

## Fruit Trees and Climate. III

### The Effect of Temperature on Fruit Set in Apple Trees

Jørgen Grauslund and Poul Hansen

#### Summary

Trees of the cultivar 'Lired', 'Golden Delicious', and 'Lobo', were exposed to three temperature levels in growth rooms during three two-weeks periods in 1973 and 1974, respectively. The periods were flowering time, 2nd – 3rd week after full bloom, and between 5th and 7th week after full bloom. The low level of temperature averages ranged between 10.6 – 15.7°C, the medium level between 13.0 – 19.3°, and the high level between 16.9 – 23.9°.

Fruit drop during or after the period of different temperature exposure was accelerated and/or increased by increasing temperature, in particular in the higher ranges of temperatures. In some cases the differences levelled off in time, so that differences in the final fruit set was small. However, an increase in temperature in the later period (near the period of June drop) more generally resulted in a decreased final fruit set.

Fruit growth rate increased by increased temperature. Only in one case could this effect clearly be proven at harvest time ('Lired', 1973). Determination of the degree of maturity in 'Lired' in 1973 did not indicate any differences due to previous temperature treatments. The average length of the 10 longest shoots per tree 3 weeks after full bloom in 1973 was increased by a previous increase in temperature. No other effects upon shoot growth were shown, but the variability was considerable.

Competition between shoots and fruits is discussed as a possible cause of fruit drop.

#### Resumé

Træer af sorterne 'Lired', 'Golden Delicious' og 'Lobo' blev behandlet i dyrkningsrum ved 3 temperatur-niveauer i hver af tre 2-ugers perioder i henholdsvis 1973 og 1974. Behandlings-tidspunkterne var blomstringstiden, 2. og 3. uge efter fuld blomstring og mellem 5. og 7. uge efter fuld blomstring. Gennemsnitstemperaturerne ved det lave temperatur-niveau lå mellem 10.6 og 15.7°C, ved det mellemste niveau mellem 13.0 og 19.3° og ved det højeste niveau mellem 16.9 og 23.9°.

Frugtfaldet blev accelereret og/eller forøget efter en periode med forhøjet temperatur, særligt ved de højeste temperatur-niveauer. I nogle tilfælde udlignedes forskellen med tiden, så forskellene i den endelige frugtsætning var små. Men behandling med forskellig temperatur i perioder op mod junifaldet gav mere generelt en mindre frugtsætning med forøget temperatur.

Frugternes væksthastighed blev større med stigende temperatur. Kun i et tilfælde kunne denne sammenhæng stadig ses ved høsttidspunktet ('Lired' i 1973), selv om der ikke forud kunne vises nogen forskel i modenhedsgraden. Gennemsnitlængden af de 10 længste skud pr. træ 3 uger efter blomstringen var i 1973 forøget, når temperaturen i forvejen havde været høj. Andre virkninger på skudtilvæksten kunne ikke vises, men variationen var betydelig.

Konkurrencen mellem frugter og skud diskuteres som en muligt mekanisme, der kan forårsage frugtfald.

## Introduction

Fruit set, the proportion of flowers on a fruit tree which develop into mature fruits, varies noticeably from one year to another. Even if the flower abundance and pollination are sufficient to assure the future crop, the final number of fruits on the tree is not determined until the so-called 'June' drop is completed, i.e., 6-8 weeks following bloom. The size of the 'June' drop is therefore decisive not only for the yield, but also for the fruit size. A possible prediction of the size of this 'June' drop would thus be of a great interest, in particular in cultivars where fruit set may be too heavy so that fruit thinning is necessary. Chemicals for thinning must be applied in the fairly early stages to be effective (Grauslund, 1972).

The purpose of the experiments has been to investigate the effect of temperature upon fruit drop in different periods during and after bloom. Previous investigations on different cultivars have shown an increased 'June' drop with increasing temperature (Lu and Roberts, 1952; Westphal-Stevels, 1970).

## Material and methods

### Experiments

Batches of 14 trees each in 1973 and of 11 trees in 1974 were placed in growth chambers in each of the periods quoted in Table 1. The temperatures were pre-set on 10, 15 and 20°C, respectively, in 1973, and on 9, 13 and 17° in 1974.

In 1973 all trees (9 batches) were moved into a slightly heated greenhouse on 12th of March, and kept there – except for the treatment periods – till 1st of June. They were then moved into the open air. In 1974 the trees were placed in the greenhouse from the preceding autumn. The greenhouse was heated from the 26th of february. The trees were all placed in the open air on the 30th of May.

