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Leaf spot and leaf drop of the apple cultivar 'Golden Delicious': a physiological disorder[1]

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Summary

The main factors affecting the physiological disorder of leaf spot and leaf drop under controlled conditions are temperature, light intensity and leaf age. The most promotive temperature is 21 °C while the inducive light intensity is generally estimated as 50 % or less of direct sunlight. The presence of a light gradient along the plants also promotes the disorder. The oldest leaves on long shoots generally are attacked first. The interactions between temperature, light intensity and leaf age are considered to be responsible for many of the almost inexplicable differences in orchards due to the microclimate. No positive effects were obtained from leaf sprays either with minerals as K, Ca, Mg and Mn, or with sugars. Variations in the amount of soil water did not affect leaf spot either.

Introduction

The apple cultivar 'Golden Delicious', grown world-wide, has a somewhat mysterious disorder of the leaves. Its occurrence has not been fully explained and up to now cannot be prevented with practical measures. It has been known for a long time in orchards. The main factors involved are reviewed elsewhere (Jonkers, 1973). Certain climatic conditions, such as high temperatures and a sudden change from high to low temperature are of vital importance. The effects of the microclimate are important but not well understood. Vigorous growth may enhance leaf drop. In spotted leaves the balance between some minerals is disturbed. The most important of these minerals are Mg, K and Mn, less important are Ca, N and P. Jonkers (1969) showed that this disorder or a very similar one can easily be provoked under the controlled conditions of growth chambers, at relatively high temperatures with an optimum at 21 °C at lower light intensities than those occurring naturally during summer. The series of experiments was extended in 1972 with trees of two ages in different phytotron rooms and other growth cabinets with either natural or fluorescent light to study the interplay of two or more of the factors temperature, light, leaf spray with minerals, sugar spray and water gift.

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Material and methods

Plant material

In Experiment 1, trees of 'Golden Delicious' (mutant Starkspur), five years old, were grown in plastic containers of 25 litres in a sand-peat mixture. The trees had a height of 1.8 m and a width of 0.8 m. The central leader was set with many branches, long shoots as well as spurs. After the dormant period trees were grown in an unheated greenhouse during the two months preceding the start of the experiment. At flowering time all trusses were removed. The plants developed a system of shoots with at least 1500–2000 leaves per tree. For Experiments 2, 3, 4 and 5, plants with a single stem out of one bud on a M 9 rootstock were grown in a container of 5 litres with a sand-peat mixture, from 1 April, 1972 till the start of the experiment.

Growth chambers and greenhouses

In Experiments 1–5 growth chambers with natural and fluorescent light and controlled

Table 1. Comparison of light energy in cal cm^{-2} day^{-1} in the different experiments. Details of lamp and plant position. TL = fluorescent light; IL = incandescent light.

Experiment	Source of light and environment	Position of tubes	Duration (h/day)	Position of the plant	Light energy (cal cm^{-2} day^{-1})
1	Sun in greenhouse		12–14		104
	TL in phytotron	horizontal at top	8	low	18
			16	low	36
			24	low	54
			24	high	60
2	TL in phytotron	horizontal at top	24	low	38
3	TL in phytotron	horizontal at top	24	high-upright	60
				high-horizontal	47
				low-upright	42
				low-horizontal	34
4	TL in phytotron	(a) horizontal at top only	24	at 180 cm	115
				at 100 cm	56
				at 45 cm	32
				at 30 cm	42
		(b) like (a) + some vertical	24	at 180 cm	140
				at 100 cm	80
				at 45 cm	62
				at 30 cm	58
5	TL and IL in small cabinets	vertical	24	at 110 cm	35
				at 75 cm	51
				at 50 cm	55
				at 25 cm	47

temperatures were used, unless otherwise stated. For comparison Table 1 gives the measured light energy in the different environments.

The values for the greenhouses have been calculated from the daily measurements of solar radiation in the open, communicated by the Department of Physis and Meteorology of our University; they are corrected by the factors 0.42 (visible fraction) and 0.7 (transmission of the greenhouse). The values for fluorescent and incandescent light have been calculated from measurements with a flat photometer.

