75 Years research at Naaldwijk

Twelve papers on current research

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Seventy-five years research at Naaldwijk

This special issue of *Netherlands Journal of Agricultural Science* contains a number of papers describing projects carried out at the research station at Naaldwijk. This issue is published to commemorate the 75th anniversary of the research station.

The experimental station 'Westland' was founded officially on 14 August 1900. Its aims were to support horticultural education and to promote production of vegetables and fruit in the Westland area of south-west Holland.

Various experiments on nutrition, varieties, plant protection and cultivation techniques were carried out. The most important crops were tomatoes and grapes.

The first experiments were rather simple, and the station was short of facilities during the first years. Money was scarce at that time, and in 1924 there was even talk of closing down the station. Yet the decision was made to continue the work, and at the same time the station was reorganized. More land was purchased on another site, where a new building was erected in 1925. The present station is still situated here.

The first director, K. Wiersma, was succeeded in 1924 by J. M. Riemens, and under the latter's spirited leadership the research work expanded considerably. The targets also became broader. In 1927, the experimental station started to cater for horticulture in the whole of the South Holland Glasshouse District. Problems of cucumbers – for instance *Fusarium* – were added to the program.

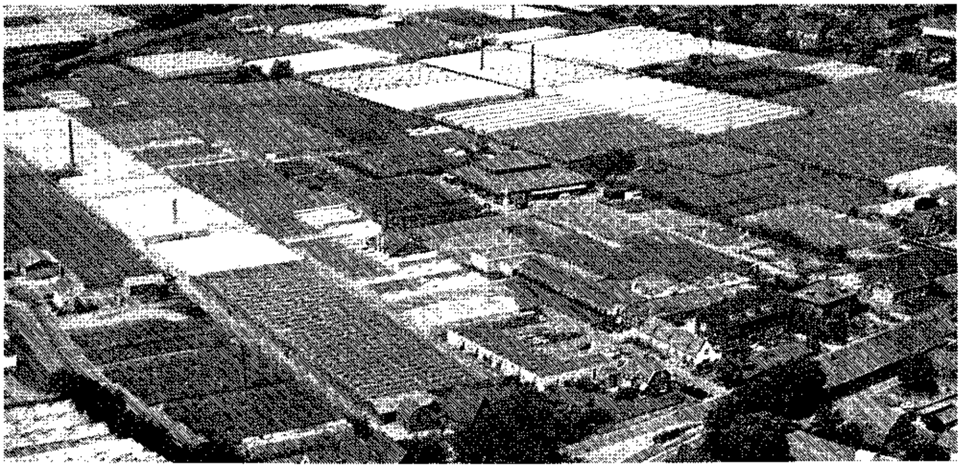
In the 1930's soil research was developed. A laboratory was equipped for chemical analyses to provide advice to growers. The interest in soil research increased rapidly.

At the end of the 1930's, the Government provided the funds for a new main building which is still being used. The building was opened officially at the beginning of 1941.

The war years again proved to be a difficult time for the station and its staff. However, after the war the station entered a new phase of growth and development. In 1949, the experimental station was given a national task besides its regional status and its name was changed to Proefstation voor de Groenten- en Fruitteelt onder Glas (Glasshouse Crops Research and Experiment Station). Research work was intensified. Since then the staff has practically doubled and is about 150 at present. New facilities were added and at the same time the research programme was enlarged. However, at all times the programme was geared to the problems found on commercial holdings. New commercial developments were furthered or initiated. Soil and nutritional research is still of great importance as is research in plant protection and crop technology.

Climatological research in glasshouses has increased substantially, and expansion has taken place in the field of plant physiology and research on biological pest control and economic and labour problems.

The work is not only applied to the main vegetable crops – tomatoes, cucumbers and lettuce – but also to minor crops like aubergines and peppers, whilst efforts are being made to introduce new crops such as crisp lettuce.



Besides the vegetable crops, various flower crops have been added to the research programme. At present about one quarter of the research capacity is devoted to flowers. This work is carried out in close co-operation with the research station at Aalsmeer. There is also close co-operation with a number of institutes engaged in horticultural research.

The experimental results have often led to substantial increases in productivity and to improvements in the quality of a number of products. The results obtained in different projects and the modern research facilities (multifactorial unit) are described in the following papers. These by no means cover the whole field of research. Nevertheless, they illustrate the wide range of activities in which the research station is engaged.

Ir E. Kooistra

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Osmotic pressure of the soil solution: Determination and effects on some glasshouse crops*

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Summary

In a factorial experiment, calcium sulphate, sodium chloride and potassium nitrate were added to the soil in various quantities. The experiment was carried out in an unheated glasshouse and several test crops were grown.

The salt status of the soil was determined with the aid of different methods of aqueous extraction. The results were correlated with the osmotic pressure of the soil solution. A very close correlation was obtained with the conductivity of the saturation extract. Crop yields were correlated with the conductivity of the saturation extract and with the osmotic pressure of the plant sap. The correlation with the conductivity of the saturation extract was generally highest. With tomatoes, a very clear relationship was found between the conductivity and the incidence of blotch on the fruits. In lettuce, there was a clear relationship between conductivity and the occurrence of tipburn.

The yield reduction of some crops was significantly greater after the application of sodium chloride than after potassium nitrate had been applied. Apparently, this was caused by specific ion effects.

The desirable salt level, the salt distribution in the soil and the determination of the osmotic pressure of the soil solution for routine soil-testing purposes are discussed. The curvilinear relationship between the salt level of the soil and the incidence of tipburn may be explained by the calcium uptake of the crop.

Introduction

The osmotic pressure of the soil solution may have an important effect on plant growth. Both high and low osmotic pressures are harmful. In glasshouses it is often possible to regulate the osmotic pressure of the soil solution by maintaining close control of fertilization and irrigation. For this purpose the osmotic pressure should be checked regularly.

A low osmotic pressure of the soil solution tends to promote lush growth. In fruiting crops this may lead to excessive vegetative growth and proportionally insufficient generative growth. The risk is particularly high in poor light conditions. The quality of the produce may also be affected by lush growth.

