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Effects of paclobutrazol on avocado (*Persea americana* Mill.) cv. 'Fuerte'*

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ABSTRACT

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Mature avocado trees (*Persea americana* Mill.) of cultivar 'Fuerte' were sprayed with Cultar®, a commercial formulation containing 25% paclobutrazol (ICI, U.K.). Hand spraying of individual trees before or at the flowering stage resulted in an increase in the number of harvested fruits per tree, reaching 97 and 174% above the controls in two groves. The phenological state of the bloom affected the results. The best additional yields, of 379 and 546% in two different groves, were obtained from sprays at the stages of elongating inflorescences and incipient anthesis.

No residual or cumulative effect of Cultar® could be detected in two consecutive years of treatment with regard to tree vigour, general appearance, yield, or other factors.

Application at 1000 l ha^{-1}, by a commercial sprayer with a blower ("Spidet"), using 3% Cultar® resulted in a 90% increase in yield.

The Cultar® sprays did not alter considerably the trends or the numbers of vegetative flushes during the season, but they did affect shoot elongation and 2% Cultar® caused a reduction of ~30% in shoot length.

The time lapse between fruit set and the start of vegetative growth was 4–5 days longer in the treated inflorescences. Cultar® may overcome the problem of low yields in trees which are considered to be of a clonal low-production type.

The Cultar® sprays seem to increase yield in the "off" year in trees which bore a heavy yield in the previous "on" year.

Keywords: avocado; paclobutrazol; yields.

INTRODUCTION

Avocado (*Persea americana* Mill.) cultivar 'Fuerte' is known to be a high-quality fruit cultivar, but also unstable and moderate to low in yielding (Bergh, 1967, 1984; Lahav and Zamet, 1975; Wolstenholme, 1988). Nevertheless,

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this cultivar flowers profusely, with a very high potential for yielding (Lahav and Zamet, 1975; Wolstenholme, 1988). The reasons for 'Fuerte's' low yields are not fully understood, but obviously a tremendous post-bloom fruitlet drop is a major cause of the eventual low crop (Lahav and Zamet, 1975; Biran, 1979; Sedgley, 1980; Degani et al., 1986).

Reducing the vigorous vegetative sink of the spring growth flush, which is likely to overlap with fruit set in 'Fuerte', led to a several-fold increase in yield (Biran, 1979). This was achieved by manual removal of the new flushes as soon as they were detected.

The growth retardant paclobutrazol delays or reduces growth in several species of fruit trees (Quinlan, 1981; Hawkins et al., 1985; Shearing et al., 1985; Kohne and Kremer-Kohne, 1987; Whiley et al., 1988). A yield increase caused by paclobutrazol treatments was shown in pears and apples (Raese and Burts, 1983; Shearing et al., 1985). Treating avocado with paclobutrazol either had some effect on the number of retained fruits on treated branches (Kohne and Kremer-Kohne, 1987), or virtually no effect when the whole trees were treated (Whiley et al., 1988).

The objective of the present research was to determine whether paclobutrazol can be useful in inhibiting the vegetative growth and increasing yields of 'Fuerte' substantially.

MATERIALS AND METHODS

Location of the experiments. – All experiments were carried out in mature 10-year-old avocado groves. Groves I and III are located 150 m below sea level in a relatively warmer region than Groves II and IV, which are located 25 km further north and ~70 m above sea level. Because of the difference in the ambient temperatures in the spring, Groves I and III flowered 3–4 weeks before groves II and IV.

The treated plots. – In each grove, one or two plots (numbered 1 and 2) were chosen for the treatments. The plots are planted mainly with 'Fuerte', with cultivar 'Ettinger' as a windbreak. The 'Fuerte' trees, 4–6 m in height, are planted 6 m apart within rows and 7 m between rows (~240 trees ha^{-1}). During the experiment, most of the trees were in very good vegetative condition and grew vigorously.

Phenological stages. – The stage of flowering was used as the criterion for the time of paclobutrazol application. The following stages were considered.

(a) "Swollen buds" (the first detectable flowering stage), referring to terminal bud swelling.