Methods in each experiment

Experiment 1. For detailed observations of the appearance of leaf spot, relatively big trees were placed at a range of temperatures and light conditions in a phytotron. On 14 June 1972 plants were placed at 9, 13, 17, 21 and 25 °C in greenhouses and growth chambers. Temperatures in the greenhouses occasionally rose by about 5 °C for a few hours on very sunny days. The temperatures in the growth chambers were practically constant. Two plants were placed in each greenhouse and eight in each growth chamber. Light in the growth chambers was supplied 24 hours per day by fluorescent tubes (Philips TL 55 and TL 57) placed horizontally outside the rooms above glass panes. Three different daylengths were given, viz 8, 16 and 24 hours; the group of 24 hours was subdivided in plants placed 'low' (on floor of the room) or 'high' (1.25 m nearer to the light source).

Experiment 2. To investigate whether a simple relation can be obtained between some of the minerals mentioned above in the review of literature and leaf spots, young rapidly growing plants were sprayed regularly with solutions containing these elements. From 5 June 1972 onwards five groups were placed at 17, 21 and 25 °C in growth chambers with continuous fluorescent light, in an unheated greenhouse and in a heated one with a minimum temperature of 30 °C. Each group was subdivided into 5 series of 5 plants each. Plants were sprayed twice a week during four weeks with: water (control), 2 % K_2SO_4, 0.75 % $Ca(NO_3)_2$, 2 % $MgSO_4$ and 0.2 % $MnSO_4$. After 8 sprays a sample of leaves was collected of each sub-group; after careful cleaning they were analysed for content of N, PO_4, Na, K, Ca, Mg and Mn by the Department of Soils and Fertilizers of the Agricultural University, Wageningen.

Experiment 3. Young plants were grown in a growth chamber at 21 °C in continuous fluorescent light. Four factors were varied in all possible combinations, viz light intensity (by placing the plants 'high' or 'low' under the tubes), sugar supply (by spraying a 2 % saccharose solution every other day on the leaves), water content of the soil and position of the plant. Water content of the soil was varied bij omitting supply to the soil of half of the plants during two weeks (after which the soil was very dry and the leaves were wilting) and giving 1/2 litre per 5 days from thereon, while the other half of the plants were watered every other day giving 1/2 litre per plant which was estimated as nearly optimal. The position of plants was varied by placing the stems upright or horizontally. All 16 combinations of these 4 factors were present, with 3 replicates.

Experiment 4. To investigate the effect of a light gradient along the plants these were grown in the phytotron of the Department of Plant Physiology of Wageningen University at 20 °C with 24 hours fluorescent light only from above or both from above and from 2 sides. The side-light was also supplied by fluorescent tubes, mounted in 2 frames with 10 tubes each.

Experiment 5. In Experiments 1–4 only fluorescent light was used. To investigate the possible effect of the light source, plants were grown in small cabinets with a basic treatment of 24 hours fluorescent light (tubes mounted vertically) without or with additional low intensity incandescent light from two 40-W bulbs for 0, 12, 16, 20 and 24 hours. The cabinets were kept at 20 °C, but as the lamps were very close to the plants, differences in leaf temperature may have existed.

Results

In *Experiment 1,* the spotted leaves were picked and counted each week during 3 months; they appeared very regularly during 3 months, although mostly during the third month. The spots were irregular in shape, grey to dark brown in colour. Table 2 shows a considerable effect of temperature: at 9 and 13 °C few spotted leaves were counted, many more at 17 °C, but by far the most at 21 °C with a sharp decline at 25 °C which was evident throughout the experiment. The plants in daylight in the greenhouses did not show many spotted leaves.

At 24 h light the positions 'low' and 'high' did not show consistent differences. The plants at 8 and 16 h fluorescent light per day showed more spotted leaves than at 24 h, however, taking the differences between the two trees per plot into account, it is not justified to set too much value on the difference between 8, 16 and 24 hours.

In *Experiment 2,* leaves were analysed after 8 sprays with water (control), K, Ca, Mg and Mn. Only small differences in mineral content were noticed between the 5 temperature groups, with one exception: the plants grown above 30 °C in a greenhouse contained a higher level of Ca, Mg and Mn than plants at the other temperatures. Table 3 shows the effects on values for four elements of leaf sprays over all temperatures. The sprays proved to be effective for K, Ca, Mg and Mn.

Furthermore, the well-known antagonism between K and Mg appeared to be present. Within one week spots appeared on the plants. In Table 4 an example is given of 5 plants sprayed with water at 17 °C and 24 h fluorescent light. Generally, the older leaves were attacked first and younger leaves later, but the sequence was not very strict and the differences between plants were large.