* Publikatie van het Proefstation voor de Groenten- en Fruitteelt onder Glas te Naaldwijk No 202.

The harmful effect of a high osmotic pressure is usually the result of an impediment of the water uptake by the crop. The consequence is that yield is reduced. Besides this so-called osmotic effect, damage to the crop may also occur through specific ion effects. However, in most crops the damage is caused mainly by the osmotic effect.

The harmful effects of a low osmotic pressure of the soil solution may be observed for instance in new glasshouses in which the salt level of the soil often is very low. Lush growth of tomatoes may result in poor fruit quality. The same symptoms may be found on soils with a high capillary capacity. Irrigation on these soils is often reduced as the plants tend to obtain a large part of their water requirements from the water rising from the sub-soil through capillary action. The sub-soil water has a low salt content.

However, in the main glasshouse areas in the west of the Netherlands, there is more trouble from high than from low osmotic pressures. In these areas the osmotic pressure of the soil solution is increased mainly by the irrigation water. Practically all the water used here is surface water which contains an average of more than 1000 mg salt per litre. The osmotic pressure may also reach high levels as a result of too liberal use of fertilizers.

At the Naaldwijk research station a great deal of research has been conducted on osmotic pressures in recent years. Some of the results obtained are discussed in this publication.

Methods

Experimental design

The results were obtained in a factorial experiment in which calcium sulphate, sodium chloride and potassium nitrate were added in various quantities to the soil. Two levels of sodium chloride and potassium nitrate were used, 0 and 2½ gmol per m^2, and four levels of calcium sulphate, 0, 2½, 5 and 7½ gmol per m^2. Further applications of these salts were made as soon as the salt levels in the soil were reduced through leaching or through salt uptake by the crop. Sodium chloride and potassium nitrate had to be replenished more often than calcium sulphate, probably because the latter did not leach very easily. Sodium chloride and potassium nitrate were always added in quantities of the same equivalence.

The conductivity of the saturation extract of the soil with the different treatments ranged generally between 3 and 10 mmho[1]/cm (25 °C).

The experiment was conducted in an unheated glasshouse block. The soil was a loamy sand with an organic matter content of 5 %, a calcium carbonate content of 2.5 % and a pH of 7.2. Soil moisture was virtually maintained at field capacity through frequent watering with spray lines.

Soil samples were obtained from a depth of 0 to 30 cm.

Soil extraction methods

Press extracts were prepared from field-moist soil with the aid of a hydraulic press.

[1] 1 mmho = 1 $m\Omega^{-1}$ = 1 mS (millisiemens, the SI unit).

Saturation extracts were prepared from air-dried soil (Richards, 1954), as were the 1 :1, 1 : 2 and 1 : 5 extracts.

Extraction of plant sap

Leaf samples were obtained from young, full-grown leaves and fruit samples from harvestable fruits. The plant tissue was killed by exposing it to temperatures of —35 to —40 °C immediately after collection. The samples were stored at this temperature for a fortnight, after which they were thawed out and pressed as quickly as possible.

Analytical methods

The osmotic pressure of soil extracts and plant sap was determined by measuring the freezing point (van den Ende & Koornneef, 1961). The osmotic pressure is expressed in atm. (0 °C). The electrical conductivity was measured with a direct reading conductivity meter and expressed in mmho/cm (25 °C).

Results

Osmotic pressure of the soil solution

The osmotic pressure of the soil solution may be determined by measuring the freezing point of the press extract or of field-moist soil (van den Ende, 1968). However, the preparation of the press extracts and the measuring of freezing points are rather laborious. This is why the osmotic pressure of the soil solution is generally estimated from the conductivity of an aqueous soil extract. Accurate estimates may be obtained if the soil solution is not diluted too much in the course of aqueous extraction. At a high rate of dilution, slightly soluble salts like calcium sulphate will dissolve in relatively large quantities.

The results of the factorial experiment confirm that high dilution rates are undesirable. During the first few years, the osmotic pressure of the press extract was compared with the conductivity of various aqueous extracts. The correlation coefficients are shown in Table 1. The table shows a high correlation of the conductivity of the saturation extract and the osmotic pressure of the press extract. With an increasing proportion of water to soil the correlation coefficients drop rapidly. In view of the results in Table 1, the conductivity of the saturation extract may be

Table 1. Correlation coefficients for the relationship between the osmotic pressure of the press extract and the electrical conductivity of various extracts.

Extracts	First year		Second year	
	tomatoes	lettuce	tomatoes	lettuce
Press extract	1.00	0.99	0.98	0.99
Saturation extract	0.92	0.99	0.99	0.98
1 : 1 extract	0.86	0.89	0.82	0.73
1 : 2 extract	0.40	0.46	0.48	0.43
1 : 5 extract	0.24	0.25	0.35	0.25

Table 2. Correlation coefficients for the relationship between the osmotic pressure (OP) and the electrical conductivity (EC) of various extracts, on the one hand, and the yield of tomatoes and lettuce on the other hand.

Extracts	Tomatoes, first year		Lettuce, first year		Tomatoes, second year	
	OP	EC	OP	EC	OP	EC
Press extract	—0.58	—0.57	—0.95	—0.95	—0.91	—0.87
Saturation extract	—0.59	—0.56	—0.94	—0.96	—0.92	—0.92
1 : 1 extract	—0.58	—0.58	—0.87	—0.81	—0.74	—0.70
1 : 2 extract	—0.47	—0.34	—0.54	—0.31	—0.29	—0.29
1 : 5 extract	—0.24	—0.34	—0.34	—0.14	—0.42	—0.17

used as a measure of the osmotic pressure of the press extract. The conductivity of the saturation extract was on average 2.1 times as great as the osmotic pressure of the press extract. The usefulness of the conductivity of the saturation extract as a measure of the osmotic pressure of the press extract is confirmed by the correlations between the crop yields on the one hand, and the osmotic pressure and conductivity of various extracts on the other (Table 2). The correlation coefficients for the yield and the conductivity of the saturation extract are practically the same as those for the yield and the osmotic pressure of the press extract. At increasing proportions of water to soil the correlation coefficients decrease rapidly.

