Effects of (2-Chloroethyl)phosphonic Acid on Development and Abscission of Maturing Sweet Cherry (*Prunus avium* L.) Fruit[1,2]

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Abstract. (2-Chloroethyl)phosphonic acid (ethephon) applied as a foliar spray to sweet cherry trees within 2 weeks of fruit maturity promoted fruit abscission at the lower (fruit:pedicel) zone, as indexed by a reduction in the fruit removal force (FRF). There was no significant effect, at the concn studied, on abscission at the upper (pedicel:peduncle) zone. Promotion of abscission with ethephon was time and concn dependent. Ethephon concn of 100 to 1000 ppm were effective with a greater response from the higher concn. Absorption periods of 4 and 24 hr resulted in responses equal to 73 and 94% of that observed when ethephon was present for the entire experimental period. Of 9 sweet cherry cultivars evaluated, all responded similarly in terms of reduction in FRF. Ethephon enhanced fruit enlargement and pigmentation when applied early in Stage III of fruit growth. The increase in wt was most pronounced in the fleshy pericarp tissue.

Control of the abscission process of maturing fruit would provide a basis for improved hand and machine removal as well as programed harvesting. Although much data have been published on the nature of leaf abscission (4, 18, 22, 28) and on premature drop of fruit (5, 10, 25), interest in the fundamental and practical aspects of promotion of abscission of maturing fruit is, with few exceptions, of recent origin (6, 8, 14, 16, 20).

Interest in the control of fruit abscission has been directed to facilitating machine harvest. Consequently, studies have been undertaken to identify chemical agents capable of reducing the force necessary to remove the fruit with little or no impairment of the parent plant or quality of the harvested fruit (8, 15, 20, 23). Several chemicals have been identified capable of reducing the fruit removal force in olives (12, 14, 15), citrus (16, 23, 29), cherries (8, 20, 31), and other crops (10). However, in several instances poor removal, excessive leaf abscission and other undesirable secondary factors have limited their usefulness. We are reporting, herein, on the effect of ethephon in promoting fruit abscission in the sweet cherry and on some concomitant effects on the growth and development of the fruit.

Experimental

General. All studies were performed on 12- to 15-year-old trees of designated cultivars grown in a commercial orchard. Experiments were conducted over a time period of approximately 20 days preceding maturity (unless otherwise stated during Stage III of fruit growth) during the 1969 and 1970 growing seasons. Treatments were assigned to individual branches of similar vigor and crop load. Ethephon (Amchem 68-240, Amchem Products, Inc., Ambler, Pa.) was applied as an aqueous spray containing 0.1% X-77 (principal ingredients -- alkylarylpolyoxyethylene glycol, free fatty acids and isopropanol) as a surfactant. Sprays were applied with a hand sprayer by wetting the foliage to the drip point. Fruit removal force (FRF) was determined with a Hunter Mechanical Force Gauge (Hunter Spring, Hatfield, Pa.), as previously described (8), on a sample of indicated size. All FRF determinations were made within 1 hr of sampling to avoid confounding of data by loss in FRF as a result of holding the harvested samples (Table 1). Randomized block designs were employed and comparisons among treatment means were made using Tukey's ω-test.

Table 1. Effect of elapsed time between harvesting a fruit sample and measuring the force required to remove the fruit (FRF) at the lower abscission zone.

Measurement	Hr held[x]			
	0	1	2	4
FRF (g)	617a	581ab	541b	489c

[x]Means followed by different letters differ significantly at P = 0.05.

In several instances, the experiments were performed on 2 cvs., Windsor and Emperor Francis, in both seasons or repeated at a second location. However, where the results were generally similar only a single representative experiment will be reported.

Nature of fruit separation. The point of fruit detachment and the force required to cause separation at the upper[5] (peduncle:pedicel) and lower (pedicel:fruit) abscission zones were determined weekly during development of the fruit. Fruit growth, as indexed by fresh wt, was monitored twice weekly utilizing a sample of 20 'Windsor' fruit.

When subjected to a pull force the site of fruit separation varied with fruit development (Fig. 1). The weakest point early in fruit growth was the pedicel. As the fruit developed the pedicel was markedly strengthened, probably through development of the vascular and associated schlerenchyma tissues, and then separation occurred at the upper abscission zone. Fruit that failed to set or had been damaged separated at the upper zone. During Stage III fruit growth separation occurred between the pedicel and fruit (lower abscission zone). When separation first occurred at the lower zone, vascular tissue was pulled from the fruit often resulting in the tearing of the epidermis, but as the fruit approached full maturity a clean separation was achieved.

