenyl)-4, 4-dimethyl-2-(1*H*-1, 2, 4-triazol-1-yl) pentan-3-one (CTPone), 390 µg $plant^{-1}$. All treatments were applied as 100 ml of solution to the soil surface and replicated two times. Root growth was assessed during the 50 d experimental period as the number of intersections with a 1.2 x 1.2 cm grid (Atkinson, 1980). At the end of the experiment root, stem and leaf weights were determined and leaves analysed for mineral nutrients using standard methods.

Experiment 2. M.25 rootstocks produced as above were grown in 12 cm diameter pots as described above. The following treatments were applied: 1) control, water only; 2) paclobutrazol at a rate equivalent to 4 kg a.i. ha^{-1}; 3) 1-(4-methoxyphenyl)-4, 4-dimethyl-2-(1*H*-1, 2, 4-triazol-1-yl) pentan-3-ol (MTPol) at 3.8 kg a.i. ha^{-1} (the molecular equivalent of 2). Transpiration and water use were measured as described by Asamoah and Atkinson (1983) for 8 days beginning 16 days after the application of treatments. All treatments were replicated four times.

Experiment 3. S50 timothy (*Phleum nodosum*) was sown in spring 1977 in 1.5 x 1.5 m plots (Atkinson *et al.*, 1980) and given the following treatments annually in the springs of 1978-1980:-

1) control, water only; 2) paclobutrazol at 4 kg a.i. ha^{-1}; 3) Mefluidide at 0.55 kg ha^{-1}. All swards were uncut and treatments replicated six times. Soil moisture was estimated as described by Atkinson *et al.* (1980).

RESULTS

Experiment 1. Applications of PGRs to the soil altered the growth of M.25 rootstocks. The treatments included representatives of the main groups of plant hormones and some synthetic regulators. The treatments both increased, a maximum of 6% with CCC, and decreased, 19% with IAA, shoot weight. Leaf weight was also both increased, up to 11% with TIBA, and decreased, up to 21% with CCC (Table 1).

Table 1

The effect of a number of PGRs on the growth of M.25 apple rootstocks g plant^{-1}

Treatment	Weight of Root	Weight of Shoot	Weight of Leaf	S/R ratio
Control	2.9	10.5	6.7	5.9
IAA	2.8	8.5	6.4	5.4
TIBA	3.5	10.6	7.8	5.3
GA_3	3.7	9.5	6.7	4.4
BA	3.9	10.8	7.6	4.8
CCC	4.6	11.1	5.3	3.6
Paclobutrazol	4.3	8.8	7.5	3.8
CTPone	3.5	9.1	7.6	4.8
S.E.D.	0.9	1.9	1.9	-

Root growth was increased by over 20% by 6 of the treatments (Table 1). Measurements of white root length during the experiment (Table 2) also showed substantial increases. The largest increase, one of 102%, was with paclobutrazol. In addition to effects on total length, IAA, TIBA, CCC and paclobutrazol all increased the ratio of short to long roots by over 18%. Treatment effects on the length of short roots were greater (up to 115% with paclobutrazol) than those on long roots (up to 83% with paclobutrazol and BA). The ratio of length of long roots to the number reaching the container base was generally increased. Some materials, especially paclobutrazol and the related CTPone, increased mean root diameter.

Table 2

The effect of a number of PGRs on the root growth of M.25 apple rootstocks cm observation window^{-1}

Treatment	Root length 21 days post-treatment: Short roots	Long roots	Total	No. at base	Ratios: Long roots/ No. at base	Short/ Long
Control	98	65	163	6	10.8	1.51
IAA	130	67	197	4	16.8	1.94
TIBA	170	87	257	3	29.0	1.95
GA_3	127	89	216	3	29.7	1.42
BA	167	119	286	5	23.8	1.40
CCC	179	86	265	5	17.2	2.08
Paclobutrazol	211	118	329	3	29.3	1.79
CTPone	73	114	187	4	28.5	0.64
S.E.D.	62	36	81	3	-	-

Concentrations of nitrogen (N), phosphorus (P), and potassium (K), in the leaves and the total amounts in the leaves were affected by PGRs (Table 3). Mineral analyses were carried out on bulked samples and so coefficients of variation (cv %) estimated from a range of other large well-replicated experiments were used to help assess meaningful differences. The values for cv used in the assessments were 2-8% for N, 4-13% for P, and 2-10% for K. On this basis N concentration was increased by paclobutrazol and N transfer to the leaves (total amount in the leaves) by BA, paclobutrazol and CTPone. CCC reduced N transfer. Paclobtrazol increased both P transfer and concentration but decreased K concentration and transfer as did CCC.