Osmotic pressure of plant sap

Table 3 shows the regression equations for the relationship between the conductivity of the saturation extract and the osmotic pressure of the plant sap of a number of crops grown in the experiment. As the regression coefficients show, there was a great deal of variation in the effect that the osmotic pressure of the soil solution had on the osmotic pressure of the plant sap of different crops. The regression

Table 3. Relationships between the electrical conductivity of the saturation extract (x) and the osmotic pressure of plant sap (y).

Crops	Regression equation	Correlation coefficient
Tomatoes (fruits)	$y = 0.435x + 5.51$	0.911
Tomatoes (leaves)	$y = 0.125x + 7.06$	0.533
Lettuce (leaves)	$y = 0.396x + 4.99$	0.978
Sweet pepper (fruits)	$y = 0.127x + 5.59$	0.649
Sweet pepper (leaves)	$y = 0.177x + 9.26$	0.488
Endive (leaves)	$y = 0.328x + 4.80$	0.946
Cauliflower (leaves)	$y = 0.207x + 6.56$	0.718
Beans (pods)	$y = 0.047x + 7.76$	0.392
Beans (leaves)	$y = 0.193x + 7.60$	0.669
Spinach (leaves)	$y = 0.474x + 5.02$	0.955

Table 4. Relationships between the electrical conductivity of the saturation extract (x), on the one hand, and the yield as a percentage of the control, together with the percentage of the yield affected by physiogenic disorders (y), on the other hand.

Crops	Regression equation	Correlation coefficient
Tomatoes (yield)	$y = -8.11x + 144.2$	—0.913
Tomatoes (uneven ripened)	$y = -0.83x + 12.5$	—0.832
Lettuce (yield)	$y = -6.84x + 136.7$	—0.956
Lettuce (tipburn)	$y = -4.78x^2 + 76.80x - 239.9$	0.948
Sweet pepper (yield)	$y = -10.00x + 151.6$	—0.870
Endive (yield)	$y = -5.17x + 114.2$	—0.912
Cauliflower (yield)	$y = -1.22x + 103.4$	—0.279
Beans (yield)	$y = -4.92x + 118.6$	—0.733
Spinach (yield)	$y = -4.12x + 124.9$	—0.745

coefficients vary from 0.474 in the case of spinach leaves to 0.047 in bean pods. There were also large differences between the different parts of the same crop plants. With tomatoes the salt content of the soil had a greater effect on the osmotic pressure of the fruit juice than on the osmotic pressure of the leaf sap. The reverse was true for beans and with peppers the differences between the regression coefficients of the fruits and the foliage were relatively small.

Yield in relation to osmotic pressure

In tables 4 and 5, the regression equations are given for the relationship between the yield on the one hand, and the conductivity of the saturation extract and the osmotic pressure of the leaf sap on the other. The yields are given in percentages of the yields in the treatment which had no salts added to the soil (control). In the case of tomatoes the relationships with the percentage blotchy fruits are given too, and for lettuce the relationships with the percentage tipburn-affected heads are shown.

Table 4 shows generally high correlation coefficients for the relationship between the conductivity of the saturation extract and the yield. The correlation coefficient for cauliflower is an exception. Apparently, cauliflower is not very salt sensitive where the curd formation is concerned. However, this crop is much more salt sensitive in respect of leaf formation. The correlation coefficient for the relationship between the conductivity of the saturation extract and the total weight of curd and leaf together is —0.753, substantially higher than the correlation coefficient given in Table 4. For lettuce a quadratic equation has been calculated, Fig. 1, for the relationship of the percentage tipburn affected heads.

The salt sensitivity of the crops shows a wide variation. A 1 mmho/cm rise in the conductivity of the saturation extract caused a yield reduction of about 1 % in cauliflower and 10 % in peppers.

The data in Table 5 show that there is also a close correlation between the yields of a number of crops and the osmotic pressure of the leaf sap. However, for toma-

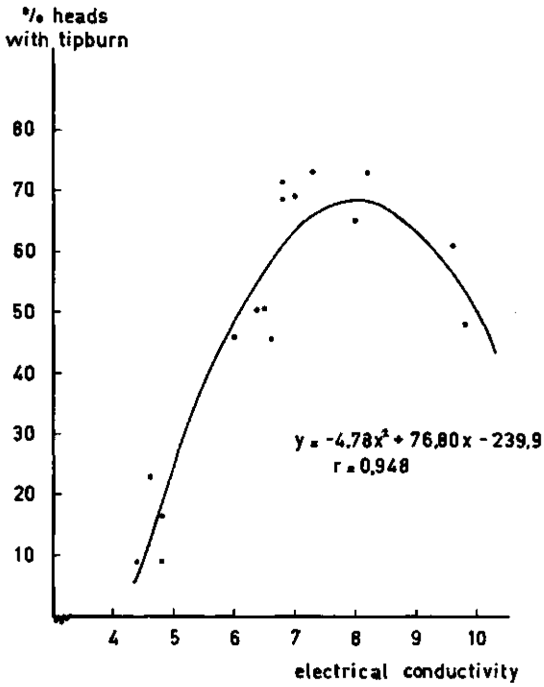

Fig. 1. The relationship between the electrical conductivity of the saturation extract and the percentage lettuce heads with tipburn.

toes, peppers and cauliflowers, the correlation coefficients are substantially lower than those obtained with the conductivity of the saturation extract. A rise of 1 atm in the osmotic pressure of the leaf sap caused yield reductions which ranged from about 1 % in cauliflowers to 20 % in tomatoes.

Table 5. Relationships between the osmotic pressure of leaf sap, (x), on the one hand, and the yield as a percentage of the control together with the percentage of the yield affected by physiogenic disorders (y), on the other hand.