The force required to effect separation at the upper zone (700 to 1000 g) showed no marked change with fruit development (Fig. 1). The lower zone, early in fruit

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[5]Generally, separation at the upper zone occurs between the peduncle and pedicel, although often separation may occur through the peduncle or between the peduncle and spur. In this paper we view this region collectively as the upper abscission zone.
[6]Unpublished data. Bedford, C. L., Department of Food Science, Michigan State University, East Lansing.
[7]Wittenbach, V. A., Morphological and physiological aspects of cherry fruit abscission with reference to 2-chloroethylphosphonic acid. M.S. Thesis, Michigan State University. 114 p. 1970.
[8]Ibid.

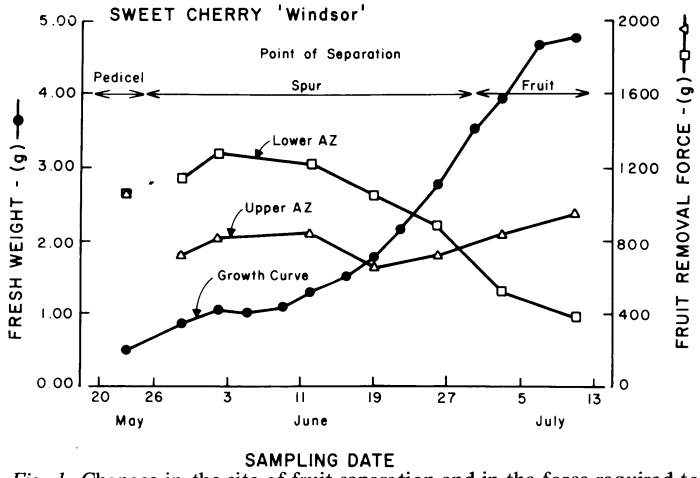

Fig. 1. Changes in the site of fruit separation and in the force required to effect separation at the upper and lower abscission zones of 'Windsor' sweet cherry as related to the development of the fruit.

development, required a larger force (1300 g) than the upper to effect separation, and at the beginning of Stage III began to decrease attaining a min value (approx 400 g) at maturity (Fig. 1).

Effect of ethephon on fruit abscission. (a) Upper vs. lower zone. Since there are 2 abscission zones in the sweet cherry through which fruit separation may occur, it was necessary to establish the relative effect of ethephon on both the upper and lower abscission zones. Two comparable branches on each of 6 'Windsor' trees were selected and 1 branch of each pair was treated with ethephon at 1000 ppm approximately 2 weeks before maturity. Twelve days after treatment the force required to cause separation was determined for both the upper and lower abscission zones. The pedicel was cut in half on 10 fruit of uniform development from each treatment and the FRF was measured for both zones of each individual fruit.

Ethephon at 1000 ppm did not cause a reduction in FRF at the upper zone (Table 2). By contrast, a significant decrease in FRF was noted at the lower zone.

Table 2. Effect of ethephon (1000 ppm) on fruit removal force (FRF) at the upper and lower abscission zones of 'Windsor' sweet cherry 12 days after foliar application.

Concn	FRF[x]	
	Upper zone	Lower zone
(ppm)	(g)	
0	946 a	391 b
1000	1011 a	204 c

[x]Means followed by different letters are significantly different at P=0.05.

Since ethephon enhanced fruit abscission primarily at the lower zone, data presented in the following experiments are limited to changes in FRF for this zone.

(b) Time-course and concentration. Designated branches of 'Emperor Francis' were sprayed with ethephon at 0, 50, 100, 200, 400, 800 and 1600 ppm. Four replications were established and FRF was determined on 50 selected fruit from each treatment initially and after 4, 8 and 14 days. All treated branches were evaluated for phytotoxicity.

FRF of the control decreased from approximately 1350 g to about 600 g during the experimental period (Fig. 2). Ethephon caused a rapid and significant decrease in FRF as compared to the control. After 8 days, concn of 100 ppm or greater significantly (P = 0.05) decreased FRF, with greater responses occurring with increasing concn (Fig. 2). An optimum response was obtained at 8 days after treatment.