(b) "Elongating inflorescences", when the swollen buds had started to elongate and form the cluster-like inflorescence. It takes several weeks from the swollen-bud stage to the anthesis of the first flowers. An elongating inflorescence will reach anthesis before it is 10–18 cm long (referring to the terminal inflorescence only).

(c) "Incipient anthesis", referring to the anthesis of the first flowers in the inflorescence. This occurs after the cessation of growth of the inflorescence. As a terminal inflorescence in 'Fuerte' contains > 100 flowers, it takes at least 3 weeks to complete flowering and fruit set.

(d) "Full bloom", when > 50% of the flowers of most of the inflorescences on the tree are at or after anthesis.

(e) "End of flowering". The time of flowering varies among the inflorescences on a tree. When < 10% of the flowers are still on the tree, we considered this to be the end of flowering for the purpose of spraying with Cultar®.

Treatments. – Paclobutrazol (2 RS, 3 RS)-1-(4-chlorophenyl)-4,4,-dimethyl-2-(1H-1,2,4-triazol-1-yl)pentan-3-01 was used in its commercial formulation, Cultar® (25%, a.i.), obtained from Makheshim Ltd., Israel, and produced by ICI Ltd., U.K. All treatments were applied as a foliar spray to run-off, with the addition of 0.1% L-77 (non-ionic surfactant). In the years 1984, 1985 and 1986, in Groves I, II and IV, treatments were applied by a 10-l hand sprayer, with 3–5 l of the solution needed to wet a single tree to run-off. In 1986, in Grove III, a commercial Spidet sprayer with a blower was used, at a pressure of ~80–100 PSI and a maximum speed of 3.5 km h^{-1}. Under these conditions, the amount of solution used was 1000 l ha^{-1}. In Grove IV, one of the treatments consisted of two successive sprays, given 1 week apart.

Measurements. – The vegetative flushes were assessed fortnightly and the results were recorded as percent estimated area of the tree which appeared to be growing actively. This is an index of the relative numbers of shoot tips that are growing actively.

All trees were harvested at horticultural maturation of the fruits and results were recorded separately for each tree.

Experimental design. – The experiments carried out in 1984 and 1985 were designed as completely randomized blocks with five blocks for each treatment and one tree per treatment per block. The results presented in Table 3 and in Figs. 1, 2 and 3 were in a completely randomized design with various numbers of trees in each of the experiments.

RESULTS

The response to increasing concentrations of Cultar® showed that the best effect, in terms of number of fruits per tree, was achieved with the highest

TABLE 1

Effect of various concentrations of Cultar® on the yield (fruits per tree) of 'Fuerte' avocado trees treated in early spring (1984) by hand sprayer (five trees per treatment; 3–5 l per tree). Application time was at "full bloom" in Grove I, Plot 1, and at "swollen buds" in Grove II, Plot 1. Figures followed by the same letter do not differ significantly at $P=0.05$

Grove	Plot No.	Phenological stage at application	Cultar® concentration (%)	Fruits per tree	% of control
I	1	Full bloom	0	232a	100
			0.4	314a	135
			0.8	282a	122
			1.6	283a	122
			3.2	457b	197
II	1	Swollen buds	0	82a	100
			0.8	155ab	189
			1.6	158ab	193
			3.2	225bc	274

TABLE 2

Effect of 4% Cultar®, applied at different phenological stages, on the number of fruits per 'Fuerte' avocado tree treated in early spring (1985) by hand sprayer (five trees per treatment; 4–5 l per tree). Figures followed by the same letter do not differ significantly at $P=0.05$

Grove	Plot No.	Phenological stage at application	Fruits per tree	% of control
I	2	Control	65a	100
		Swollen buds	88a	135
		Elongating inflorescences	420c	646
		Incipient anthesis	347c	534
		End of flowering	196b	301
II	2	Control	72a	100
		Swollen buds	214b	297
		Elongating inflorescences	345b	479
		Incipient anthesis	357b	496
		End of flowering	284b	394

concentration used, viz. 3.2% (Table 1). The difference in results between Groves I and II could be attributed to the difference between the two groves in phenological stage at the time of Cultar® application.