Table 3

The effect of a number of PGRs on mineral nutrient content mg g^{-1}

and the total nutrient content of leaves mg $plant^{-1}$

Treatment	Nitrogen Conc	Nitrogen Total	Phorphorus Conc	Phorphorus Total	Potassium Conc	Potassium Total
Control	25.2	169	3.4	23	30.5	205
IAA	27.2	175	3.1	20	30.2	194
TIBA	24.9	195	3.5	27	29.2	229
GA_3	23.7	158	2.9	19	28.3	188
BA	28.0	211	3.2	24	28.5	215
CCC	22.3	118	3.2	17	31.4	167
Paclobutrazol	29.6	221	3.9	29	20.7	155
CTPone	26.5	200	3.0	23	24.0	181

Experiment 2. Both paclobutrazol and the related MTPol reduced leaf area but without much effect on leaf weight (Table 4). Root weight was reduced to a similar extent to leaf area. As the root system supplies the plant with water, effects on water use were investigated. Paclobutrazol and MTPol reduced total water use, transpiration and the flux of water into the root system (Table 4). This ought to reduce the drought susceptibility of plants treated in this way but effects on transpiration obscure direct effects on the water supplying power of the root system.

Table 4

The effect of paclobutrazol and PP201 on leaf area (cm^2), leaf weight (g), root weight (g), water use g $plant^{-1}hr^{-1}$, transpiration (mg $cm^{-2}hr^{-1}$), and water flux (mg, g $root^{-1}d^{-1}$)

Treatment	Leaf area	Leaf weight	Root weight	Water use	Transpiration	Water flux
Control	857	5.9	12.3	6.61	7.7	76
Paclobutrazol	687	5.7	8.3	3.09	4.5	46
MTPol	665	5.5	8.7	3.49	5.2	49
S.E.D.	99	0.8	1.7	0.57	0.38	12.3

Effect of treatment on water use and transpiration significant at $\geqslant$ P = 0.01
Transpiration of paclobutrazol plants significantly different from MTPol at P = 0.05

Experiment 3. Paclobutrazol, but not mefluidide, applied to an uncut established grass sward increased root density and the proportion of the root system in the surface 7 cm of soil (Table 5). Mefluidide had little apparent effect on root distribution.

Table 5

The effect of paclobutrazol and mefluidide on root weight g m^{-2} in the surface 30 cm of soil and % root weight at depths for uncut S50 timothy

Treatment	Root weight	% at depth (cm) 0-7	7-15	15-30
Control	705	42	38	20
Paclobutrazol	1222	74	16	10
Mefluidide	628	51	18	32

Both paclobutrazol and mefluidide reduced, at least in the early part of the season, the estimated soil moisture deficit (SMD) by 42 and 35% respectively. With paclobutrazol the reduction in SMD, 14%, in the surface 10 cm of soil was smaller than that in the rest of the profile, 55% (Table 6). Relative reductions caused by mefluidide at these depths were 27 and 45%.

Table 6

The effect of paclobutrazol and mefluidide on soil moisture deficit (mm) at different depths under an uncut S50 timothy sward on 3rd July 1979

Treatment	Depth 10	20	30	Total 0-75
Control	6.2	4.4	2.9	21.5
Paclobutrazol	5.3	2.2	1.1	12.4
Mefluidide	4.5	2.8	1.2	14.0

DISCUSSION

Plant growth regulators, e.g. chlormequat, are routinely used to modify the aerial parts of crop plants. This paper has explored some of the possibilities of manipulating the plant root system using soil applications of synthetic PGRs.

The application of a range of materials suggested that it should be possible to alter total plant growth and the partition of assimilates between root and shoot. In experiment 1 many of the PGRs increased root growth. When considering soil applications of PGRs there is little guidance as to optimal rates and so much further work is needed to test a range of concentrations for plants of varying sizes.

In fruit trees where the ratio of leaf or shoot to root is high (Atkinson, 1980) a reduction as obtained with paclobutrazol and CCC (Table 1) should be of benefit with regard to the supply of water under stressful conditions. Under conditions of high potential evaporation the high root system and root-soil interface resistances caused by limited relative root lengths will have their major impact in reducing water flux. Under irrigated or favourable soil moisture supply conditions this limitation may result in unnecessarily reduced growth. An increase in the length of root supplying a given area of leaf should reduce this limitation. Although the results presented here are complicated by the direct anti-transpirant effects of materials like paclobutrazol, the reduction in water flux (Table 4) and root system changes (Tables 1 and 4) should mean that treated plants are less limited by hydraulic resistances.