Leaf abscission, particularly on weak spurs located in the interior of the tree, terminal dieback, gummosis, occasionally enlarged lenticels and longitudinal cracks (on current season's

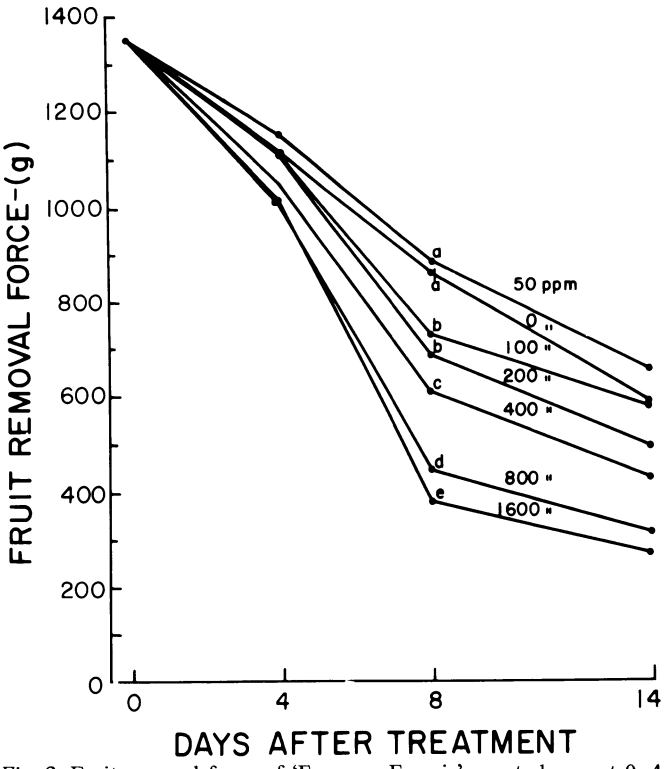

Fig. 2. Fruit removal force of 'Emperor Francis' sweet cherry at 0, 4, 8 and 14 days after foliar application of selected concn of ethephon. Points at 8 days followed by different letters are significantly different at P = 0.05.

wood) were noted on the 1600 ppm treatment. At lower concn, little (abscission of spur leaves) or no phytotoxicity was noted.

(c) Time of application in relation to maturity. Since FRF of the lower abscission zone decreases rapidly with maturity, a comparison was made to establish the relative effect of ethephon in reducing the FRF when applied at various times over approximately a 3-week period just prior to maturity. Branches of 'Windsor' were selected and assigned to 5 treatments. Several branches were collectively designated the control (to provide adequate fruit for a series of FRF determinations). One of the remaining branches was treated with ethephon at 500 ppm on 7/2, 7/6, 7/10 or 7/15, representing approximately 18, 14, 10 and 5 days before fruit maturity. The first treatment (7/2) was applied at the transition from Stage II to III while the remaining treatments were applied during Stage III. At time of treatment and again after 5 days, FRF was determined on a 50-fruit sample. The data were expressed as the decrease in FRF of the treated compared to the control. In addition, FRF was determined on a fruit sample from all treatments at maturity (7/20). Four replications were employed.

There was no significant change in effectiveness of ethephon when applied over a 3-week period just prior to maturity (Table 3). The FRF at maturity reflected time of application in that the greater the elapsed time between treatment and FRF measurement generally the greater the effect.

Table 3. Effect of time of ethephon (500 ppm) application in reference to maturity[x] on fruit removal force (FRF) of 'Windsor' sweet cherry.

Measurement	Date of treatment[y]			
	7/2	7/6	7/10	7/15
	(Reduction compared to control)			
FRF - after 5 days (g)	190a	124a	144a	178a
FRF - at maturity (g)	307a	291a	225ab	171b

[x]Estimated maturity date - 7/20.

[y]Means within a row followed by different letters differ significantly at P = 0.05.

Excessive premature abscission of fruit, with pedicel

attached, was noted when ethephon was applied on 7/2, but not for the remaining treatments. These fruit appeared to senesce and resembled those abscising with aborted embryos.