Crops	Regression equation	Correlation coefficient
Tomatoes (yield)	$y = -20.2x + 248$	—0.535
Tomatoes (uneven ripened)	$y = -1.8x + 21$	—0.414
Lettuce (yield)	$y = -16.3x + 216$	—0.925
Lettuce (tipburn)	$y = -29.2x^2 + 475.5x - 1869$	0.931
Sweet pepper (yield)	$y = -13.2x + 225$	—0.417
Endive (yield)	$y = -15.5x + 188$	—0.948
Cauliflower (yield)	$y = -1.3x + 106$	—0.089
Beans (yield)	$y = -17.9x + 242$	—0.767
Spinach (yield)	$y = -7.5x + 159$	—0.678

Table 6. Relative yields and the electrical conductivity of saturation extracts (EC).

Crops	Without NaCl and KNO_3		NaCl application		KNO_3 application	
	yield	EC	yield	EC	yield	EC
Tomatoes	100	5.0	82	7.4	89	7.1
Lettuce	100	4.6	86	7.0	89	6.4
Sweet pepper	100	5.4	85	6.3	89	6.6
Endive	100	3.2	85	5.3	90	5.3
Cauliflower	100	4.3	98	7.2	100	6.9
Beans	100	5.3	71	8.8	90	8.4
Spinach	100	3.6	89	7.2	103	6.4

Specific effects of NaCl and KNO_3

As sodium chloride and potassium nitrate were added to the soil in equivalent quantities, a comparison of the yields of the different crops gives an impression of their specific salt sensitivity. In Table 6 the yields are given as percentages of the yields obtained from the treatments which did not have sodium chloride or potassium nitrate added. The conductivity of the saturation extract is also shown.

The application of sodium chloride gave a greater yield reduction in all crops than potassium nitrate. The differences were greatest in beans and spinach. Sodium chloride generally caused a greater increase in the conductivity of the saturation extract than potassium nitrate. A possible explanation is that the uptake of potassium and nitrate by the crops was greater than the uptake of sodium and chloride. Denitrification of the nitrate possibly also played a part in this.

The differences in conductivity were not large enough to be able to say that the variations in yield reductions caused by the different salts were osmotic effects. Apparently most crops have a specific sensitivity to sodium chloride. Beans in particular are sensitive to sodium chloride. The large difference in the yield reductions in spinach was caused mainly by the relatively high yields obtained after the application of potassium nitrate. Although the nitrogen and potassium levels in the soil were quite satisfactory, in the case of spinach there was a bonus effect of the addition of potassium nitrate. This effect may probably be explained by the shallow rooting of the crop which would have depleted the nutrients in the surface layers of the soil. This theory is supported by the fact that the beneficial effect of the potassium nitrate applications only started to show up towards the end of the cropping period.

Sodium chloride caused a greater incidence of tipburn in lettuce than potassium nitrate. The percentages of heads affected were 70 % and 48 %, respectively. With regard to the percentages of blotchy tomatoes, no great differences were found between the effects of the two salts. With sodium chloride the percentage blotchy fruit was 6.8 % and with potassium nitrate 6.0 %.

Effects of calcium sulphate

In tomatoes, peppers and cauliflowers, no clear effects were found by the application of calcium sulphate to the soil. Lettuce, endive, beans and spinach on the other hand showed clear effects. Some of the results have already been published in a previous report (van den Ende and Sonneveld, 1968).

Discussion

A low osmotic pressure of the soil solution appears to be beneficial for most of the crops tested. Growth and yield increase the lower the osmotic pressure. However, there must be a limit. The soil must contain sufficient nutrients which means that the osmotic pressure of the soil solution should not fall below a certain value. However, in the case of tomatoes a higher osmotic pressure than is necessary for the nutrition of the plant is often desirable. This experiment has shown again that with the tomato crop a low osmotic pressure may affect the quality of the fruits. The level to which the osmotic pressure should be raised is determined to a large extent by the environmental conditions of the crop (van den Ende, 1962).

Tipburn in lettuce may also be prevented by raising the osmotic pressure of the soil solution. However, in this case the osmotic pressure would have to be raised to such high levels that the result would be a very slow growing crop and coarse produce. It is therefore better to combat tipburn in lettuce by keeping the osmotic pressure of the soil solution at a low level. The effect of the osmotic pressure on tipburn may probably be explained by the calcium uptake of the crop. Several research workers have found a relationship between tipburn and calcium deficiency (Ashkar & Ries, 1971; Kruger, 1966; Thibodeau & Minotti, 1969). The incidence of the disorder on saline soils is probably also the result of low calcium uptake. The decrease in the disorder at very high salt concentrations is probably the result of a relatively better calcium supply of the young leaf as a result of the slower rate of growth (Geraldson, 1957). Increasing the osmotic pressure by the application of sodium chloride resulted in more tipburn than with the use of potassium nitrate. This is confirmed by other research work in which it was found that the sodium ion promotes tipburn more than the potassium ion (Sonneveld & van den Ende, 1975).

On the whole, the osmotic pressure of the soil solution was a better indicator of the crop development than the osmotic pressure of the leaf sap. A possible explanation for this is that the osmotic pressure of the leaf sap is only partly determined by the salts contained in the sap.

A good assessment of the osmotic pressure of the soil solution may be obtained by determining the conductivity of the saturation extract. We, as well as other research workers, have used this extract for many years (Arnold Bik, 1970; Massey & Winsor, 1968; Winsor et al., 1963). The preparation of the saturation extract is very laborious for routine soil-testing purposes, which is why a method was developed at our research station which is less laborious and in which the analytical results are closely correlated with those obtained with the saturation extract (Sonneveld & van den Ende, 1971).

With the determination of the osmotic pressure of the soil solution, divergent values may be obtained as a result of the salt distribution in the soil and the method of sampling. Particularly in the glasshouse soils large differences may occur in the distribution of salts in the horizontal as well as the vertical plane. Vertical differences for example occur if little water is applied and the salts accumulate in the top few inches of the soil. Horizontal differences are often the result of the use of irrigation systems, such as trickle irrigation and strip irrigation which apply water to certain areas of the soil only (van den Ende & De Graaf, 1974).