The balance of long and short roots and the absolute lengths of these are important in relation to the exploitation of soil at depth which is often poor in fruit trees and which needs long roots, and the utilization of specific soil areas and infection with V.A. mycorrhizas both of which depend on short roots. Both long and short root lengths and the balance between them were changed by paclobutrazol in apple (Table 2) and in grass (Table 5). With grass this and perhaps a direct effect on transpiration caused a transient reduction in total water use. In grass the absolute length of root present may be so great that PGRs may not be able to have sufficient impact so as to reduce root presence in deeper soil horizons enough to have the required impact on total water use over the whole season.

Although experiment 1 showed that a number of root system parameters could be altered not all materials at the rates used had the effects expected, e.g. the auxins IAA and TIBA and the anti-gibberellin paclobutrazol all increased branching (Table 2) while CTPone behaved very differently from paclobutrazol. Some results from experiment 1 are inconsistent with those from experiment 2, e.g. the effects of paclobutrazol on root weight (Tables 1 and 4). These differences could be due to a number of factors. The differences are however less important than the demonstrations of the plasticity within many root system characteristics and the magnitude of changes which can be affected using PGRs.

The results obtained with materials like paclobutrazol and CCC showed that foliar nutrition can be changed with PGRs. Effects on a given element vary between chemicals and even for a given chemical between elements (Table 3). The mechanism(s) of these effects need further study. The possibility of changing water use and so liability to water stress which can influence mineral nutrition also exists with paclobutrazol which changes parameters apparently of importance. Here effects on the contribution of the root systems were obscured by direct effects on stomatal conductance (Asamoah and Atkinson, 1983).

The root systems of both trees and the other plants grown in our orchards are often sub-optimal for specific situations. The use of PGRs seem to offer some potential for changing this.

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THE CONTROL OF GRASS GROWTH IN APPLE ORCHARDS WITH PLANT GROWTH REGULATORS

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Summary. The effect of five plant growth regulators on the growth of a *Poa pratensis/Festuca rubra* orchard sward has been studied in three separate trials. Different rates and dates of application of the chemicals were compared with an unsprayed sward.

Aminotriazole plus banlene, mefluidide (at the 1.0 kg a.i./ha rate) and maleic hydrazide + 2,4-D all significantly reduced grass dry matter production and the number of cuts over a season. Paclobutrazol was the most effective treatment.

Apple tree growth or blossom density was not significantly affected by any of the treatments. Results suggest that grass growth in an orchard can be satisfactorily controlled with the use of plant growth regulators. Grasses, sward, rate, date, repeat, applications, Paclobutrazol, Aminotriazole/MH, mefluidide.

INTRODUCTION

Traditionally English fruit trees were grown under arable conditions and weed competition eliminated by continual cultivation. Grassing down the orchards practised in the 1940's improved tree nutrient and fruit quality (Wallace, 1953) and provided a better working surface than that produced by cultivation. The grass beneath the vigorous trees was not too competitive as its vigour was checked by the shade from the extensive canopies.

Currently dwarf trees on less vigorous rootstocks are grown in herbicide strips with grassed alleys. These small bush trees intercept less light (Jackson, 1978) allowing the grass in the unshaded alley to grow vigorously. The grass competes with fruit trees for water and nutrients (Atkinson and White, 1976). Regular mowing reduces this competition (Atkinson and Petts, 1978) but is expensive and a reduction in the number of mowings by using grass growth regulators would be advantageous in dessert apple orchards.

In cider orchards where fruit is shaken to the ground prior to harvest, a short grass sward is required to assist mechanical harvesting and to help keep the fruit clean for processing. Maintaining a short sward by mowing after July when the branches are weighed down with fruit and in close proximity to the ground is often difficult. Hence the use of a chemical regulator to reduce grass growth would also be of great value in cider orchards.

Early attempts to control grass growth with TCA and dalapon did not meet with complete success (Stott, 1972). These materials were rejected in favour of maleic hydrazide which offered the combination of characteristics required to suppress grasses without killing them and so maintain the sward at a given height. However because of inconsistent results and high costs (Stott, 1966), maleic hydrazide has not achieved widespread use in amenity grasslands or commercial orchards. More recently a number of new chemicals have shown promise as growth inhibitors of grasses (Watschke, 1978; Stinchcombe and Stott, 1978; and Stinchcombe and Stott, 1980). In this paper results are reported of trials made at Long Ashton Research Station to test a number of plant growth regulators as grass retardants in the alleyways of a mature dessert apple orchard. The effects on the sward and the trees are presented and discussed.