(d) Absorption period. An effective absorption period was determined by comparing the effectiveness of ethephon in reducing the FRF when the applied chemical was removed by washing after designated time intervals. Ethephon was applied to selected branches at the rate of 500 ppm. After 1, 2, 4, 12 or 24 hr, designated branches were washed with a spray of water (equivalent to 0.35 inches of rainfall) delivered from a nozzle. Comparable nontreated branches were designated as controls. In addition, a comparison was made with the FRF observed when ethephon was present for the entire experimental period. Four replications were used; however, because of limited plant material 2 replications were established on 'Bing' and 2 on 'Early Rivers'. An initial FRF was recorded immediately before ethephon application on a fruit sample from each replication and a second measurement was made 8 days later. The data were expressed as percent reduction in FRF.

There was a rapid increase in response, as indexed by reduction in FRF, with increased absorption time for the first 4 hr (Fig. 3). Only a slight additional increase (approx 8%) was observed over the following 20 hr. After a 4- and 24-hr absorption period, the response was comparable to 73% and 94%, respectively, of that observed when ethephon was present for the entire experimental period.

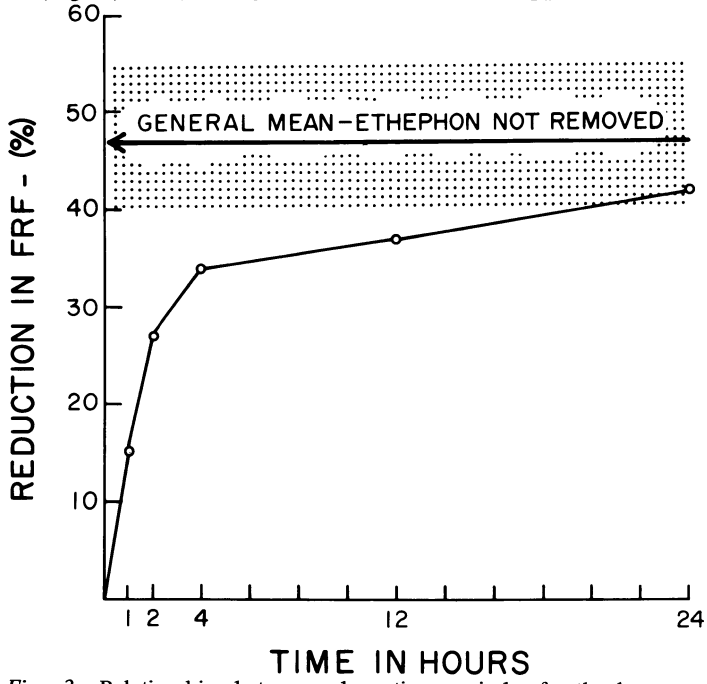

Fig. 3. Relationship between absorption period of ethephon, as established by washing-off the foliar-applied ethephon with water after 1, 2, 4, 12 or 24 hr, and reduction of fruit removal force (FRF) in sweet cherry. The shaded area around the general mean represents the standard error.

(e) Cultivar response. Two treatments, control and ethephon (500 ppm), were established for each of 9 cultivars and replicated 4 times. Since time of maturity varied among cultivars, the ethephon treatment was applied on different dates but for all cultivars from 15 to 20 days before anticipated maturity (Stage III of fruit growth). The exact date of treatment and measurement of FRF are given for each cultivar in Table 4. In addition, observations on phytotoxicity and fresh wt of 50 random fruit were recorded.

Ethephon reduced the FRF in all cutivars evaluated (Table 4). FRF was decreased with ethephon by 36% to 58% over a 7- to 11-day period. There is some possibility of environmental modification of response since time of treatment differed among cultivars; therefore, quantitative comparisons among cultivars should be considered in light of this limitation.

Table 4. Effect of ethephon (500 ppm) on fruit removal force (FRF) and wt of fruit of several sweet cherry cultivars.

Cultivars[a]	FRF		Decrease in FRF	Change in fresh wt[c]
	Control	Treated[b]		
	(g)	(g)	(%)	(%)
Vista[d]	485	287	44	-1
Vega[d]	899	436	51	0
Venus[d]	757	365	52	+2
Schmidt[e]	524	322	39	0
Napoleon[f]	508	308	40	+6
Emperor Francis[h]	626	294	58	+11
Windsor[i]	529	314	36	+10
Vic[d]	900	450	53	+30
Hedelfingen[d]	947	481	49	+11

[a]Cultivars listed in order of early to late maturity.
[b]All FRF values significantly less than control at P = 0.05.
[c]Values indicate change in wt compared to non-ethephon-treated controls.
[d]Treated 7/2, measured 7/13.
[e]Treated 7/11, measured 7/20.
[f]Treated 7/7, measured 7/14.
[h]Treated 7/11, measured 7/22.
[i]Treated 7/11, measured 7/21.