Two trials were conducted in 1985 in order to determine the optimum application time. Both trials were in Groves I and II, but in plots different from those treated in 1984. The high concentration of Cultar® used in these trials was to avoid a limiting factor and emphasize only the effect of the differences

TABLE 3

Yields of 'Fuerte' avocado trees as affected by location, Cultar® concentration, application method and previous Cultar® treatments. Trees were sprayed at the elongating inflorescence stage in early spring (1986). Figures followed by the same letter do not differ significantly at $P=0.05$

Grove and application method	Plot No.	Number of trees	Cultar® concentration (%)	Previous application	Yield	
					kg per tree	% of control
I	1	8	0	1984	47a	100
hand,		8	2		95b	200
3-5 l per tree		8	4		103b	219
I	2	14	0	1985	35a	100
hand,		14	2		110b	314
3-5 l per tree		16	4		103b	294
II	1	7	0	1984	104a	100
hand,		7	2		132b	126
3-5 l per tree		7	4		137b	131
II	2	12	0	1985	118a	100
hand,		12	2		114a	96
3-5 l per tree		12	4		126a	107
III	1	31	0	–	50a	100
Spidet,		44	3		98b	196
1000 l ha^{-1}						

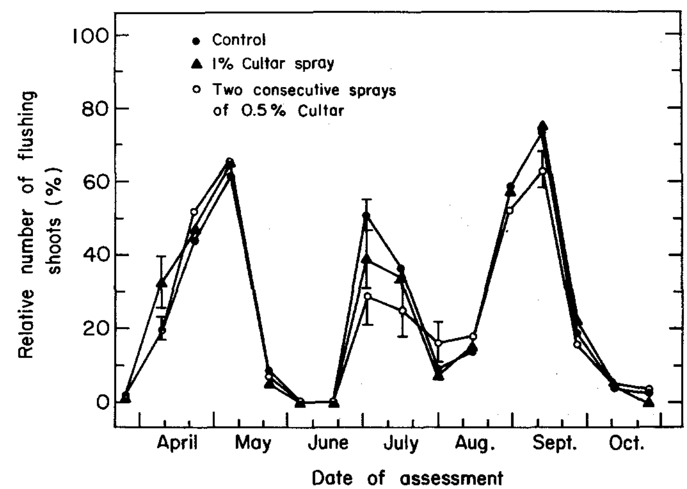

Fig. 1. Effect of Cultar® sprays on the number of flushing shoots (as a percent of tree surface area) during the growing season. 'Fuerte' avocado trees were hand sprayed at the stage of elongating inflorescences in early spring, 1986. Five trees were used per treatment and 40 trees for the control used as replications in Grove IV, Plot 1.

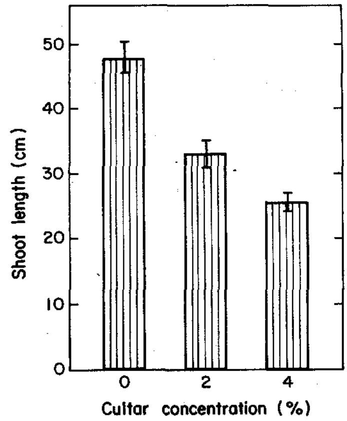

Fig. 2. Effect of Cultar® sprays on the seasonal shoot length of 'Fuerte' avocado trees (Grove I, Plots 1 and 2). Trees were treated at the elongating inflorescence stage in early spring, 1986. Results are averages (±SE) of five trees (three shoots per tree).

