5.
Fruit Crops

Chairman: Dr G. K. GOLDWIN

USE OF PACLOBUTRAZOL IN ORCHARD MANAGEMENT TO IMPROVE EFFICIENCY OF FRUIT PRODUCTION

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ABSTRACT

Paclobutrazol is very effective for controlling the growth of fruit trees and may ease problems of tree management particularly in high density planting systems. Reduction of tree growth and increased cropping levels point to improved partitioning of assimilates between the crop and vegetative growth. Reduction in tree growth is frequently accompanied by increased yield efficiency in terms of crop produced per unit crown volume. More efficient production systems are suggested, based on use of paclobutrazol to regulate tree growth.

INTRODUCTION

Many modern orchard systems are based upon the establishment of plantings designed to achieve maximum productivity at a relatively early stage in the life of the orchard. The most recent orchard designs for crops such as apple take only two or three years to achieve cropping levels previously not attained until five or six years after planting. This is the result of increased density of planting giving higher early light interception and yield potential combined with cultural techniques such as branch bending and modified pruning systems to induce early cropping. With this trend towards more intensive planting, particularly in Europe but increasingly in other fruit growing regions also, regulation of tree growth has become of paramount importance. The success or failure of the modern high density orchard is to a large extent determined by the ability of the grower to control inter-tree competition which might otherwise adversely affect fruit production and quality. Although pruning and dwarfing rootstocks may be used to control tree size, these methods are often inadequate. Furthermore, pruning is the major labour cost in orchard management and heavy pruning is not only expensive but represents a loss of potential cropping wood.

Use of a chemical plant growth regulator offers a means whereby tree growth may be more efficiently controlled. Although orchard management systems have incorporated plant growth regulator treatments such as the use of daminozide to improve fruit bud formation (e.g. Luckwill 1978), relatively little use has been made of growth regulating chemicals to control tree size even where no dwarfing rootstocks are available. However, discovery of the triazole growth regulators, effective in controlling the growth of a wide range of species (Lever *et al*. 1982) has been a significant advance. Paclobutrazol, a triazole growth regulator inhibiting gibberellin biosynthesis (Hedden and Graebe 1985), is a potent retardant of shoot extension growth which shows promise for use in the management of orchard crops.

Use of paclobutrazol in orchard management

Paclobutrazol (Cultar) is effective for controlling the growth of many tree fruit crops when applied as a foliar spray or as a soil treatment (e.g. Quinlan 1981, Williams 1983, Tukey 1983, Quinlan & Richardson 1984, Erez 1984, Webster *et al*. 1986). The most effective method of application to pome fruits is by foliar sprays (Quinlan & Richardson 1984) whereas stone fruits tend to respond well to soil application (Webster & Quinlan 1984).

Taking apple as an example, application of paclobutrazol may result not only in a reduction in tree growth but also in an increase in yield (Table 1), particularly in the second and subsequent years of treatment.

TABLE 1

Effect of paclobutrazol sprays applied for three years to Bramley apple on MM.106

	Crop (kg) in treatment years:		
	1	2	3
Untreated	72.7	56.7	105.2
Paclobutrazol*	70.0	69.1	126.1

	Tree size and cropping efficiency in third year	
	Crown volume (m^3)	Yield (kg)/ m^3 crown volume
Untreated	140	0.76
Paclobutrazol*	89	1.45

*Paclobutrazol applied as 4 x 500 mg $litre^{-1}$ sprays at two-week intervals starting three weeks after full bloom.

This increase in yield may be attributable to a reduction in competition from shoot growth for assimilates necessary for fruit development (Quinlan & Preston 1971) leading to a greater relative allocation of assimilates to fruit production and a smaller proportion to vegetative growth. Improvements in yield are also often attributable to a greater production of flowers by trees treated with paclobutrazol (Shearing *et al*. 1986). The overall result therefore tends to be a reduction in tree growth (with consequent saving of up to 50% in the time required for pruning) and an increase in cropping efficiency in terms of yield per unit tree crown volume (Table 1).

Improved control of growth suggests the possibility of growing apple trees at closer than conventional spacings, allowing the available space to be filled as rapidly as possible before the use of paclobutrazol to limit inter-tree competition.

An illustration of this develoment is a planting at East Malling of Bramley on MM.106 (a semi-dwarfing rootstock producing trees which are free-standing) at close spacing normally employed for trees on M.9 (the most commonly used dwarfing rootstock; suffers from the defect of producing trees which need to be supported). Tree growth was well controlled by annual application of paclobutrazol sprays (Table 2) and after three years of treatment the sprayed trees had produced significantly less growth than

TABLE 2

Accumulated yield and shoot growth per tree during the first three years of paclobutrazol treatment (4-6 years old) and tree size and yield efficiency in the seventh year of paclobutrazol application (10 years old). Bramley on MM.106 and M.9 at a spacing of 4.5 m x 3 m