There was no significant phytotoxicity apparent at this concn (500 ppm) with the exception of 'Vic'. This cultivar exhibited excessive leaf abscission, terminal dieback and gummosis.

An interesting relationship among cultivars was apparent in the effect of ethephon on fresh fruit wt (Table 4). The late maturing cultivars appeared more responsive than the early maturing ones. This effect, however, for 'Vic' and 'Hedelfingen' may reflect treatment in early Stage III, since these 2 cultivars were least advanced in development at time of treatment in relation to their maturity date. Further, in a subsequent experiment (data not published) a lesser response in fresh wt was observed with ethephon when applied in late Stage III.

Concomitant effects of ethephon on fruit growth and development. (a) Concentration effect on fresh wt. We observed in the experiment just described that ethephon appeared to enhance fruit enlargement. Consequently, ethephon was applied at 0, 50, 100, 200, 400, 800 and 1600 ppm to designated branches of 'Windsor' when the fruit was in early Stage III (approx 18 days before maturity) of development. Six replications were used. Fresh wt was determined on 50 selected fruit for each concn 10 days after treatment.

Ethephon at 50 to 800 ppm resulted in a 10 to 20% increase in fresh wt compared to the control (Fig. 4). The max response was obtained between 200 and 400 ppm. At 1600 ppm fresh wt was less than the control.

(b) Effect on pigment formation. Ethephon was applied to individual branches of 'Windsor' at 0, 500 and 1000 ppm approx 15 days before maturity. Three replications were established. A 50-fruit composite sample was randomly collected for each treatment at time of application and after 2, 4, 6, 8, 10, 12 and 14 days. Duplicate samples of 10 fruit each were then selected for each treatment and a cylinder of tissue, including epidermis and fleshy pericarp, was removed from each fruit with a cork borer (5.8 mm diam). An estimate of anthocyanin content was made by a procedure developed by Bedford[6]. The tissue (1.5 g) was extracted with 25 ml of 0.5% oxalic acid for 24 hr in the dark at 2°C. The extract was filtered (Whatman #5) and made up to 50 ml with 0.5% oxalic acid. Absorbance at 515 nm was determined with a colorimeter.

Ethephon at 500 and 1000 ppm, markedly enhanced pigment development as compared to the control (Fig. 5). There was a particularly marked increase about 10 days after treatment coinciding with fresh market maturity.

(c) An analysis of the growth of fruit tissue. From studies on effect of time of application and cultivar response, it was apparent that ethephon, when applied at the transition of fruit

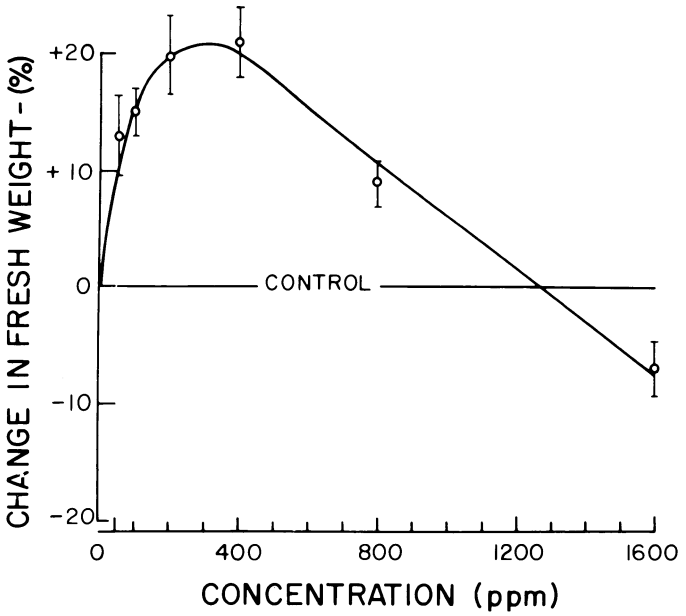

Fig. 4. Effect of varying concn of ethephon on fresh wt of 'Windsor' sweet cherry fruit 10 days after treatment.