In both years during bloom bee-hives were placed in the greenhouse and the growth chambers. Furthermore selected spurs were

pollinated by hand with pollen from another cultivar (Williams and Wilson, 1970).

### Growth chambers

The three levels of temperature were established in growth chambers, ground area 5.5 × 2.25 m, height 2.5 m, built in a greenhouse. The walls were made from double, clear plastic, the roof from glass. Along the floor of the room was placed a 25 × 25 cm pipe with holes in the sides and a ventilator at the end. When the temperature exceeded that pre-set by a thermostat, air was drawn in by the ventilator from the outside. At the lowest temperature a helical cooling coil situated in the pipe was switched on at the same time. When the temperature fell below the pre-set one, an electric heating coil was switched on and only the inside air was circulated by the ventilator. The floor was covered with moist peat to maintain a high level of humidity.

### Material

Each batch of trees treated in 1973 consisted of 4 two-year-old 'Lired/M 26', 4 two-year-old 'Lired/M 9', 3 three-year-old 'Golden Delicious/MM 106', and 3 three-year-old 'Lobo/MM 109'. In 1974 each batch comprised 3 three-year-old 'Lired/M 26', 2 three-year-old 'Lired/M 9', 2 three-year-old 'Golden Delicious/M 26', and 4 four-year-old 'Golden Delicious/M 26'. The trees were divided as uniformly as possible upon the nine combinations of treatments. The trees were grown in 15 litre plastic pots with drain in a porous soil. They were watered with a standard nutrient solution.

### Measurements

*Fruit set.* In 1973 20 well-developed spurs were selected and labelled on each cultivar/rootstock combination. Each spur was thinned to 5 lateral flowers. The number of fruits on these spurs were counted on the 9th of May, i.e., 3 weeks after full bloom, in order to determine the initial fruit set (Williams and Wilson, 1970). The final fruit set was measured by countings of 'Lired' and 'Lobo' on 5th July

and of 'Golden Delicious' on the 12 th of July.

10 spurs per tree were selected in 1974, each was thinned to 4 lateral flowers. Fruits were counted on the 17th of April and the 2nd of May, and finally for 'Lired' on 25th of June and for 'Golden Delicious' on the 11th of July.

*Fruit size and fruit development.* The fruits on the selected spurs were harvested and weighed at the final counting date. In 1973 the number of remaining fruits per tree were determined at the same time. In 1974 the remaining fruits per tree were counted and weighed for 'Lired' on the 17th July and for 'Golden Delicious' on the 12th of September.

In 1974 the diameter of the largest fruit on each of the selected spurs was measured on April 9 and 22 and on May 17, respectively.

In 1973 fruits of 'Lired' were sampled on July 23, and on August 1 and 6. The degree of maturity was determined by the iodine-starch reaction of the fruit flesh (0 = completely dark, 5 = uncoloured.)

*Shoot growth.* In 1973 the 10 longest extension shoots of each tree were measured on the 5th of May and on the 12th of November. In 1974 the number and total length of extension shoots were measured on the 22nd of April and on the 1st of November.

Table 1. Periods of treatments

Year	Period	Stage of development
1973	1. 9/4-24/4	Bloom
	2. 25/4- 8/5	ca. 2nd and 3rd week after full bloom <sup>1)</sup>
	3. 16/5- 1/6	ca. 5th and 6th week after full bloom <sup>1)</sup>
1974	1. 19/3- 2/4 <sup>2)</sup> 22/3- 5/4 <sup>3)</sup>	Bloom
	2. 5/4-19/4	ca. 2nd and 3rd week after full bloom
	3. 30/4-14/5	ca. 6th and 7th week after full bloom

<sup>1)</sup> Full bloom defined as the stage where first petals drop.

<sup>2)</sup> For 'Lired'.

<sup>3)</sup> For 'Golden Delicious'.

*Temperatures.* The temperatures in the growth chambers were continuously recorded by thermographs. Thermometer readings were taken at 8 a.m., 12 a.m. and 4 p.m. Thermometer readings were used to correct the thermograph readings which at temperatures above 20 °C were often about 1° too low. Average temperatures from each growth chamber and period were then calculated from two-hour periods of the corrected thermograph measurements for the total experimental period.