MATERIALS AND METHODS

The orchard was planted at Long Ashton Research Station in 1970 at 4 x 2.75 m and consisted of alternate trees of Cox's Orange Pippin and Golden Delicious on MM106 rootstock (Stott, 1976). The bush trees were grown in a herbicide treated strip with a grassed alleyway. The grass sward was sown in 1970 with a 50/50 mixture of *Poa pratensis* L. (Meadow grass) and *Festuca rubra* L. (red fescue). The alleyways were divided into experimental plots measuring 8 x 2 m. Each was sprayed with one of the following eight treatments:-

1) Proxazalon at 2 kg a.i./ha.
2) Proxazalon at 3 kg a.i./ha.
3) Maleic hydrazide (MH) + 2,4-D at 3.7 + 3.7 kg a.i./ha.
4) Aminotriazole at 0.84 kg a.i./ha plus a mixture of MCPA 1.06, dicamba 0.08 and CMPP 0.355 kg a.i./ha (banlene).
5) Mefluidide at 0.5 kg a.i./ha.
6) Mefluidide at 1.0 kg a.i./ha.
7) Paclobutrazol (2*RS*, 3*RS*)-1-(4-chlorophenyl)-4,4-dimethyl 2-(1*H*-1,2,4-triazol-1-yl) pentan-3-ol at 2 kg a.i./ha.
8) Paclobutrazol at 4 kg a.i./ha.
9) Unsprayed standard for comparison.

Time of application

Three separate trials were conducted. The chemicals were applied using an Oxford Precision Sprayer on:-

Trial 1) 31 May 1979 and 27 May 1980
Trial 2) 31 May and 16 July 1979
27 May and 18 July 1980
Trial 3) 18 July 1980

In each trial, treatments were replicated six times in a randomised block design.

Records

The grass was cut 5 days prior to spraying; thereafter each treatment was mowed when it reached 8-16 cm high. The number of cuts and dry weight of clippings were recorded. Observations on sward appearance were made.

To monitor possible effects on the trees, (trial 2), in spring 1980 the number of blossom clusters were counted on two Cox's Orange Pippin trees adjacent to each plot. In November 1980, shoot extension on two Cox's Orange Pippin trees adjacent to each treatment was measured on six shoots per tree selected at random.

RESULTS

Trial 1

Table 1 which gives the mean value for both year's results shows that grass dry matter production was significantly reduced by all treatments and that a single application of aminotriazole, mefluidide at 1.0 kg a.i./ha or MH + 2,4-D reduced dry matter production by over 40% compared with the untreated sward and almost halved the number of cuts required over the season.

The most effective treatment was Paclobutrazol. At rates of 2 and 4 kg a.i./ha, dry matter production was reduced by 64 and 77% and the number of cuts by 57 and 70% respectively compared to the unsprayed sward.

Table 1

Effect of growth retardants applied in May 1979 and 1980 on grass growth from May-October (mean for 1979 and 1980)

Treatment	Rate a.i. (kg/ha)	Total dry wt (g/m^2) (May-October)	% reduction from unsprayed (May-October)	No. cuts	% cuts saved
Proxazalon	2	314	19	6	14
	3	318	20	6	14
Aminotriazole (+ banlene)	0.84	228	42	4	43
MH+ 2,4-D	3.7 + 3.7	221	44	4	43
Mefluidide	0.5	301	24	5	29
	1.0	214	46	4	43
Paclobutrazol	2	142	64	3	57
	4	89	77	2	70
Unsprayed	-	395	-	7	-
S.E.D.	-	16.2	-	-	-

Trial 2

Applications in May, repeated in July, of aminotriazole plus banlene, mefluidide at 1.0 kg a.i./ha or MH+2,4-D significantly reduced dry matter production and the number of cuts over the whole season (May-October) by approximately 60%. Paclobutrazol at rates of 2.0 and 4.0 kg a.i./ha reduced dry matter production by 87 and 90% and the number of cuts by 71 and 86% respectively compared to the unsprayed sward (Table 2).