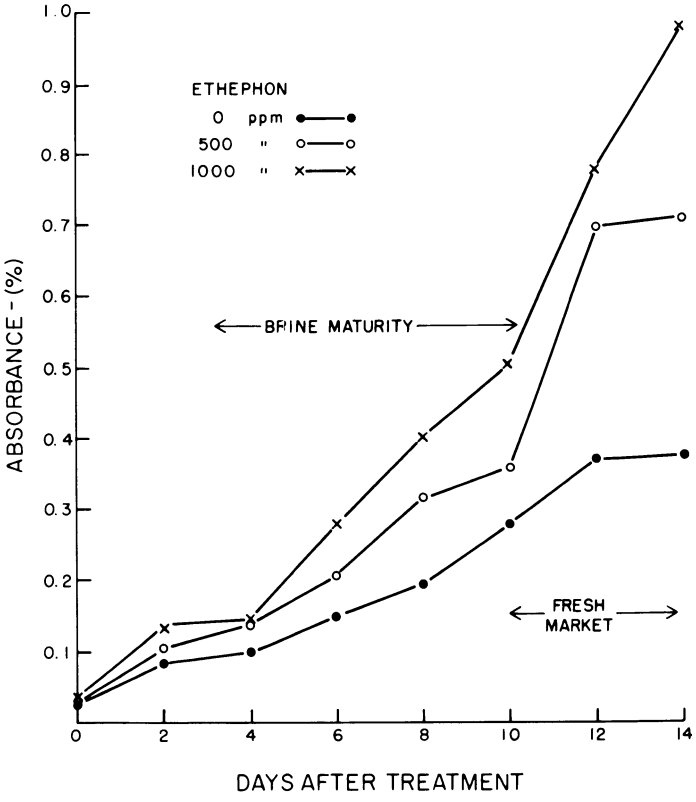

Fig. 5. Effect of ethephon on anthocyanin accumulation in 'Windsor' sweet cherry fruit. Arrows indicate an approx time range during which 'Windsor' fruit would be acceptable for brining and fresh market.

growth from Stage II to III, may cause premature abscission of some fruit and enhance the enlargement and maturity of others on the same tree. It appeared that those fruits in Stage II at time of treatment abscised while those in early Stage III were promoted in their development. To test this hypothesis ethephon (500 ppm) was applied to 'Hedelfingen' on July 3; this being an estimate of the transition period from Stage II to III. Four replications were established.

Fourteen days after treatment, 40 fruit were collected from each replication representing the following: (a) control, (b) developing fruit from ethephon treatment and (c) potentially abscising fruit (abscised with stems attached when pulled lightly) from ethephon treatment. Detailed measurements were made on fruit size. Dry wt of the fleshy and stony pericarp, seed and embryo were determined on 10 representative fruit from each replication.

There was no significant difference in fruit length between the control and ethephon-treated persisting fruit (Table 5).

Table 5. Comparison of the gross morphology of non-treated and ethephon-treated (500 ppm) 'Hedelfingen' fruits.[x]

Treatment	Fruit length	Fruit diam	
		Cheek	Suture
	(mm)	(mm)	(mm)
Non-treated persisting	20.7a	20.6a	18.0a
Ethephon-treated persisting	20.9a	21.2b	18.4b
Ethephon-treated abscising	17.5b	16.8c	14.6c

[x]Means within a column followed by different letters are significantly different at P = 0.05.

However, fruit diam, both cheek and suture, of ethephon-treated persisting fruit was greater than for the control. Fruit length and diam of ethephon-treated abscising fruit were significantly less than for ethephon-treated persisting or control fruit.

Compared to the control, the ethephon-treated persisting fruit were significantly greater in total and fleshy pericarp dry wt, less in dry wt of the stony pericarp and not different in dry wt of the seed and embryo (Table 6). The fruit about to abscise, with the exception of the stony pericarp, which was the same as for the ethephon-treated persisting fruit, was lower in total fruit, fleshy pericarp, seed and embryo dry wt than either the control or ethephon-treated persisting fruit (Table 6).

Table 6. Effect of ethephon (500 ppm) on dry wt (mg) of various tissues of 'Hedelfingen' cherry fruit[x].

Treatment	Fruit dry wt				
	Total	Fleshy pericarp	Stony pericarp	Seed	Embryo
	(mg)	(mg)	(mg)	(mg)	(mg)
Non-treated persisting	717a	487a	182a	48a	38a
Ethephon-treated persisting	817b	608b	161b	49a	39a
Ethephon-treated abscising	408c	225c	158b	25b	19b

[x]Means within a column followed by different letters are significantly different at P = 0.05.