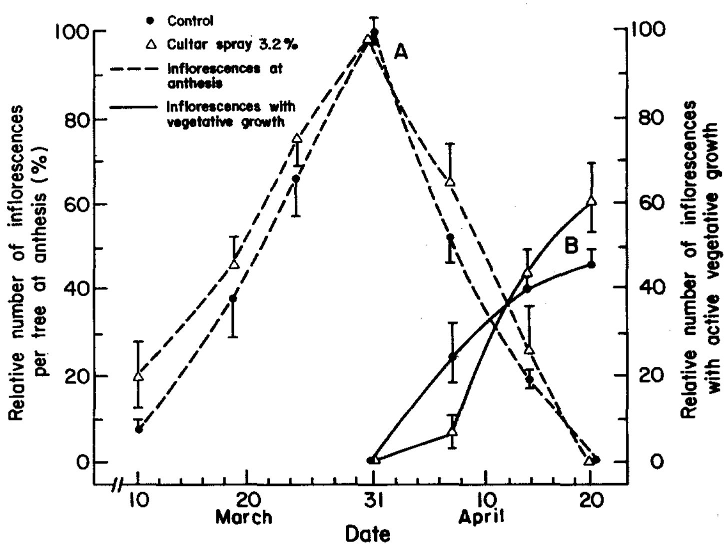

Fig. 3. The course of flowering (A) and the emergence of the vegetative growth from inflorescences (B) as affected by 3.2% Cultar® spray. 'Fuerte' avocado trees were treated in Grove II, Plot 1, in 1984 at the swollen-bud stage. Results are averages of 10 replications ± SE.

in the time of application. The best response to Cultar® was at the stages of "elongating inflorescences" and "incipient anthesis" (Table 2). However, significant yield increases were also obtained with other application times (Table 2). The trees were very productive in 1986, and untreated trees in Grove II gave a yield of > 100 kg per tree, which is ~24 000 kg ha^{-1} (Table 3). On such overloaded trees, the effect of the Cultar® sprays was not very pronounced. Even so, increased yields were obtained from the treated trees in Groves I and III, since these control trees were not overloaded (Table 3). Comparing Plot 1 with Plot 2 in Groves I and II (Table 3) shows a non-significant effect of previous Cultar® treatments on the current yield. Spraying trees with a commercial Spidet sprayer added nearly 100% to the yield of the control trees (Table 3, Grove III).

The vegetative flushes showed three peaks during the season (Fig. 1) and growth inhibition as a result of the Cultar® application in the early spring could be detected only in the second and perhaps third peaks (Fig. 1). Cultar® treatment inhibited total shoot length in the sprayed trees (Fig. 2).

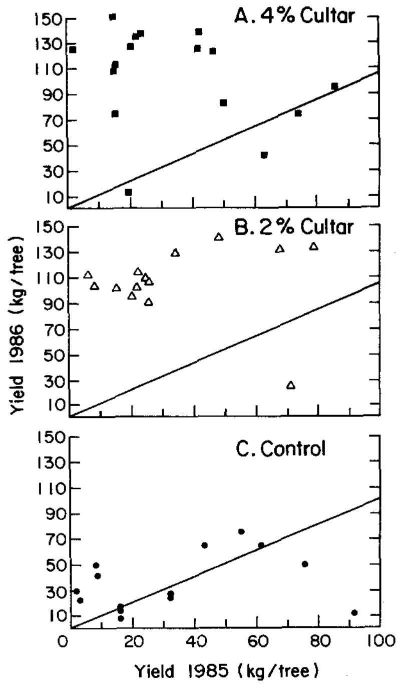

Fig. 4. Effects of 2 and 4% Cultar® sprays on the yield of 'Fuerte' avocado trees in 1986, with various yields from the previous year given on the abscissa. Trees were treated in the elongating inflorescence stage in early spring, 1986 (Grove I, Plot 2). The diagonal line represents the hypothetical location of equal yields for the x and y axes.

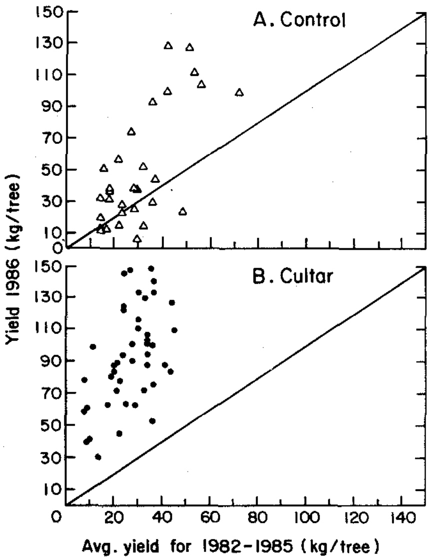

Fig. 5. Detailed effects of 3% Cultar® spray on the yield of 'Fuerte' avocado trees in 1986 with various 4-year average yields given on the abscissa. Trees were treated with 3% Cultar® at the elongating inflorescence stage in early spring, 1986 (Grove III, Plot 1). The diagonal line represents the hypothetical location of equal yields for the x and y axes.