Table 2

Effect of growth retardants applied in May and July 1979 and 1980 on grass growth (1979+80 mean) and blossom density and shoot extension on Cox's Orange Pippin (1980 season)

Treatment	Rate a.i. (kg/ha)	Total dry wt (g/m^2) (May-Oct)	% reduction from unsprayed	No. cuts (May - October)	% cuts saved	Blossom cluster number/ tree	Shoot extension (cm)
Proxazalon	2	265	33	6	14	217	61.8
	3	259	34	6	14	223	62.1
Aminotriazole (+ banlene)	0.84	165	58	3	57	248	61.4
MH+2,4-D	3.7+3.7	166	60	3	57	256	62.4
Mefluidide	0.5	264	33	5	29	260	60.3
	1.0	146	63	3	57	231	61.3
Paclobutrazol	2	52	87	2	71	251	60.9
	4	38	90	1	86	242	63.1
Unsprayed	-	395	-	7	-	238	61.7
S.E.D.	-	17.6	-	-	-	ns	ns

ns = Not significant

Trial 3

A single application of aminotriazole plus banlene, mefluidide at 1.0 kg a.i./ha or MH + 2,4-D in July 1980 significantly reduced dry matter production by over 40% and the number of cuts between July and late October by 67%. Paclobutrazol at either rate stopped grass growth completely from July onwards (Table 3).

Table 3

Effect of growth retardants applied in late July on subsequent grass growth

Treatment	Rate a.i. (kg/ha)	Total dry wt wt. (g/m^2) (July - October)	% reduction from unsprayed	No. cuts (July - October)	% cuts saved
Proxazalon	2	138	10	3	0
	3	128	16	3	0
Aminotriazole (+banlene)	0.84	84	45	1	67
MH+2,4-D	3.7+3.7	80	47	1	67
Mefluidide	0.5	125	18	2	37
	1.0	88	43	1	67
Paclobutrazol	2	0	100	0	0
	4	0	100	0	0
Unsprayed	-	152	-	3	-
S.E.D.	-	8.2	-	-	-

DISCUSSION

In a dessert apple orchard where the grass cover in the alleyway was composed of a 50/50 mixture of *Poa pratensis* and *Festuca rubra* results over 2 years have shown that a single application of aminotriazole plus banlene, mefluidide at 1.0 kg a.i./ha or MH+2,4-D in May (trial 1) reduced dry matter production and the number of cuts over a full season compared with the unsprayed sward. However, paclobutrazol was the most effective grass retardant and a single application in May at the higher rate (4.0 kg a.i./ha) produced a prostrate sward and reduced the number of cuts over a season by 70% compared to the untreated sward. Both rates of proxazalon, and mefluidide at 0.5 kg a.i./ha were the least effective treatments.

Two applications per year of aminotriazole plus banlene, mefluidide at 1.0 kg a.i./ha or MH+2,4-D (trial 2) resulted in a further 20% reduction in dry matter and in the number of cuts compared to a single May application, over a full season. A repeat application of paclobutrazol in July at either rate stopped grass growth completely which at the higher rate gave a 90% reduction in dry matter production and an 86% saving in the number of cuts over a full season compared with the unsprayed sward.

The first spraying of aminotriazole plus banlene or MH+2,4-D (May applications, trial 1) resulted in a discolouring of the grass and a second application in July killed some of the grass, producing bare patches which allowed the ingress of undesirable broad leaved weeds. In contrast spraying with mefluidide gave a dense, compact sward with little or no seedheads.

Paclobutrazol produced a dense, prostrate, dark green sward which had a coarse appearance; these characteristics are the result of biological properties of the chemical and a consequence of reduced mowing frequency. Seedheads were reduced following paclobutrazol treatments but not eliminated and although some retardation of broad leaved weeds was achieved more weed of this type was observed in paclobutrazol treated swards than in unsprayed swards. This problem could be controlled with a hormone weedkiller e.g. 2,4-D, used as a tank mix with paclobutrazol. The altered appearance of the sward is of no serious consequence but may not be acceptable in an amenity area.

The results of trial 3 show that a single application of paclobutrazol in July at either rate completely stopped grass growth until late October. In practice the cider apple grower who mows the grass sward until July could then best inhibit growth until November with a single application of paclobutrozol. However, adequate suppression of grass growth at this time may be achieved with mefluidide at 1.0 kg a.i./ha or MH+2,4-D also.

These results show that significant reductions in growth and dry matter production of orchard swards and, thus, in the number of cuts, can be achieved by the use of plant growth regulators, without damaging the fruit trees. Although Quinlan (1981) has shown that paclobutrazol applied to the herbicide strip around the base of young fruit trees can retard shoot growth, Table 2 shows that the application of paclobutrazol to the alley sward only in these trials, had no significant effect on apple tree shoot extension growth or blossom cluster number of 12 year old Cox's Orange Pippin trees.

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