Discussion

There are 2 abscission zones in the sweet cherry through which fruit separation can occur (7). Fruit that fail to set (lack of fertilization, embryo abortion, etc.) or are mechanically damaged generally abscise at the upper zone, while fruit at maturity separate at the lower zone. It is interesting that at maturity there is a definable (morphologically) abscission layer in the upper zone although it does not develop[7]. The upper abscission layer can be experimentally induced to develop simply by detaching the fruit from the pedicel or by removing the greater portion of the fleshy pericarp.

Ethylene has long been known to promote leaf abscission (2, 3, 9, 13). Recently, precise roles have been ascribed to ethylene during the development of the abscission layer (3). In general, ethylene appears to promote the activity of hydrolytic enzymes which attack the cell wall leading to a reduction in the force required to separate the abscising organ (1, 17, 19).

Numerous chemicals when applied to plants will induce the biosynthesis and evolution of ethylene (2, 21, 23). Probably the primary mode of action of ethephon is by inducing ethylene biosynthesis through release of ethylene during degradation of

the molecule (21, 30).

In the sweet cherry, ethephon causes a marked reduction of FRF of the lower abscission zone (Table 2). This effect is concn and time dependent (Fig. 2), and is related to the absorption period up to about 24 hr (Fig. 3). Abscission can be enhanced equally well over a 2-week period just prior to maturity, however, it appears that the effect on fruit growth may be greater early in Stage III than later.

To what extent ethephon influenced abscission directly by acting on the tissue contiguous to the pedicel and fruit has not been established. In Stage III the reduction in FRF appears to be closely related to accelerated maturity. Wittenbach[8] found histochemically no qualitative differences in the abscission zones on control and ethephon-treated fruit, the primary difference appeared to be a marked acceleration of localized separation and what appeared to be a mechanical shearing of tissue in the abscission zone of ethephon-treated fruit. Stösser (26) reported similar findings.

Although ethephon caused a marked decrease in FRF of the lower zone, there was no significant effect on the upper zone (Table 2). Perhaps the relative sensitivity of the 2 zones is different. Ethephon at extremely high concn (2000 and 4000 ppm) does, in fact, cause separation layers to develop in the upper zone (Bukovac, unpublished data). Interestingly, numerous layers may be formed simultaneously in the peduncle, and the peduncle can be carefully teased into several segments of tissue 1 to 2 mm in thickness.

Abscission at the upper zone was also observed when ethephon was applied during the transition from Stage II to III of fruit growth. More recent work (Wittenbach, unpublished data) suggests that the upper zone is more sensitive to ethephon during Stage II than Stage III. Excessive premature abscission of fruit with stems attached, observed in the time of application experiment (Table 3), may indicate that those fruits which were induced to abscise with stems were still in Stage II of development at time of treatment. It is not clear if these fruits were potential drops (result of embryo abortion) and that their abscission was merely accelerated, or if ethephon somehow directly influenced their development. It may be that these fruits, in the absence of a stress induced with ethephon, would have persisted under optimum conditions and developed into small early maturing cull fruit often found in the sweet cherry crop.

The marked effect of ethephon on the growth of the seed and embryo suggests that the embryo or perhaps other tissues, namely the endosperm, nucellus and integuments, are particularly sensitive at this time to ethephon or ethylene. Tukey (27) has shown that in late maturing sweet cherry cultivars, the embryo and endosperm continue to develop during Stage III, but at a slower rate than during Stage II. Arrested embryo growth might result in fruit abscission or accelerated maturity specifically depending on the exact stage of development of the individual fruit at time of treatment. To what extent retarded embryo development may be a cause for the premature abscission observed in this study cannot be conclusively established by our data. Further study specifically directed to this question is needed.

The concomitant effects of ethephon on fruit growth and development may have practical importance. The marked effect on fresh and dry wt (Tables 4, 5), which was primarily due to an enlarged fleshy pericarp, can be potentially meaningful to the cherry brining industry. Here the fruit are generally harvested before they are fully mature and size is often a limiting factor. It may be that through careful selection of concn and timing the industry can realize a significant increase in fruit size concomitant with a reduction in FRF. The increased pigmentation may impose some limitation for those areas where 'Windsor' is used for brining purposes, since degree of pigmentation is related to "finished" quality. This observation resembles that made by Crane et al. (11) on the effect of ethephon on the development of the fig.

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