Table 2. Experiment 1. Number of spotted leaves during 3 months under phytotron conditions on 5-year-old pot-grown trees on M 9.

Temperature (°C)	Sunlight	Fluorescent light				Total
		8 h/day	16 h/day	24 h/day		
				low	high	
9	1	0	1	19	53	74
13	0	1	3	3	9	16
17	35	226	258	119	100	738
21	20	401	508	344	335	1608
25	3	26	9	35	21	94
Total	59	654	779	520	518	

Table 3. Experiment 2. Data of leaf analysis in mmol/kg of dry matter. In a column two figures are significantly different if they have no letter in common.

Leaf sprays	Analysis of			
	K	Ca	Mg	Mn
Water	720 ab	418 c	119 e	113 g
K	869 a	402 c	118 e	111 g
Ca	730 ab	456 c	136 de	117 g
Mg	680 b	429 c	179 d	123 g
Mn	665 b	426 c	131 de	619 f

Table 4. Experiment 2. Number of days for the appearance of leaf spots since start of treatment on 5 June 1972 for 5 plants which were sprayed with water twice a week and grown in the phytotron at 17 °C and 24 h fluorescent light. In column 1 leaf position is indicated with L (1 = oldest leaf near the roots). A dash means: no spots visible after 19 days.

Leaf position	Plant				
	1	2	3	4	5
L 17–30	—	—	—	—	—
L 16	—	17	—	—	—
L 15	—	17	—	—	—
L 14	—	19	—	15	—
L 13	17	19	—	15	—
L 12	17	17	19	15	—
L 11	15	—	—	11	—
L 10	11	19	11	17	—
L 9	13	13	—	11	—
L 8	17	17	19	15	9
L 7	8	7	—	15	—
L 6	19	13	19	13	—
L 5	13	9	15	8	15
L 4	13	7	—	7	13
L 3	8	—	15	7	7
L 2	7	11	—	7	17
L 1	11	15	—	7	—

For the plants sprayed with minerals at 24 h fluorescent light at 17, 21 and 25 °C, Table 5 does not show any important effect of leaf sprays; after 30 days all plants had been attacked to the same degree. However, a striking effect of the temperature was observed. Those at 21 °C were attacked more severely than those at 17 °C, while the plants at 25 °C had the smallest number of spotted leaves. After 30 days the experiment was carried on with the group at 25 °C. Table 5, bottom line, shows an increase in leaf spot with the duration of the experiment. After 87 days only 2–3 healthy leaves were left near the apex.

After the first 30 days of Experiment 2, plants from 17 and 21 °C were removed to an unheated greenhouse. Here the appearance of new leaf spots stopped quickly.

Table 5. Experiment 2. Cumulative number of spotted leaves per plant, as influenced by leaf sprays and temperature on the indicated number of days since start of treatment on 5 June 1972.

	Number of days since start of treatment										
	7	9	11	13	15	17	19	21	23	25	30
Leaf sprays											
Water	0.8	2.3	4.3	5.5	7.5	9.1	10.7	12.4	13.1	14.0	15.7
K	0.7	1.3	2.7	4.1	5.3	7.1	8.6	10.2	11.2	12.1	13.6
Ca	0.7	1.1	2.6	3.1	4.7	5.7	6.5	8.1	9.4	10.2	12.4
Mg	0.5	1.5	2.7	3.8	5.5	6.9	8.3	10.1	11.2	11.9	13.3
Mn	0.7	1.9	3.5	5.1	6.6	8.5	9.7	11.6	12.5	13.5	14.8
Temperature (°C)											
17	1.7	2.4	3.9	5.1	7.1	9.0	10.0	11.0	11.8	12.3	14.0
21	0.3	2.2	4.8	6.8	8.8	10.8	11.9	14.4	16.2	17.4	19.1
25	0.1	0.3	0.8	1.1	1.9	2.7	4.4	6.0	6.5	7.2	8.9
Temperature (°C)	Number of days since start of treatment										
	32	35	37	42	49	53	60	67	74	81	87
25	9.0	9.2	9.6	10.4	10.4	12.8	13.2	16.4	20.6	25.8	30.0

In the next ten days hardly any new leaves were attacked, probably due to the combined effect of the higher light intensity and the lower temperature. Of the original five groups in Experiment 2 the plants in the unheated greenhouse did not show any leaf spots during the first 30 days of the experiment, nor did the plants in the greenhouse with a minimum temperature of 30 °C. However, between the 37th and 73rd day these plants showed a cumulative number of 13 spotted leaves per plant.