		Years 4 to 6		Year 10	
	Rootstock	Yield (kg/tree)	Shoot growth (m/tree)	Crown vol (m^3)	Yield (kg/ m^3 crown vol)
Untreated	MM.106	112.3	155.5	52.0	1.19
Paclobutrazol*	MM.106	126.0	44.0	21.2	2.41
Untreated	M.9	114.0	101.0	31.0	1.52

*Paclobutrazol sprays: year 4 2000 mg $litre^{-1}$ at 3 weeks after full bloom; year 5 1500 mg $litre^{-1}$; years 6-8 1000 mg $litre^{-1}$; years 9 & 10 two sprays, 1000 mg $litre^{-1}$ and 500 mg $litre^{-1}$.

untreated trees (P = 0.001). At the end of the seventh treatment year the untreated trees on MM.106 had outgrown the space available whilst the sprayed trees on this rootstock were well contained in size and were the most efficient in terms of yield per unit crown volume. In addition, trees on MM.106 had remained well anchored without the need for staking whereas those on M.9 required staking from the outset. Elimination of staking costs

TABLE 3

Effect of tree spacing on response to paclobutrazol (Six-year-old Cox's Orange Pippin on M.9)

Between row spacing (m)	Shoot growth (m)/tree		No. shoots/tree	
	Untreated	Paclobutrazol	Untreated	Paclobutrazol
1.75	31.7	9.1	102.7	47.2
2.00	31.2	14.2	103.2	64.3
2.35	31.7	12.3	103.0	58.8
2.90	40.4	20.2	133.3	85.7
3.70	35.0	27.7	112.8	111.7
SED	7.0		20.4	

is an important development as stakes may represent over 20% of the planting costs of high density orchards (Jackson 1985).

Increasing plant density can have a large negative effect on growth of fruit trees (e.g. Parry 1978). Likewise, close planting can greatly increase the growth retarding effect of paclobutrazol. For example, Table 3 shows the effects of different tree spacings on the response of Cox to sprays of paclobutrazol applied twice for three successive years (750 mg litre^{-1} applied at three and nine weeks after full bloom). In this case the differences in response were largely shown as differences in numbers of shoots produced.

Clearly, paclobutrazol shows promise for improving the control of apple tree growth and the interacting effect of spacing suggests that trees in high density plantings will be most efficiently controlled by this growth regulator.

The need for improved methods of growth control is even greater with tree crops such as sweet cherry for which no dwarfing rootstock is yet available to the grower. The problem of large tree size has resulted in the decline in cherry growing in several European countries despite unsatisfied demand for this fruit. The ease with which it is possible to control the growth of sweet cherry with paclobutrazol applied to the soil (Webster *et al*. 1986) is illustrated in Table 4. Annual application of the chemical for four years resulted in a marked reduction in tree size.

TABLE 4

Influence of paclobutrazol on growth and cropping of Early Rivers sweet cherry in the seventh year (third year of treatment)

	Crown volume (m^3)	Crop/tree (kg)	Crop (g)/ m^3 crown volume
Paclobutrazol*	20.6	6.1	307.2
Untreated	52.2	8.8	160.3
SED	3.6	0.6	41.2

*Paclobutrazol applied as a soil treatment: 1.6 g/tree year 5 and 0.8 g in years 6 and 7.

Although yield per tree was also reduced, cropping efficiency in terms of yield per unit crown volume was increased suggesting that this treatment may be used to increase sweet cherry productivity by growing trees at close spacings whilst relying on chemical growth regulation to contain tree growth. Systems based on this approach are now under test at East Malling and elsewhere.

Paclobutrazol therefore offers potential for improving the efficiency of fruit production in several respects. A reduction in the need for pruning not only reduces the cost of orchard management but also reduces the waste, through prunings, of the tree's resources. Improved crop production per unit crown volume is a direct measure of improved cropping efficiency, particularly where better control of growth allows trees to be planted at close spacings so that they rapidly fill the available orchard space. However, paclobutrazol is only one factor in efficient fruit production; it will complement rather than replace good tree management.

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THE ECONOMIC BENEFITS OF 'CULTAR' USE IN PEACHES AND NECTARINES

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ABSTRACT

Plant growth regulators are becoming increasingly accepted as means of increasing the economic productivity of orchard crops. Costed demonstration plots using 'Cultar' in Australia, Italy and the USA on peaches have shown that the product can reduce the costs of summer and winter pruning (through reduction of vegetative growth) and increase the value of fruit produced. Crop value per hectare has been increased by up to £12,000/ha through advances in maturity, which enable higher prices to be achieved per tonne of fruit, and increases in total economically harvestable yield. The general levels of crop value increase was in the £1,500-6,000/ha range compared with a mode of about £150-300/ha for pruning cost reductions.

INTRODUCTION

The use of chemical fungicides and insecticides is a well established part of the production process for high quality fruit. Plant growth regulators are now beginning to offer additional means of enhancing the profitability of fruit production. Their economic role may be to increase fruit quality, and thereby fruit value, to increase yield or to reduce production cost. For example, 'Regulex', a mixture of gibberellins A_4 and A_7 is used to reduce apple russet, leading to a higher percentage of class 1 fruit. 'Berelex', gibberellin A_3, is used to increase fruit set and yield of pears. Daminozide is used to enhance fruit colour and value in red apple varieties. Naphthyl acetic acid and carbaryl are used as fruit thinners in apples to reduce hand labour costs and produce larger apples.