## Results

### Temperatures

Average temperatures are shown in Table 2. In sunshine, temperatures increased some degrees above the pre-set temperature level (similar fluctuations would occur under natural conditions). So temperatures at the lowest level might increase to between 14 and 24°, at the medium level to between 18 and 25°, and at the high level to between 21 and 26°, i.e., daily temperature fluctuations in sunshine were greatest at the low level of temperature. The trees were placed in a greenhouse when not under treatment proper. In 1973 the temperature here were near the medium temperature level of growth chambers, but in 1974 only about ½ °C below the temperature at the highest level (based upon thermometer readings).

Table 2. Averages of temperatures. Calculated as average of all two-hour-periods during the experimental period

Period of treatment	Level of temperature			
	Low	Medium	High	
1973 1. 9/4-24/4	10.6	14.8	19.4	
	2. 25/4- 8/5	11.9	16.0	21.9
	3. 16/5- 1/6	15.7	19.3	23.9
1974 1. 19/3- 2/4 <sup>1)</sup>	10.4	13.0	16.9	
	22/3- 5/4 <sup>2)</sup>	10.7	13.4	17.0
	2. 5/4-19/4	- <sup>3)</sup>	14.9	19.1
3. 30/4-14/5	11.2	14.2	17.8	

<sup>1)</sup> 'Lired'.

<sup>2)</sup> 'Golden Delicious'.

<sup>3)</sup> Temperature control out of function.

From Figure 1 comparisons to natural temperature fluctuations under Danish conditions at similar developmental stages can be made. The temperatures investigated are broadly taken within the natural variations.

The relative air humidity during nights was 85-90 % in the coldest room against ca. 70 % at the highest temperature level. During the day minimum values were 63-70 % at the lowest against 57-65 % at the highest temperature level.