In *Experiment 3,* carried out at 24 h continuous fluorescent light at 21 °C, spots appeared as soon as 3 days after the start of the experiment, irrespective of the treatment. Table 6 does not show any important effect of location, sugar sprays, water level or plant position on the cumulative number of spotted leaves per plant after 19 days.

Table 6. Experiment 3. Cumulative number of spotted leaves per plant at 21 °C as influenced by location (high or low), sugar spray, water gift and position (upright or horizontal), given on the indicated number of days since start of treatment on 16 June 1972.

Treatment		Number of days since start of treatment							
		3	4	6	8	10	12	14	19
Location:	high	0.9	1.9	2.7	2.8	5.0	8.5	11.4	16.1
	low	0.2	0.7	1.7	1.9	3.4	6.9	11.0	16.6
Sugar:	—	0.6	1.4	2.3	2.4	3.6	7.1	10.6	16.2
	+	0.6	1.2	2.1	2.3	5.0	8.4	11.9	16.7
Water:	—	0.5	1.4	2.3	2.4	4.2	7.8	11.1	17.1
	+	0.6	1.3	2.1	2.3	4.3	7.7	11.3	15.8
Position:	upright	0.4	1.1	1.9	2.0	4.1	7.5	10.9	15.3
	horizontal	0.7	1.6	2.5	2.7	4.4	8.0	11.5	17.5

Fig. 1. Experiment 3. A young tree, bent horizontally, with leaf spots on the oldest leaf.

From the 3rd to the 12th day the 'high' plants, located nearer to the fluorescent tubes, showed more spotted leaves than plants located 'low' (Fig. 1). No interactions of any importance between the 4 factors were found.

In *Experiment 4,* carried out at 24 h of continuous fluorescent light at 20 °C, a striking difference was noticed between plants with light from above (a) and plants with light from above and from 2 sides (b). In Table 7 it can be seen that after 5 days plants of the former group showed as many as 20.3 spotted leaves, while plants of the latter group showed only 4.4 spotted leaves.

When the light intensities at different heights are compared for both groups (see Table 1, the data regarding Experiment 4) the lower leaves at 45 cm and 30 cm of (b) received about twice the amount of cal/cm^2 as the lower leaves of (a). Probably at this level the amount of light is critical. This result shows the negative effect of a strong light gradient along the plant when light is only given from above.

Table 7. Experiment 4. Cumulative number of spotted leaves per plant at 20 °C, as influenced by fluorescent light from above (a) or from above and two sides (b). Start of treatment was on 6 July 1972.

Days since start of treatment	24 h fluorescent light from	
	above (a)	above + 2 sides (b)
3	1.4	0
5	20.3	4.4
7	22.4	7.3
11	23.1	7.3
13	26.4	7.3
18	28.5	8.6
22	31.9	9.9
26	32.3	11.5
28	32.5	11.6

Table 8. Experiment 5. Cumulative number of spotted leaves averaged per plant, at 20 °C, as influenced by additional incandescent light to a basic period of 24 h fluorescent light. Start of treatment was on 3 July 1972.

Days since start of treatment	Additional incandescent light (h)				
	0	12	16	20	24
2	0	0.2	0.2	0.4	1.2
3	0.2	0.5	1.2	4.0	6.4
4	0.4	0.5	2.6	6.2	9.8
7	3.4	8.5	10.2	11.4	15.2
8	5.8	10.5	12.8	12.8	16.6
10	10.0	13.0	16.2	16.0	19.4
14	14.0	19.5	21.4	20.0	20.6
16	15.4	20.8	22.0	20.4	21.0
21	17.6	23.3	24.4	24.0	24.2
25	19.8	27.3	26.4	27.0	25.8