'Cultar', a plant growth regulator containing paclobutrazol and marketed by ICI, has shown benefits in both increased crop value and reduced labour costs for pruning in a wide range of stone fruit crops. A number of these results have been reported in the literature. This paper reports the results of large and small scale demonstration trials on peaches to assess the economic benefits of 'Cultar' use, measuring increases in crop value and effects on labour costs.

MATERIALS AND METHODS

Commercial demonstration trials were carried out on peaches in Italy, Australia and the USA to assess the economic benefit of 'Cultar' use. 'Cultar', formulated as a 250 g/l suspension concentrate of paclobutrazol was appled for 1 or 2 years in established productive orchards. The application method, a foliar spray or a soil application, was chosen to reflect the climatic conditions. Paclobutrazol is taken up by the plant either through green stem tissue or via the roots. In rainfed agriculture in Northern Italy, foliage spray treatments were used in mid-May (shuck-split to pit hardening). In the arid irrigated conditions of Australia and California, soil applications during the dormant season were preferred. In Australia the soil applications were applied as narrow band sprays in areas of soil kept moist by sprinkle irrigation. Under the flood irrigation of California, a sub-surface injection was used 50-100 cm either side of the tree row. Crop varieties, plot sizes, application rates and trial duration are set out in Table 1.

Paclobutrazol suppresses endogenous gibberellin biosynthesis, reducing vegetative growth and diverting assimilates into reproductive growth (Lever, 1985).

Data were obtained, where possible, on vegetative growth, pruning costs, crop yields, grade-outs and selling prices. Growers were requested to continue all normal management practices according to the needs of the 'Cultar' and the untreated blocks. Fruitlets were thinned to similar levels for both treated and untreated. Fruit was harvested on each plot at the appropriate size and maturity. For consistency of comparison within this paper, all costs and prices were converted to pounds Sterling at the exchange rates prevailing in November 1986.

RESULTS

Australia

In both the peach and nectarine trials the vegetative growth control allowed a reduction in costs of pruning (Tables 2 and 3). The most significant reduction was recorded on the nectarines where the cost of summer pruning was reduced by 80%. Reduced competition for assimilates allowed increased fruit yields of 20 and 21%. These increases were partly achieved through increased total fruit numbers harvested (15 and 20% respectively) and partly through increased size leading to more fruit in the larger size categories. In Tables 2 and 3 fruit size gradings are expressed in terms of the numbers of fruit packed into a 3.3 kg tray. The larger fruit achieves a premium price but also because fewer fruit are packed per box, more boxes are sold for a similar number of smaller fruit. In these trials, the value of the crops was increased by £5,726/ha on peaches and £4,646 on nectarines (23 and 22% respectively). Including pruning benefits, the total economic benefit before deduction of 'Cultar' cost was £5,897/ha on peaches and £4,992 on nectarines.

Italy

The two Italian case studies in high density orchards also showed that 'Cultar' can dramatically reduce the need for summer and winter pruning. Reduction of summer pruning requirements are particularly useful because they ease labour management problems at a busy time of the year.

Table 1

Trials Details

Country	Crop	Variety	Age at First Treat-ment (yrs)	Density trees/ha	Plot Size	Irrigation Method	Application Method	Application Rate kg ai ha^{-1}
Australia	Peach	Spinks	6	746	20 trees	Sprinkler	Soil-narrow band	1.0 (1985)
Australia	Nectarine	Sunred	4	768	20 trees	Sprinkler	Soil-narrow band	1.0 (1985)
Italy	Peach	Spring-crest	7	1,481	0.5 ha	Rainfed	Foliar spray	0.75 + 0.50 (1985/1986)
Italy	Peach	Red haven	8	1,111	0.5 ha	Rainfed	Foliar spray	0.75 + 0.50 (1985/1986)
USA	Peach	Cal-red	8	331	1 x 4 trees	Flood	Soil injection	0.5 + 0.5 (1985/1986)
USA	Peach	O'Henry	8	331	1 x 4 trees	Flood	Soil injection	0.5 + 0.5 (1985/1986)

Table 2

Economic benefits of 'Cultar', Spinks peaches, Australia, 1985/1986

Parameter		'Cultar' treated		Untreated		Benefit of 'Cultar'
Fruit yield (te/ha)		19.6		16.4		3.2 (20%)
Fruit grading						
Fruit/tray*	A $/tray	Trays/ha	A $/ha	Trays/ha	A $/ha	
25-28	12	1,370	16,440	924	11,088	-
30-32	12	3,561	42,732	2,416	28,992	-
36	10	448	4,480	911	9,910	-
40	10	498	4,980	593	5,930	-
Total		5,877	68,632	4,924	55,920	12,712
Sterling equivalent £/ha						5,726
Winter pruning costs A $/ha		-	2,156	-	2,536	380
Total benefit A $/ha		-	-	-	-	13,092
Sterling equivalent £/ha		-	-	-	-	5,897