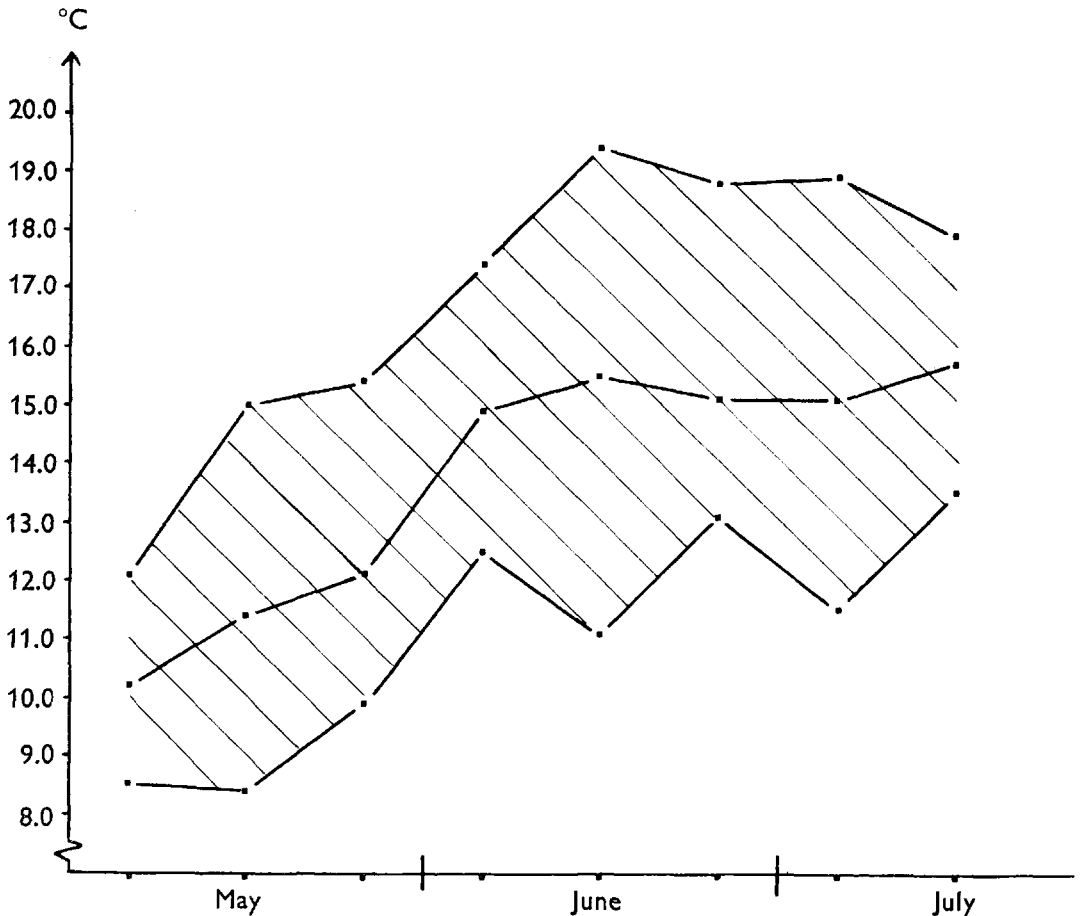


Figure 1. Mean temperatures of ten-days periods as a function of time

Upper graph: Maxima of means 1960-1972

Medium graph: Average of means 1960-1972

Lower graph: Minima of means 1960-1972

2 meter height, open air, Blangstedgaard

#### Fruit set

1973. The initial fruit set falls with increasing temperature during flowering, as well as in the period shortly after flowering (Table 3). The only exception is 'Lired/M 9' in the 2nd period. The final fruit set falls after increased temperature in the 2nd and 3rd period, and in 1st period for 'Lired' but not for 'Lobo' and

'Golden Delicious'. Thus 'June' drop was especially high for the two latter cultivars after low-medium temperature in the 1st period, where also initial fruit set was highest.

1974. Also this year the fruits dropped more heavily during the time following increased

Table 3. Average number of fruits of the initial 5 flowers per spur left on May 9 and in July, 1973

Period of treatment	Level of temp. °C	1. 9/4-24/4			2. 25/4-8/5			3. 16/5-30/5			LSD <sup>1)</sup>
		11	15	19	12	16	22	16	19	24	
<i>Cultivar</i>	<i>Date</i>										
'Lired/M 26'	9/5	4.7	4.1	3.3	3.7	3.4	2.8	—	—	—	0.7
	5/7	1.9	1.8	1.3	1.7	1.4	0.9	1.7	1.3	0.7	0.6
'Lired/M 9'	9/5	4.2	4.6	3.0	4.2	3.8	3.9	—	—	—	0.7
	5/7	2.3	2.2	1.3	1.9	2.3	1.3	1.6	2.1	0.7	0.6
'Golden Del.'	9/5	4.7	4.2	2.1	3.3	3.5	2.6	—	—	—	0.7
	12/7	1.0	1.6	1.6	1.6	1.5	1.0	1.3	1.1	0.9	0.5
'Lobo'	9/5	3.6	3.0	2.1	3.8	2.7	3.0	—	—	—	0.7
	5/7	1.2	0.7	0.9	1.1	0.6	0.1	0.8	0.4	0.3	0.5
Av. of cultiv.	9/5	4.3	4.0	2.6	3.8	3.4	3.1	—	—	—	0.6
	5/7-12/7	1.6	1.6	1.3	1.6	1.4	0.8	1.4	1.3	0.6	0.4
Av. % fruit set <sup>2)</sup>	9/5	86	80	52	76	68	62	—	—	—	12
	5/7-12/7	32	32	26	32	28	16	28	26	12	8

<sup>1)</sup> Least significant difference (95 % level).

<sup>2)</sup> Av. of cultiv. in per cent of initial number of flowers.

Table 4. Average number of fruits of the initial 4 flowers per spur left on different dates, 1974

Period of treatment	Level of temp. °C	1. 19/3-2/4 <sup>2)</sup>			2. 5/4-20/4		3. 30/4-14/5			LSD	
		10	13	17	<sup>1)</sup> 15	19	11	14	18		
'Lired'	17/4	3.9	3.8	3.6	—	3.9	3.8	—	—	—	0.2
	2/5	2.1	2.1	1.5	—	1.6	1.1	2.4	2.1	1.9	0.4
	25/6	0.9	0.9	0.7	—	0.8	0.7	1.0	0.9	0.4	0.3
'Golden Del.'	17/4	3.9	3.6	3.0	—	3.4	2.4	—	—	—	0.3
	2/5	1.9	1.9	1.3	—	1.5	0.6	1.7	1.9	1.3	0.4
	11/7	1.3	1.8	1.1	—	1.2	0.5	1.3	1.3	0.9	0.4
Av. of cultiv.	17/4	3.9	3.7	3.3	—	3.7	3.1	—	—	—	0.3
	2/5	2.0	2.0	1.4	—	1.6	0.9	2.1	2.0	1.6	0.4
	25/6-11/7	1.1	1.4	0.9	—	1.0	0.6	1.2	1.1	0.7	0.4
Av. % fruit set	17/4	98	93	83	—	93	78	—	—	—	8
	2/5	50	50	35	—	38	21	51	50	40	10
	25/6-11/7	28	34	23	—	25	15	29	28	16	10

<sup>1)</sup> Temperature control out of function.