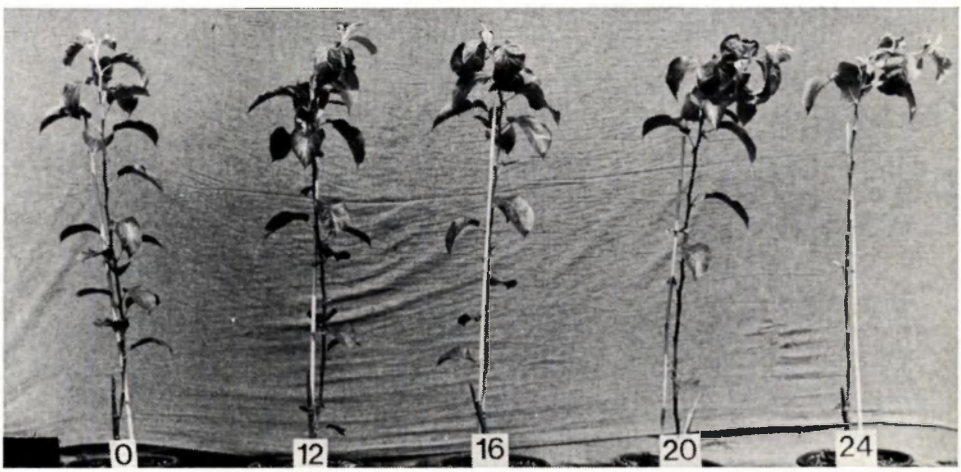

Fig. 2. Experiment 5. Plants grown at a basic treatment of 24 h fluorescent light show a promotive effect of 0, 12, 16, 20 and 24 h additional incandescent light on leaf drop.

Finally, Table 8 for *Experiment 5,* with plants in continuous fluorescent light at 20 °C, shows that for the days 2–10 the number of spotted leaves increases, with the duration of additional incandescent light (Fig. 2). The intensity of the latter was negligible but may have raised leaf temperature as was mentioned before.

Discussion

The earlier results on leaf spot and leaf drop in growth chambers and greenhouses with controlled temperatures (Jonkers, 1969) were confirmed and extended. The question arises whether the disorder and its symptoms under controlled conditions and in nature have the same background and are identical. Under controlled conditions the spots are as irregular as in nature, but generally larger and lighter in colour. Leaf drop is regular under controlled conditions, most leaves drop between 4 and 10 days after the appearance of spots and the drop does not show 'waves' like in nature. The relation of spots to leaf age is similar under controlled conditions and in nature, the older leaves generally show symptoms first. The real identity of the symptoms still has to be proven by their evocation under field conditions.

In nature, climate is considered of primary importance as was discussed in 'Material and Methods'. Experiments 1 to 5 have shown that temperature and light intensity are major factors. With constant temperatures Experiment 1 clearly has shown 21 °C to be optimal for the appearance of leaf spots. This was confirmed in Experiment 2. In the earlier paper it was shown that spots also appeared when the temperature showed daily fluctuations. Therefore the temperature level itself is the main factor and not its constancy. Further experiments will have to be carried out to show if rapid changes in temperature are important for the induction of leaf spots.

The present experiments clearly demonstrate the importance of the light factor: light intensity (Experiment 4) is more critical than daylength which had little effect in Experiment 1. In July 1972 the natural amount of available solar radiation per day, measured by the Department of Physics and Meteorology of the Agricultural University at Wageningen, varied between 92 and 683 cal/cm^2; within a tree the variation will be much more. Besides temperature and light intensity, leaf age is of much interest. As in nature, in all experiments the older leaves of the plants were attacked first, although, as Table 4 showed, the pattern is not very regular.

The combination of an optimal temperature of about 21 °C, a specific light intensity and a certain leaf age may explain the intrigueing differences between orchards, discussed in 'Materials and methods', caused by factors of the microclimate. The specific effect of the light energy has not been proven. To investigate if starvation of the older leaves plays a role, sugar sprays were used in Experiment 3, however without effect.

In the same experiment no relation could be shown between the appearance of leaf spots and the moisture of the soil, which confirms observations that in orchards there is no effect of sprinkling or irrigation in general.

As differences in the level of minerals have been shown to exist between healthy and spotted leaves, the question can be raised whether these are the cause or the effect of this disorder. The application of Mg, K, Ca and Mn by leaf sprays in Experiment 2, which significantly raised the level of these elements in the leaves, did not make any difference with regard to leaf spots. This suggests that these minerals are not the direct cause of the leaf spot. For Mg these results confirm the negative outcomes of several field trials with sprays of $MgSO_4$.

Nothing is known about the effect of growth regulators on leaf spot e.g. auxins and cytokinins which, if they had an effect, might give a clue for a practical solution. The present contribution has confirmed the important effect of orchard temperature, which is not easy to change. However, one grower (Theuns, personal communication, 1973) reduces temperature and thereby the disorder by irrigating the orchard just after a sharp rise in temperature has been predicted, but not many growers have these facilities under the conditions in the Netherlands.

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