* 3.3 kg trays

Table 3

Economic benefits of 'Cultar', Sunred nectarines, Australia, 1985/1986

Parameter		'Cultar' treated		Untreated		Benefit of 'Cultar'
Fruit yield (te/ha)		16.7		13.8		2.9 (21%)
Fruit grading						
Fruit/tray*	A $/tray	Trays/ha	A $/ha	Trays/ha	A $/ha	
28	14	26	364	0	0	-
30	14	185	2,590	80	1,120	-
32	10	609	6,090	450	4,500	-
36	10	1,404	14,040	1,245	12,450	-
40	10	3,339	33,390	2,809	28,090	-
Total		5,563	56,474	4,584	46,160	10,314
Sterling equivalent £/ha						4,646
Summer pruning costs A $/ha		-	154	-	768	614
Winter pruning costs A $/ha		-	1,382	-	1,536	154
Total pruning costs A $/ha		-	1,536	-	2,304	768
Total benefit A $/ha		-		-	-	11,082
Sterling equivalent £/ha		-	-	-	-	4,992

* 3.3 kg trays

In both studies in 1985, the first year of treatment, the total yields were unchanged but a larger proportion of the harvest on the 'Cultar' treated plots was harvestable at the first two pickings. This gained the higher prices available at the start of the marketing season for the earlier variety Spring Crest and led to a value increase of £1,066/ha (Table 4). The total benefits in 1985, adding crop value increases and pruning saving, were worth £1,208/ha before deduction of 'Cultar' treatment costs for Spring Crest. Because of no price premium for the later variety Red Haven, the benefits in the first year were limited to the pruning saving of £71/ha.

The 0.75 kg ai/ha rate used in 1985 gave some carryover of vegetative growth effects into 1986 and also led to more blossom and a higher fruit set. This was perfectly manageable but did lead to an increase in the cost of hand thinning (Tables 4 and 5). It was judged that a lower application rate would be adequate in 1986 and 0.5 kg ai/ha was used.

Yields were increased in both trials in the second year of tretment by 22% for Spring Crest and 28% for Red Haven. With the price premium for early harvest for Spring Crest this gave crop value benefits in 1986 of £2,747/ha. Red Haven gained £1,416/ha. Over the two years the total benefits average £1,977/ha and £744/ha for the two varieties respectively.

USA (California)

The two Californian case study trials were carried out in low density (331 trees/ha) mid to late season peach varieties, Cal-red and O'Henry. 0.5 kg ai/ha injected into the soil in a band either side of the trees gave moderate to strong growth suppression. In the variety Cal-red there was 21% suppression in 1985 and 63% in 1986. In O'Henry, growth reduction was 24% in 1985 and 13% in 1986. The reasons for this variability are unclear. No pruning cost measurements were taken due to the small plot sizes, but it was considered that growers would be able to achieve some cost saving on a typical £200/ha winter pruning bill. Summer pruning is not a major practice in low density peaches in California.

These studies again showed increases in crop sale value to be the greatest benefit of 'Cultar' use. On both varieties the normal harvest period is spread over a 2 to 3 week period during which the price for fruit can drop by $3 to $5 per 24 lb box.

'Cultar' increased the total yield of fruit and the proportion harvested in the more valuable early pickings. Maturity was advanced in both years (Tables 6 and 7). Complete harvest data are only available for 1986. The combination of yield increases and advance in maturity on the case study sites resulted in increases of crop value of £6,090 for Cal-Red and £12,098/ha for O'Henry.

Table 4

Economic benefits of 'Cultar', Spring Crest peach, Italy, 1985/1986

Parameter	'Cultar' treated		Untreated		Benefit of 'Cultar'
1985 Fruit yield	te/ha	'000 Lire/ha	te/ha	'000 Lire/ha	'000 Lire/ha
1st harvest @ 600 Lire/kg	17.5	10,500	7.0	4,200	-
2nd harvest @ 500 Lire/kg	10.5	5,250	10.5	5,250	-
3rd harvest @ 400 Lire/kg	7.0	2,800	17.5	7,000	-
Total	35.0	18,550	35.0	16,450	2,100
Sterling equivalent £/ha					1,066
Labour costs	man hrs/ha	'000 Lire/ha	man hrs/ha	'000 Lire/ha	
Summer pruning costs	7	49	15	105	56
Winter pruning costs	48	336	80	560	224
Total pruning costs	55	385	95	665	280
Sterling equivalent £/ha					142
Total benefit '000 Lire/ha					2,380
Sterling equivalent £/ha					1,208
1986 Fruit yield	te/ha	'000 Lire/ha	te/ha	'000 Lire/ha	'000 Lire/ha
1st harvest @ 600 Lire/kg	14.1	8,460	0	-	-
2nd harvest @ 500 Lire/kg	10.5	5,250	8.7	4,350	-
3rd harvest @ 500 Lire/kg	7.0	3,500	11.5	5,750	-
4th harvest @ 400 Lire/kg	3.6	1,440	8.7	3,480	
Total	35.2	18,650	28.9	13,580	5,070
Sterling equivalent £/ha					2,573
Labour costs	man hrs/ha	'000 Lire/ha	man hrs/ha	'000 Lire/ha	
Hand thinning	82.4	824	59.2	592	- 232
Summer pruning	8.8	88	27.3	273	185
Winter pruning	45.0	450	84.0	840	390
Total labour costs	136.2	1,362	200.5	2,005	343
Sterling equivalent £/ha					174
Total benefit '000 Lire/ha					5,413
Sterling equivalent £/ha					2,747