<sup>2)</sup> 'Lired'.

<sup>3)</sup> 'Golden Delicious'.

temperature, and this applies to all treatment periods (Table 4). The effect was strongest from medium to high levels of temperature. High temperature during or shortly after flowering in particular for 'Lired' may accelerate the 'natural' fruit drop only, since the effect on the final fruit set on 25th of June is small. On the other hand, final fruit set is clearly reduced when the temperature is high in the period close to the time of the 'June' drop.

So results from both years indicate that especially after periods with average temperatures near 20 °C or more an accelerated or increased fruit drop takes place. However, in the weeks shortly after flowering these differences in fruit drop amount to only about 15 % of the flowers investigated, in one case about twice that value. In some cases these differences level off during the 'June' drop, so that differences in the final fruit set are small.

However, high temperatures close to the period of 'June' drop reduce the final fruit set for an average of years and cultivars to only half of the fruit set after low-medium temperature. On an average, the final fruit set in the experiments was high, i.e., on 26-29 % of the selected flowers. This was so also in 1974 when the temperature was rather high in the greenhouse where the trees were kept when not under treatment.

#### Fruit size

The diameter of the largest fruit on the spurs investigated increases with increasing temperature from measurements just after a period of different temperature treatments (Table 5). The fruit diameter at the highest temperature is, in several cases, 60-70 % greater than at the lowest temperature. This difference is still seen, but is relatively smaller, when the diameter is measured at a longer interval of time after the temperature treatments. Due to the increased fruit drop, significant results were not always obtained for the later treatments and measurements.

Calculations on corrected fruit sizes at harvest time in 1973 proved for 'Lired' in particular, that fruits still were larger the higher had been previous temperatures (Table 6). The

Table 5. Diameter (mm) of the largest fruit per spur at different dates, 1974

Period of treatment	1.	19/3-2/4 <sup>1)</sup>			
Level of temperature, °C	10	22/3-5/4 <sup>2)</sup>	13	17	LSD
Cultivar	Date				
'Lired'	9/4....	7.1	10.0	12.0	0.7
	22/4....	17.8	21.2	23.7	1.5
'Golden Del.'	9/4....	4.1	5.6	6.6	0.3
	22/4....	10.8	14.5	16.3	0.9
	17/5....	28.3	32.2	34.1	1.3

<sup>1)</sup> 'Lired'.

<sup>2)</sup> 'Golden Delicious'.

tendency was the same for 'Golden Delicious'. In 'Lobo', fruit numbers were too small to be conclusive.

In 1974 similar calculations were made, but no significant differences were found. However, variations were considerable, so that only differences of 18-29 % or more of the average values would be significant.

#### Degree of maturity

Disintegration of starch in the fruits of 'Lired' was estimated in 1973, where 0 indicates a complete dark colouring by iodine and 5 is uncoloured. The values were 0-2 on July 23, about 2 on August 1, and 0-2 on August 6, but without clear differences attributable to previous temperature treatments.

Table 6. Fruit size (g fresh weight per fruit) and number of fruits per tree for 'Lired' on July 5 and for 'Golden Delicious' on July 12, 1973

Period of treatment	1.	9/4-24/4		2.	25/4-8/5		3.	16/5-30/5	
Level of temperature, °C	11	15	19	12	16	22	16	19	24
<i>Fruit size</i>									
'Lired'	78	90	106	67	82	103	80	85	101
'Lired' <sup>1)</sup>	81	93	108	74	90	100	83	86	96
'Golden Delicious'	70	62	85	61	65	79	62	71	76
<i>Fruit number</i>									
'Lired'	19	18	17	22	21	14	19	17	12
'Golden Delicious'	57	81	55	65	65	25	70	55	40

<sup>1)</sup> Average of fruit size/tree corrected to 16 fruits/tree by the regression between average fruit size/tree and number of fruits/tree. LSD = 11.

#### Shoot growth

The average length of the 10 longest shoots per tree on the 9th of May 1973 (about 3 weeks after full bloom) increases with a pre-

vious increase in temperature. This applies to temperature treatment during flowering as well as shortly after flowering (Table 7). Thus shoot growth intensity in these early stages was cor-

related negatively with the size of initial fruit set. The shoot length was still small in 'Lobo' where growth was delayed due to a previous cutting. No general effects upon the average additional growth in shoot length during the remaining part of the season were found. Due to the previous cutting the total shoot growth intensity was great in 'Lobo' where average fruit set was particularly low.