Mentioned variations in the osmotic pressure of the soil solution have an effect on the relationship found between the yield and the conductivity of the saturation extract. The result of this is that varying data may be obtained in experiments. In our experiment, beans were shown to be not particularly salt-sensitive, whilst the crop is described as salt-sensitive by most research workers (Hayward & Bernstein, 1958). In our case the beans received little water which caused the salts to accumulate in the top soil. The response of the crop will have been mainly to the lower soil layers which contained lower salt levels. As the top layer was sampled for the determination of the conductivity of the saturation extract, it is likely that the assessment of the osmotic pressure of the soil solution was too high.

Besides the osmotic effect of the salts on beans, an important specific effect of sodium chloride was found. The high salt sensitivity of beans appears to be based to a large extent on specific ion effects.

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The effect of some salts on head weight and tipburn of lettuce and on fruit production and blossom-end rot of tomatoes*

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Summary

In an experiment with tomatoes and lettuce grown in containers various salts were added to the irrigation water. Binary salts were added in quantities of 12½ and 25 mmol and tertiary salts in quantities of $8^1/_3$ and $16^2/_3$ mmol per litre water. The tomato yield was reduced by 16 % at the low salt level and by 28 % at the high salt level. The yield reductions for lettuce were 11 and 26 %, respectively. No significant differences were found in tomato yields as a result of the various salts. Sodium bicarbonate gave a greater yield reduction in lettuce than the other salts.

The incidence of tipburn in lettuce was influenced by the different salt treatments. Calcium chloride reduced tipburn but most other salts, in particular sodium bicarbonate, increased the disorder. Some blossom-end rot occurred in tomatoes as a result of the salt applications. Magnesium chloride resulted in more blossom-end rot than the other salts.

The soil was analysed at regular intervals by means of the saturation extract. Low calcium and magnesium figures were obtained after the application of sodium bicarbonate. The uptake of nutrients in the different treatments was determined by the analysis of leaf and fruit samples. The application of the different salts was clearly reflected in the chemical composition of the crop.

Introduction

Almost all crops grown under glass are salt sensitive. High salt concentrations in the soil result in reduced growth and yield. Yellowing, leaf scorch and other physiogenic disorders may also occur, often causing a reduction in the quality of the harvested produce. The main cause of salt damage is usually the osmotic effect. In other words, the damage is mainly the result of reduced availability of soil moisture. However, sometimes the damage on saline soils may be caused to a large extent by the specific effect of one ion or another. In these cases the damage is partly the result of either the uptake of toxic quantities of a certain ion or the inadequate uptake of an essential nutrient element. Extensive research has been carried out at the Naaldwijk Research Station, directed in particular at the osmotic effect of salts on glasshouse crops. Specific ion effects were also found during these

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investigations. For example, tipburn in lettuce proved to be closely related to the sodium chloride concentration and less so with the total salt concentration.

To obtain more information about specific ion effects in horticultural crops, an experiment was started in 1971 in which the effects of various salts were compared. The results for lettuce and tomatoes are reported in this publication.

Methods

Experimental design

The experimental crops were irrigated with water to which various salts has been added. The salts were divided into two groups. One group consisted of salts with the same anion but different cations. The reverse was true for the other group. A control treatment was included in both groups. The following salts were compared:

cation group	anion group
NaCl	$NaNO_3$
KCl	NaCl
$CaCl_2$	Na_2SO_4
$MgCl_2$	$NaHCO_3$

The binary salts were added in concentrations of 12½ and 25 mmol and the tertiary salts in concentrations of $8^1/_3$ and $16^2/_3$ mmol per litre water. The total ion concentration of the irrigation water was therefore the same in all cases.

The salts were added to tap water which itself contained about 4½ meq Na^+, 6 meq Ca^{2+}, 1 meq Mg^{2+}, 3 meq $H\ CO_3^-$, 2½ meq SO_4^{2-} and 6 meq Cl^- per litre.

A nutrient solution was added in a concentration considered optimal for the development of the crop. Overhead irrigation was used for lettuce and low-level irrigation for tomatoes.

The treatments were in four replicates. An experimental plot consisted of two containers with a surface area of 50 by 50 cm and a depth of 50 cm. A gravel layer on the bottom of the container provided for drainage of surplus water. The experiment was carried out in an unheated Venlo block. The soil was a light calcareous loam with about 5 % organic matter.

Growing conditions

The experiment included two tomato and four lettuce crops. Two tomato or four lettuce plants were grown in each container. The tomatoes were planted at the end of April and cleared at the end of September. Three of the lettuce crops were grown in the period January/February to March/April. The fourth lettuce crop was planted at the end of September and harvested mid-November. Water was applied regularly and the soil moisture tension was therefore low, usually 40 to 50 mmHg (5332 to 6665 Pa). Higher values were obtained from time to time with tomatoes. The quantity of irrigation water was such that some leaching of salts occurred during the cropping season. Once a year the soil was thoroughly leached with 200 to 300 mm of water after the main crop had been cleared. For this purpose water was used to which salts had been added according to the salt treatments of the plots.

Soil testing

With both tomato crops the soil was sampled and analysed half way through the cropping season. With lettuce the soil was also sampled twice immediately after the crop had been harvested. The soil samples were taken from the upper 25 cm of the profile. The soil was dried and the main cations, anions, the pH, and the electrical conductivity were determined in the saturation extract. The phosphate content was expressed in mg P per litre, the other ions in meq per litre and the conductivity in mmho (= mS = $m\Omega^{-1}$) per cm at 25 °C.

Tissue analysis

Crop samples were collected from one tomato and two lettuce crops. In the case of tomatoes samples of mature fruits and young fully grown leaves were taken three weeks after the start of picking. The lettuce samples consisted of whole heads taken at harvest. The samples were dried and analysed for chloride, sodium and the main nutrient elements.

Results with tomatoes

Yield

The results obtained with the two tomato crops were consistent and they have therefore been averaged (Table 1). The salts in the irrigation water have clearly affected yield. However, the differences in yield between the different salts were small. Statistically significant differences could only be demonstrated within the anion group. The application of sodium chloride gave a slightly lower yield and the application of sodium bicarbonate a slightly higher yield than the other salts.