Table 5

Economic benefits of 'Cultar', Red Haven, peach, Italy, 1985/1986

Parameter	'Cultar' treated		Untreated		Benefit of 'Cultar'
1985 Fruit yield	te/ha	'000 Lire/ha	te/ha	'000 Lire/ha	'000 Lire/ha
1st harvest @ 400 Lire/kg	9.0	-	15.1	-	-
2nd harvest @ 400 Lire/kg	21.4	-	8.0	-	-
3rd harvest @ 400 Lire/kg	11.3	-	15.1	-	-
4th harvest @ 400 Lire/kg	4.5	-	8.0	-	-
Total	46.2	18,480	46.2	18,480	-
Labour costs	man hrs/ha	'000 Lire/ha	man hrs/ha	'000 Lire/ha	
Summer pruning costs	-	None	-	None	-
Winter pruning costs	56	392	76	532	140
Sterling equivalent £/ha					71
Total benefit '000 Lira/ha					140
Sterling equivalent £/ha					71
1986 Fruit yield	te/ha	'000 Lire/ha	te/ha	'000 Lire/ha	'000 Lire/ha
1st harvest @ 400 Lire/kg	13.3	5,320	15.0	6,000	-
2nd harvest @ 400 Lire/kg	15.0	6,000	8.9	3,560	-
3rd harvest @ 400 Lire/kg	4.5	1,800	1.7	680	-
Total	32.8	13,120	25.6	10,240	2,880
Sterling equivalent £/ha					1,462
Labour costs	man hrs/ha	'000 Lire/ha	man hrs/ha	'000 Lire/ha	
Hand thinning	111	1,110	102	1,020	- 90
Summer pruning costs	-	None	-	None	-
Winter pruning costs	n/a	-	n/a	-	-
Sterling equivalent £/ha					- 46
Total benefit '000 Lire/ha					2,790
Sterling equivalent £/ha					1,416

n/a - Data not available

Table 6

Economic benefits of 'Cultar', Cal-Red peach, California, USA, 1985/1986

Parameter	'Cultar' treated		Untreated		Benefit of 'Cultar'
1985 Fruit yield*	Boxes/ha**		Boxes/ha		
1st harvest	882		277		
2nd harvest	1,640		331		
3rd harvest	1,186		511		
4th harvest	Data not collected				
Total	3,708		1,119		
	(= 40.5 te/ha)		(= 12.2 te/ha)		
'Cultar' benefit not assessed due to incomplete harvest data					
Labour costs					
No measurements were taken					
1986 Fruit yield*	Boxes/ha	$/ha	Boxes/ha	$/ha	$/ha
1st harvest @ $8/box	207	1,656	131	1,048	-
2nd harvest @ $8/box	605	4,840	316	2,528	-
3rd harvest @ $6/box	400	2,400	247	1,482	-
4th harvest @ $6/box	3,749	22,494	2,729	16,374	-
5th harvest @ $5/box	800	4,000	1,062	5,310	-
Total	5,761	35,390	4,485	26,742	8,648
	(= 62.8 te/ha)		(= 48.9 te/ha)		
Sterling equivalent £/ha					6,090

* >$2^7/_{16}$ ins dia

** 1 box = 24 lb

Table 7

Economic benefits of 'Cultar', O'Henry peach, California, USA, 1985/1986

Parameter	'Cultar' treated		Untreated		Benefit of 'Cultar'
1985 Fruit yield*	Boxes/ha**		Boxes/ha		
1st harvest	716		289		
2nd harvest	4,592		3,680		
3rd harvest	Data not collected				
Total	5,308		3,969		
	(= 57.9 te/ha)		(= 43.3 te/ha)		
'Cultar' benefit not assessed due to incomplete harvest data.					
Labour costs					
No measurements were taken					
1986 Fruit yield *	Boxes/ha	$/ha	Boxes/ha	$/ha	$/ha
1st harvest @ $9/box	1,875	16,875	551	4,959	-
2nd harvest @ $9/box	2,095	18,855	800	7,200	-
3rd harvest @ $7/box	1,667	11,669	1,694	11,858	-
4th harvest @ $7/box	855	5,985	1,339	9,373	-
5th harvest @ $6/box	69	414	538	3,228	
Total	6,561	53,798	4,922	36,618	17,190
Sterling equivalent £/ha	(= 71.6 te/ha)		(= 53.7 te/ha)		12,098
Labour costs					
No measurements were taken					