In 1974 no significant effects of temperature treatments were found on total shoot length measured on April 22 (nearly 4 weeks after full bloom) or on November 1. However, the variation was big, so that differences of about 40 % of the average values would be necessary to obtain significant results.

Table 7. Average length (cm) of the 10 longest shoots per tree on the 9th of May, 1973

Period of treatment	1. 9/4-24/4			2. 25/4-8/5			LSD	
Level of temp. °C	11	15	19	12	16	22		
Cultivar								
'Lired/M 26'	..	20	27	28	15	26	23	4
'Lired/M 9'	...	17	20	20	13	18	18	3
'Golden Del.'	..	20	23	31	20	22	26	3
'Lobo'	.....	7	9	8	5	11	17	2
Av. of cultivars		16	20	22	13	19	21	2

## Discussion

The results indicate that high temperatures during flowering or in the period until 'June' drop reduce fruit set temporarily or permanently. This conclusion is supported by a few investigations in other countries. Lu and Roberts (1952) found that the fruit set of the cultivar 'Delicious' was very low at temperatures of 21-24 °C compared to 12° during the period from onset of flowering until 'June' drop. A change of temperature from 12° to 21-24° at different times following bloom also reduced fruit set. A few days of increased temperature were enough to induce a great 'June' drop. The cultivar 'Wealthy' and 'McIntosh' were less sensitive to high temperatures. Westphal-Stevens (1970) found a gradual drop in fruit set with increasing temperature in 'Cox's Orange Pippin' and 'Jonathan'. The temperature treat-

ments were 12, 15, 18, 21 and 24 °C from onset of flowering until the end of the 'June' drop.

Together with a reduced fruit set at high temperatures an increased shoot growth intensity has been indicated (Table 7). According to Quinlan and Preston (1971) an elimination of terminal shoot growth by removal of shoot tips increases fruit set. This is interpreted as a result of competition for building materials and growth factors between fruits and shoots. This competition is assumed to be most pronounced in the early stages of fruit growth, i.e., from flowering until the end of 'June' drop when fruits normally are most exposed to dropping due to periods with low levels of hormones in the seeds (Luckwill, 1953), and when shoots compared to fruits are strong sinks (Hansen, 1975).

The results of the present investigations may be interpreted on the basis of the same relationships of competition. In order to know for certain, a more detailed analysis of shoot growth rate and fruit drop under well defined climatic conditions is necessary. But the simultaneous tendencies to accelerated and/or increased fruit drop and increased shoot growth after a period of high temperature render the competition between shoots and fruits demonstrated by Quinlan and Preston (1971) probable as the decisive factor.

The increase in the rate of fruit growth in the early stages by increasing temperatures agrees with results obtained by Tromp (1975). However, the effect upon the final fruit size may vary among cultivars.

## References

- Grauslund, J. (1972). Frugtudynding. I. Virkningen af carbaryl til 'Golden Delicious'. - Tidsskr. Planteavl 76: 408-414.
- Hansen, P. (1975). Produktion, fordeling og udnyttelse af fotosyntater i æbletræer. - Tidsskr. Planteavl. 79: 133-170.
- Lu, C. S. and R. H. Roberts (1952). Effect of temperature upon the setting of Delicious apples. - Proc. Amer. Soc. Hort. Sci. 59: 177-183.
- Luckwill, L. C. (1953). Studies of fruit develop-

- ment in relation to plant hormones. I. Hormone production by the developing apple seed in relation to fruit drop. - *J. hort. Sci.* 28: 14-24.
- Quinlan, J. D.* and *A. P. Preston* (1971). The influence of shoot competition on fruit retention and cropping of apple trees. - *J. hort. Sci.* 46: 525-534.
- Tromp, J.* (1975). The effect of temperature on growth and mineral nutrition of fruits of apple, with special reference to calcium. - *Physiol. Plant.* 33: 87-93.
- Westphal-Stevels, J. M. C.* (1970). Bestuiving en vruchtzetting van Cox's Orange Pippin en Jonathan in een fytotron (II). - *De Fruiteelt* 60: 874-875.
- Williams, R. R.* and *D. Wilson* (ed.) (1970). Towards regulated cropping. - *Grower Books, London.*

Manuscript received March 7, 1975.