The differences in yield were caused by both differences in the number of harvested fruits and in the average fruit weight.

Table 1. Average yield of two tomato crops in kg per plant.

Salts	Concentration[1]			Salts	Concentration[1]		
	1	2	average		1	2	average
NaCl	5.49	4.52	5.00	$NaNO_3$	5.28	4.67	4.98
KCl	5.37	4.34	4.86	NaCl	4.93	4.52	4.72
$CaCl_2$	5.37	4.49	4.93	Na_2SO_4	5.41	4.75	5.08
$MgCl_2$	5.52	4.72	5.12	$NaHCO_3$	5.58	4.88	5.23
Average	5.44	4.52	4.98	Average	5.32	4.70	5.01
Control			6.52	Control			6.31

[1] Concentration 1: 12½ mmol/l water for binary salts, 8⅓ mmol/l water for tertiary salts.
Concentration 2: 25 mmol/l water for binary salts, 16⅔ mmol/l water for tertiary salts.

Table 2. Tomatoes with blossom-end rot and uneven ripened fruits (%).

Treatment	Blossom-end rot	Uneven ripened
Control	0.0	1.5
Concentration 1*	0.3	0.4
Concentration 2*	1.4	0.3

* See footnote to Table 1.

Blossom-end rot and uneven ripening

Blossom-end rot and blotchy ripening were not very prevalent. Blotchy ripening occurred mostly in the first year and blossom-end rot in the second year. The percentage affected fruits, averaged for both years, is shown in Table 2. An increase in the salt concentration of the irrigation water encouraged blossom-end rot and discouraged blotchy ripening. The percentage of fruits affected by blossom-end rot was relatively high at the high magnesium chloride concentration (4.1 %). Otherwise there were no great differences in the appearance of the fruits.

Results with lettuce

Yield

The weight of the heads was consistent for the different crops and the averages for the four crops are shown in Table 3. Increased salt concentrations resulted in lower head weights. Generally sodium bicarbonate proved to be more harmful than the other salts, particularly at the high concentration. Significant differences were hardly found between the other salts.

Table 3. Average yield of four lettuce crops (g per head).

Salts	Concentration[1]			Salts	Concentration[1]		
	1	2	average		1	2	average
NaCl	251	218	234	$NaNO_3$	255	222	238
KCl	258	210	234	NaCl	249	198	224
$CaCl_2$	244	218	231	Na_2SO_4	252	218	235
$MgCl_2$	248	203	226	$NaHCO_3$	235	170	202
Average	250	212	231	Average	248	202	225
Control			279	Control			282

[1] See footnote to Table 1.

Fig. 1. 'Normal tipburn' of lettuce.

Tipburn

Tipburn occurred in all four lettuce crops; the symptoms are illustrated in Fig. 1. They have been described as 'normal tipburn' by Termohlen & van der Hoeven (1965) and Roorda van Eysinga & Smilde (1971). Average assessments of the degree of tipburn are shown in Table 4. The effects of the various salts on tipburn were consistent in the four lettuce crops. Most of the salts caused an increase in tipburn, particularly sodium bicarbonate. Potassium chloride did not increase tipburn and calcium chloride prevented the disorder almost completely.

The high concentration of sodium bicarbonate caused more severe tipburn than the low concentration. The opposite effect was obtained with potassium chloride. The effects of concentration of the other salts varied with the different crops.

Table 4. Average index figures for tipburn of four lettuce crops. 1-3 light; 4-6 moderate, and 7-10 severe symptoms.

Salts	Concentration[1]			Salts	Concentration[1]		
	1	2	average		1	2	average
NaCl	3.2	2.8	3.0	$NaNO_3$	3.9	3.4	3.6
KCl	2.3	1.4	1.8	NaCl	2.8	2.6	2.7
$CaCl_2$	0.4	0.2	0.3	Na_2SO_4	3.8	4.2	4.0
$MgCl_2$	4.6	4.8	4.7	$NaHCO_3$	4.9	7.6	6.2
Average	2.6	2.3	2.4	Average	3.8	4.4	4.1
Control			1.7	Control			1.6

[1] See footnote to Table 1.

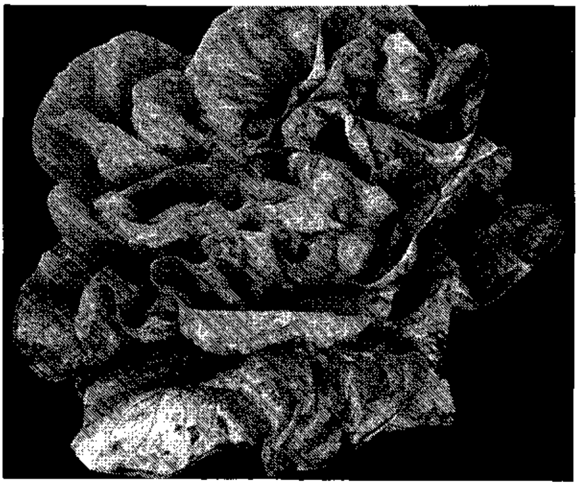

Fig. 2. Yellowing and leaf scorch of the older leaves of lettuce caused by high sodium bicarbonate concentrations.

Sometimes tipburn was more severe at the high concentrations and at other times it was more severe at the low concentration. Apart from causing severe tipburn, the high level of sodium bicarbonate sometimes resulted also in yellowing and leaf scorch of the older leaves (Fig. 2).

Table 5. Analytical data of saturation extracts. The electrical conductivity (E.C.) is given in mmho/cm at 25 °C, the phosphate in mg P per litre and the other ions in meq per litre.