* $>2^{7}/_{16}$ ins dia

** 1 box = 24 lb

DISCUSSION

'Cultar' use was shown to give economic benefits both through reduced pruning costs and, more importantly, increased crop value. There appears to be scope in high density orchards to minimise the need for summer pruning and to make a significant reduction in winter pruning. Diversion of assimilates from vegetative to reproductive growth and alterations in harvesting patterns, however, open the way to potentially large improvements in fruit yields and prices. It is hypothesised that the yield increases and maturity advances seen are the result of a virtuous spiral. The initial reduction of vegetative growth allows the most precocious fruit to mature earlier. Once this is harvested, it reduces competition for the later maturing fruit. The increase in the total number of fruit harvested is thought to be because those smaller fruit which would not reach harvestable size by the final picking round on the untreated plots do have the opportunity on the 'Cultar' treated plot to reach acceptable size and maturity.

This paper has shown that the way in which the grower gains economic benefits from 'Cultar' will vary depending on his growing system, variety and local fruit price trends. It will be necessary for each grower to refine the use of 'Cultar' to suit his particular system within the guidelines given in the manufacturers' recommendations. Good management practices of fruit thinning and selective pruning will need to be maintained to maximise benefits.

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6.
Chemical Hybridizing Agents and Biotechnology

Chairman: Dr T. THOMAS

ACTIONS & INTERACTIONS OF A CHEMICAL HYBRIDISING AGENT (CHA)

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ABSTRACT

A CHA (Chemical Hybridising Agent) must fulfil a number of requirements, induction of male-sterility being paramount. In practice the action of a CHA is also interactive with genotype and environment. Assessment is substantially indirect since hybrid seed of high purity is the criterion of success. In these circumstances progress in a hybrid development programme is necessarily iterative. Such a conclusion is drawn from experience with the experimental CHA from Shell, WL84811 on winter wheat.

INTRODUCTION

The advantages that have been achieved in many species of crops, vegetables or decorative plants through the production and sale of F1 hybrid seed are widely recognised. Hybrid maize is the outstanding example, because of its wide adaption, marked hybrid vigour and, not least, a convenient diclinous habit. It is simple to detassel strips of maize on a field scale as a basis for hybrid seed production.

Species that are monoclinous present more of a challenge and, as was explained to an earlier meeting (Batch, 1978), wheat and barley are attractive candidates of this type for hybrid development. Breeders have for a number of years been trying to create workable systems based on male sterility for both these species. Cytoplasmic male sterility has indeed enabled commercial quantities of F1 hybrid wheat to be sold in the USA, notably by Cargill. For barley, there have been other systems such as the balanced tertiary trisomic technique (Ramage, 1975). But complexities in parent development and difficulties with seed increase have limited the adoption of such routes for both wheat and barley.

The possibility of creating functional male sterility by chemical means therefore excited plant breeders and by the early 1970's some successes were being reported. Shell Research Ltd. responded to Nickerson interests in that direction, with a wide remit as to target species. Suffice to record that two effective compounds were discovered at Sittingbourne and that since 1981 WL84811 (Azetidine-3-carboxylic acid) has been the basis of a substantial development programme world-wide. WL84811 is not a gametocide but a chemical which can cause disfunction at the pollination stage. This behaviour with WL84811 is confined to the <u>Gramineae</u> and the sensitivity has been most effective with wheats (Foster 1984, Cubitt and Curtis 1986).

At this point let us be reminded of the prime attributes of an ideal CHA:-

It induces complete male sterility.
It allows normal female fertility.
It offers a wide window of application in time and dosage.
It has no adverse effect on seed quality.
It is safe to use.
It presents no environmental hazard.

Practical experience with WL84811 especially as applied to wheat has led us to considerable understanding in these areas. Much detail is necessarily proprietary; but it is appropriate to discuss broader observations as to the performance of a CHA. The context for this is a field system to produce hybrid seed in quanity where two parental stocks are drilled in alternating strips of several metres width, one to be made male-sterile and the other to act as pollen donor. The provision of additional male parent as a surround, plus a measure of isolation, completes the pattern and should permit the harvesting of pure hybrid F1 seed off the treated (female) strips. However, in assessing the suitability of a CHA the focus will be upon the actions and interactions at plant level.

EFFICACY FROM A CHA.

Though simple enough in concept, the use of a CHA requires appreciationof the complexities in the processes of flowering, pollination and maturation of seed for the target species.

By interfering in the floral system with a CHA solely aimed at providing male sterility, we may introduce further disturbances. The components of flowering and seed setting in a CHA-modulated system can be expressed schematically to explain that statement and pin-point the vulnerabilities. (Fig.1).

We can now proceed to examine the scheme sectionally, provided we alsc recognise the consequence of inter-relationships.