Many of the inflorescences in 'Fuerte' avocado initiated a vigorous shoot during the second half of the flowering period (Fig. 3). The Cultar® spray, when applied at the "swollen-bud" stage, caused a delay in this shoot initiation and at the same time there was some effect on the earliness of the anthesis and fruit set, so that the gap between the initial fruit set and the initial vegetative growth became 4–5 days longer than in the control (Fig. 3).

The heavy-bearing 'Fuerte' trees tended to alternate in yield on an individual tree basis. Cultar® affected this tendency and a 2 or 4% concentration of the material increased the yields in trees which bore heavily in the previous year (Fig. 4).

Cultar® treatment doubled and tripled the yields of large groups of trees which were considered to be low yielding on a 4-year-average basis (Fig. 5).

DISCUSSION

It has been suggested that paclobutrazol acts by inhibiting the biosynthesis of the endogenous gibberellin (Goldsmith et al., 1983; Dalziel and Lawrence, 1984). There are indications of the involvement of the inhibitor in processes such as cold hardiness (Kolodziejczak and Hamer, 1985) and water stress (Swietlik and Miller, 1983). The distinct effect of Cultar® on yield promotion in 'Fuerte' avocado (Tables 1, 2 and 3) seems to be a result of the growth-inhibiting effect (Fig. 2), part of which occurred concomitantly with the fruit-setting process (Fig. 3). Such an effect was found in grapes and in avocado by eliminating the young growth (Coombe, 1972; Biran, 1979). The removal of the young growth could encourage the development of newly set fruits without the competitive interference for essential assimilates (Finazzo and Davenport, 1987; Wolstenholme, 1988).

One of the major reasons for the relatively low yields in 'Fuerte' is that quite a large proportion of trees are genetically of low-yielding potential (Ben-Ya'acov, 1975). Cultar® seems to have an effect on such poorly producing trees. Yields of the individual trees (shown as averages in Table 3, Grove III), as presented in Fig. 4, show quite surprisingly that Cultar® improved their yields.

Examination of the differences between low- and high-yielding 'Fuerte' avocado trees (Bar-On, 1986) uncovered a significant difference: the time lapse between peak fruit set and the appearance of the new terminal vegetative growth was 5 days more in the high-yielding trees. In the present work, Cultar®-treated trees showed the same trend and magnitude of effect (Fig. 3).

The effect of Cultar® in improving the yield of trees expected to have a poor yield after the "on" year (Fig. 5) is probably a result of its effect on fruit retention, since such "off-year" trees flowered only 10–30% of their "on-year" potential.

The results described suggest that the expected effect of paclobutrazol (and similar compounds) on yield improvement is via improved fruit retention, as a result of the retardation effect on vegetative growth concomitant with the fruit-setting process. It is possible, therefore, that paclobutrazol will have no effect when such vegetative growth is not simultaneous with fruit set, as would be the case with cultivars 'Reed', 'Nabal', etc. However, it is possible to find a phenological stage at which it would make sense to use paclobutrazol, even in these cultivars, because it might reduce fruit drop in a later stage ("June-drop").

As gibberellins themselves are essential for fruit growth and retention, it might be that paclobutrazol will have a favourable effect on yield only when the application method, concentration and timing will all ensure a very limited effect, so that vegetative growth will be retarded, but the reduction of gibberellin levels in the fruits will be minimal. Therefore, tree vigour is a major factor for recommending the concentration of Cultar® to be used: 2% will be suitable for very vigorous trees and presumably no more than 1% should be used in moderately growing orchards. Application should be just before anthesis, but only if that coincides with weather conditions suitable for fruit set. Several tons per hectare of additional yield, as a result of such Cultar® treatments, is unquestionably profitable for the 'Fuerte' avocado grower.

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