Treatment[1]	Na^+	K^+	Ca^{2+}	Mg^{2+}	NH_4^+	Cl^-	NO_3^-	SO_4^{2-}	HCO_3^-	P	E.C.	pH
Control	10.9	3.7	17.3	9.2	0.2	11.1	8.7	19.5	1.9	6.2	3.66	7.0
NaCl 1	34.2	4.3	18.3	10.0	0.2	36.4	8.7	20.9	1.9	7.7	6.00	7.2
2	47.7	4.1	16.5	7.7	0.2	49.5	9.0	16.7	1.9	8.6	7.02	7.3
KCl 1	10.6	22.2	20.9	10.6	0.2	33.6	8.8	21.2	1.7	7.7	6.22	7.3
2	10.2	41.7	21.0	10.2	0.2	53.0	8.8	18.1	1.9	6.9	7.94	7.1
$CaCl_2$ 1	11.6	4.4	48.4	13.3	0.2	46.1	8.9	21.0	1.5	3.4	6.64	7.3
2	10.2	4.5	65.0	11.9	0.2	64.9	9.7	15.8	1.4	2.6	7.91	7.2
$MgCl_2$ 1	10.4	4.3	22.7	32.9	0.2	41.8	9.6	17.6	1.7	11.0	6.26	7.1
2	9.4	5.1	23.9	52.5	0.1	62.7	9.3	18.2	1.8	13.8	7.57	7.2
Control	11.3	4.0	17.7	9.9	0.3	11.8	9.6	19.5	1.9	7.2	3.81	7.1
$NaNO_3$ 1	36.3	4.6	17.5	9.2	0.2	17.2	29.8	18.3	2.2	7.6	6.15	7.1
2	54.7	5.3	18.2	9.4	0.2	11.5	55.7	18.8	2.2	10.3	7.40	7.3
NaCl 1	32.9	3.7	16.5	8.0	0.2	32.9	8.3	17.6	2.0	8.2	5.60	7.5
2	47.4	4.3	13.1	7.9	0.3	44.9	12.0	13.4	2.2	10.5	6.67	7.3
Na_2SO_4 1	41.0	4.4	19.6	10.0	0.3	10.3	7.8	51.5	2.4	9.8	5.98	7.4
2	65.8	4.9	19.2	9.8	0.3	10.1	8.8	79.2	2.7	12.5	7.56	7.5
$NaHCO_3$ 1	35.2	4.1	7.7	4.8	0.3	12.8	11.0	24.2	3.9	12.5	4.78	7.7
2	43.5	4.0	3.9	2.8	0.4	12.2	13.0	21.5	8.6	21.9	4.96	8.1

[1] 1 and 2 denote concentrations 1 and 2; see footnote to Table 1.

Results of soil analyses

The results of the soil analyses were consistent and the averages are shown in Table 5. Application of the various salts in the cation group is clearly reflected in the results. In the anion group this is also the case with sodium nitrate, sodium chloride and sodium sulphate. However, application of sodium bicarbonate caused only a slight increase in the bicarbonate content of the saturation extract. This salt also reduced the calcium and magnesium contents. Apparently, the major part of the bicarbonate precipitated in the soil as calcium and magnesium carbonate.

The phosphate content was clearly affected by calcium chloride and sodium bicarbonate. In the former case the phosphate content was appreciably lower and in the latter case higher than in the control treatments. This may be explained by the high and low calcium contents in the respective treatments. The conductivity reflected the salt applications very well. However, there was only a relatively small increase in conductivity as a result of sodium bicarbonate applications, especially at the high concentration. This was probably related to the precipitation of calcium and magnesium carbonate.

The pH showed a relatively sharp increase as a result of the application of bicarbonate. With the other salts there was only a slight increase.

Table 6. Analytical data of tomato leaves. Dry matter is expressed in % of the fresh material and the elements in % of the dry matter.

Treatment[1]	Dry matter	Na	K	Ca	Mg	P	Cl	N	S
Control	9.3	0.60	3.67	4.74	0.83	0.26	2.60	3.98	1.25
NaCl 1	9.1	1.54	2.93	5.04	0.90	0.26	3.84	4.11	1.27
2	9.1	1.72	2.71	5.30	0.87	0.28	4.24	3.98	1.43
KCl 1	9.7	0.43	4.74	4.56	0.76	0.26	3.24	4.18	1.32
2	9.3	0.38	6.70	4.03	0.72	0.28	4.20	4.13	1.07
$CaCl_2$ 1	10.2	0.27	3.52	6.00	0.64	0.22	3.88	3.57	1.38
2	9.9	0.28	3.71	6.10	0.72	0.22	4.08	3.95	1.05
$MgCl_2$ 1	9.8	0.35	3.20	4.64	1.41	0.29	3.54	3.80	1.41
2	10.1	0.31	2.81	4.04	2.31	0.33	3.75	3.87	1.55
Control	9.6	0.59	3.69	4.34	0.92	0.28	2.60	4.00	1.24
$NaNO_3$ 1	10.1	1.11	3.47	4.72	0.70	0.30	1.95	3.97	1.47
2	10.5	1.78	2.63	4.84	0.78	0.29	1.11	4.38	1.39
NaCl 1	9.5	1.24	2.95	4.80	0.80	0.28	3.58	3.99	1.36
2	9.3	1.52	3.27	4.66	0.85	0.29	3.03	3.92	1.10
Na_2SO_4 1	9.6	1.56	3.21	4.22	0.74	0.28	2.14	4.33	1.42
2	9.7	2.09	3.00	4.22	0.67	0.32	1.66	4.45	1.41
$NaHCO_3$ 1	10.0	1.54	2.93	4.82	0.71	0.24	2.06	3.80	1.41
2	9.8	1.71	2.82	3.73	0.65	0.30	1.44	4.07	1.28

[1] 1 and 2 denote concentrations 1 and 2; see footnote to Table 1.

ception was magnesium chloride.

Greater variations were expected in the incidence of blossom-end rot as there were large differences in the calcium levels in the soil. Blossom-end rot is usually associated with calcium deficiency (Geraldson, 1957; Spurr, 1959), especially with calcium deficiency in the fruit (Wiersum, 1966). Hardly any blossom-end rot will occur if the calcium content of the fruit is in excess of about 0.08 % (Wiersum,

Results of tissue analyses

The analytical results obtained from tomato leaves and fruits are shown in Tables 6 and 7. The dry matter content of the fruits was increased by the salt applications, but this was not always the case with the leaves. The application of the various cations was clearly reflected in increased levels in the leaves. The sodium content

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1966; Ward, 1973). The crop analyses showed that the calcium content of the fruits was higher than this in all treatments.