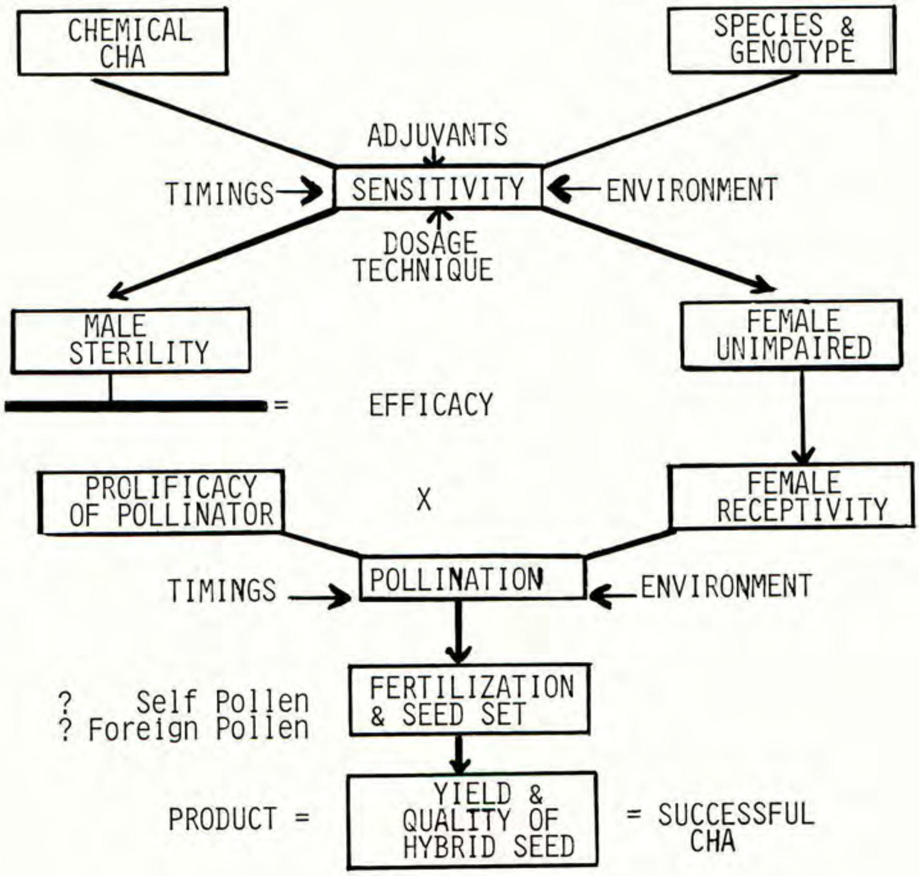
Sensitivity

Initial studies will have established that the chemical compound applied at an appropriate growth stage and in experimental dosage has potential for development as a CHA, and also that it does not cause gross disturbance of normal plant behaviour.

Successful development will require that this sensitivity to the CHA is rigorously examined across a broad range of genotypes and a matrix of dose and timing combinations. Initially these combinations will be selected to establish general effect, hoping for a wide window of application. Later the search will be for optimum performance consistent with specified levels of performance, on a narrower basis. As patterns become clearer, and an operational protocol is required, this accent will be further emphasised and may focus on specific genotypes. Thus the concept of efficacy is relative to the advancement of the project.

Figure 1.

ACTIONS & INTERACTIONS OF A CHA



Whether the CHA is proving effective in each test has to be assessed unambiguously. If the anthers abort before they mature, the test is direct, but a CHA can be effective without killing the anthers or the pollen. So efficacy may have to be indirectly assessed by checking for lack of normal selfing in protected flowers (bagged heads in wheat). However bagging and tenting can be detected as partial suppressors of seed sets, so a cautionary word is inserted here on the assessment technique involved.

As one endeavours to determine the sensitivity pattern(s) for given genotypes, there is inevitable concern for differences over environments, and consistency over seasons. Where differences in sensitivity become recognised between countries, this may be enviromental or due to differences of germplasm (or a combination of both). With environment one is firstly aware of contrasts in temperature patterns and growth rates, but other components of environment cannot be ruled out.

Before moving from immediate aspects of efficacy, it must be mentioned that adjuvants and application technique are contributors (and variables) in the system. Even preliminary definitions of the performance of the CHA inevitably reflect an experimental protocol. The specifications that are ultimately chosen for a commercial formulation and recommended field technique may, indeed almost certainly will, be slightly different.

Thus far we have discussed efficacy towards the male element, the pollen. It is axiomatic that the female function should not be impaired. Initially that means that ovules and egg cells should not be disturbed by the CHA; i.e., female fertility needs to be normal (or very nearly so). Gross disturbance would be self evident, but partial loss of female capacity can be overlooked by being compounded with behaviour at or after pollination: suffice to record that here too we are concerned with another indirect evaluation.

To recapitulate so far, the CHA is deemed effective on the basis of experimental studies wherein genotype, environment (in various manifestations), dose, timing and application technique (including adjuvants) all affect the data obtainable. But male sterility, as an observed lack of seed set, is not of itself the "object of the exercise". It is an interim condition and success must be judged by the yield of hybrid seed. For that to occur a further section of the system must function.

Pollination

Given that a high degree of male sterility has been induced in desired genotypes, achievement of a high yield of hybrid seed (an economic yield) requires the arrival of an adequate supply of pollen from the adjacent plantings of the male parent. It must arrive during an appropriate period that synchronises sufficiently with receptivity in the female. It was soon recognised that individual genotypes of wheat differ in their suitability to act as male parents: they differ in anther volume, in extrusion of those anthers and in the duration of anthesis. These are not related to any behaviour with a CHA, but are nevertheless significant elements for the CHA system to be useful: a good pollen donor is essential.

Synchrony of flowering was mentioned, and now deserves further comment. It is recognised that maturation of the male and female functions will not necessarily coincide; indeed they seldom do so exactly. For wheat to cross pollinate well a slight offset in flowering time has been found desirable. However, treatment of the plants with CHA may (and in the case of WL84811 does) introduce a slight delay in flowering. Judgement therefore of an appropriate male parent for timeliness of flowering with a given female parent must to that extent allow for any offset caused, as a side effect, by the CHA treatment.

The concept of female receptivity also needs recognition. Not all genotypes prove equally receptive to donor pollen. Adequate gaping of the flower and sustained functioning of the style are the obvious requirements at this point, but there may be others.

The suitability of the respective genotypes, male and female, is thus crucial for successful cross-pollination, with an accent on timeliness. Again environment is a significant factor. Genotypes differ in their response to day length, so relative flowering dates may be shifted by differences in geographical latitude. Gross differences in winter weather particularly can cause perturbation of growth patterns that in extreme cases upset the timing, the "nick". Inclement weather at flowering is a more local manifestation. These factors are distant from the CHA and are not controllable but their influence must be assessed and the system must be robust enough to accommodate the risks they pose.

Presuming at this point that floral behaviour has been appropriate (good female receptivity, good pollen availability and good nick), cross-pollination should occur with high frequency.

Fertilization and Maturation of Seed

Successful growth of donor pollen through a style and eventual fertilization is dependent upon a set of interactions at cellular level.

Firstly, it must be reminded, the treated female parent is potentially carrying self pollen (unless the anthers were aborted). Such pollen whether dead or rendered ineffective may reach the style, with the potential to interfere with the success of the donor pollen that arrives. Interference there would be physical or chemical. At the same time we need to recognise that the style itself may have sufficiently high concentration of residual CHA that donor pollen is affected on arrival. Pollen grains perform in consort: fertilization is more successful in wheat when a cluster of grains are involved (Barnabus, 1985).

Pollen behaviour in these circumstances is insufficiently understood. But there is reason to be mindful that pollination and fertilization are linked by a further chain of events, in which there may be continuing influence of the CHA and unusual competition effects. Depending upon the frequency of foreign pollen arriving as a contaminant there can also be a problem here with impurity from "illegal" fertilization, though self-pollinations are more normally the risk, in our experience.

After fertilization has occurred there should be little cause for further disturbances and maturation of seed should proceed normally. However, in some cases there has, with the CMS system, been tendency for grain to be abnormally pinched, and if seed set is low individual grains may become enlarged. Some tendency to elevated levels of   amylase and sprouting has occurred also. These are unlikely to be directly attributable to the CHA per se; however they may result from disturbance of developmental sequences in the grain, as a sink, consequent upon the delayed pollination required for hybrid production.

Subject to satisfactory plant behaviour throughout all the foregoing stages, a candidate CHA may be judged effective functionally, for undertaking extensive hybrid seed production.

Breeding & Development

Parallel to the evaluation of a CHA and the development of appropriate protocols for is use, breeders have been endeavouring to perfect the choice of parents and identify the most advantageous hybrids to issue. It is therefore very necessary that development of the CHA be advanced with the most up-to-date germplasm, in a totally integrated approach. Co-evolution is undoubtedly required if the technique is to provide attractive, high-performance hybrids on a sound economic basis. That is certainly the experience that we have enjoyed with WL84811 at Nickerson and Shell Research.

Conclusions

It will now be clear that the efficacy of a CHA has to be established not only at the target point (male gametes) but throughout development till regular production of F1 hybrid seed in abundance can be assured. The system is simple yet fraught with uncertainties and interactions with environments and with genotypes (which themselves will need to be changed over time).

A practical programme of development can only cope with such a complex scenario by iterative procedures. This has been the basis of Nickerson operations with WL84811 over the past six seasons, here and abroad. As the body of data and experience grows and relevant genotypes for hybrid production are found, there must be further refinements of the CHA usage for production purposes. Doses and timings particularly can be chosen which provide an adequate window of application for field purposes whilst achieving optimal levels of seed yield with due economy and required purity. That is the need: it is however of considerable importance to appreciate that the task can be more complex than such a simple technique would appear to suggest.

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