Despite the very low calcium status of the soil in the sodium bicarbonate treatments, the calcium content of the fruits was still sufficiently high. This was probably the result of the relatively low salt concentration of the soil solution in these treatments. According to Wiersum (1965), a low concentration of the soil solution is beneficial for the transport of calcium to the fruit. The more severe incidence of blossom-end rot with the high concentration of magnesium chloride is difficult to explain. The calcium content of the fruits with this treatment was not lower than with the other treatments.

As far as yield is concerned, lettuce appears to have a specific sensitivity to sodium bicarbonate. The yield reduction was much greater if this salt was applied than with any of the other salts. The occurrence of tipburn in lettuce showed wide variations according to the salts applied and there was a clear relationship with the calcium supply to the crop. This relationship has also been found by others (Ashkar & Ries, 1971; Kruger, 1966; Thibodeau & Minotti, 1969). The fact that tipburn also occurred with the control treatments proves that the tipburn risk exists even with a slight imbalance in the relationship of the ions. An adequate supply of calcium to the roots is therefore not always sufficient if the transport of calcium to the young leaves is not satisfactory (Thibodeau & Minotti, 1969). In such cases calcium sprays may be effective for the prevention of tipburn (Kruger, 1966; Thibodeau & Minotti, 1969). The good effects of calcium chloride in our experiment may be the result of a satisfactory calcium supply via the roots as well as via the leaves, as the crop was given overhead irrigation. However, the severe tipburn obtained with the sodium bicarbonate treatment is an indication that the ion relationship of the soil solution played a major part in the incidence of tipburn. The same conclusion may be drawn from the fairly severe cases of tipburn obtained with the application of other sodium salts and magnesium chloride. It is interesting that the application of potassium chloride did not encourage tipburn.

Several research workers (Ashkar & Ries, 1971; van der Kloes, 1952) have suggested that tipburn of lettuce is encouraged particularly by large nitrogen dressings. In our experiment there was not much difference between the sodium nitrate treatments and the treatments with other salts. However, tipburn is stimulated more by ammonium than by nitrate (Leh, 1970; Wiebe, 1967). The reason for this is probably a reduced calcium uptake in the presence of ammonium (Barker & Maynard, 1972; Wilcox et al., 1973).

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CO_2 from gas-fired heating boilers - its distribution and exchange rate*

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Summary

CO_2 measurements were carried out on two tomato and two chrysanthemum nurseries on which CO_2 generated by the gas-fired heating boilers was used for CO_2 enrichment. The CO_2 contents may vary a great deal in the course of a day, from 300 to 6000 ppm. Where a main duct with lay flats (perforated plastic tubes) was used, the CO_2 gradients were measured along the plastic tubes. This system of distribution was shown to give fewer variations than the more primitive system of a main duct with holes through which the CO_2 is fed into the glasshouse. The latter system produced a more pronounced gradient with tomatoes than with chrysanthemums.

No differences were recorded in the CO_2 contents at various heights in the glasshouse. Only in the case of chrysanthemums where a main duct with lay flats was used could a difference be found in the CO_2 levels in and outside the beds.

Calculations were made of the exchange rates of glasshouse air with the ventilators closed. A close relationship was found between the exchange rates and the wind speed. The exchange rates varied from 0.2 to 1.4 times per hour. Opening of the ventilators caused a sharp decrease in the CO_2 content. Relatively the strongest effect was noted for the first few centimetres of opening the ventilators.

Introduction

Since the end of 1971, Dutch growers have been changing over wholesale from atomising paraffin burners for CO_2 enrichment to gas-fired boiler installations. The switch is taking place simultaneously with the change-over from oil to natural gas for heating purposes.

Instead of using a decentralized system of separate burners growers are now using central boiler installations which provide heating as well as CO_2. Part of the boiler combustion gases is extracted with the aid of a primary fan. A secondary fan adds air to the combustion gases and feeds the gas mixtures which contains 2 to 3 % CO_2 into the main duct which runs from the boiler house to the glasshouses. Further distribution takes place via lay flats (perforated plastic tubes) which run at right angles to the main duct into the glasshouses.

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When the new distribution system was introduced, the question cropped up whether a network of lay flats was really necessary. Would not openings in the main duct serve the same purpose which would be much more convenient for lettuce and flower crops. Older questions like 'what is the vertical CO_2 distribution in the glasshouse' and 'what is the effect of ventilation' were also being asked again.

To find answers to these questions, CO_2 measurements were carried out on two commercial tomato and chrysanthemum nurseries, with the aid of self-registering measuring apparatus.

Materials and methods

In 1973 and 1974, the CO_2 levels were measured in 4 glasshouses on 4 nurseries. The houses were of the multispan type with a bay width of 3.2 m, a gutter height of about 2.5 m and a ridge height of about 3 m. Two of the houses were used for growing tomatoes, the other two for chrysanthemums. In the tomato houses the plants were spaced at 45 cm in the row and 80 cm between the rows. The heating pipes were installed below the gutters and the ridge at a height of 30 to 60 cm.

The chrysanthemum plants were grown in beds of 1.25 m wide, separated by paths of 0.35 m wide, and at a plant density of 58 to 62 plants per m². The heating pipes were installed at a height of 1.8 m below the gutters only.

The CO_2 was transported via one main duct suspended above the main central path, or via two main ducts running along opposite gables (Fig. 1). Further distribution took place via a number of 35 m long lay flats, running from the main duct into the glasshouse at a spacing of one tube to each bay.

The lay flats were removed if unrestricted CO_2 distribution was required. In that case the gas moved from the main duct openings into each glasshouse bay in a horizontal direction. If necessary, short, flexible laterals were fitted to the main duct so that the gas stream could be directed amongst or over the crop.

The CO_2 levels were measured with two IRGA's, each having six measuring points. The results were registered by a recorder. The measuring points for the horizontal measurements were just above the crop, at a height of 1.8 m for toma-

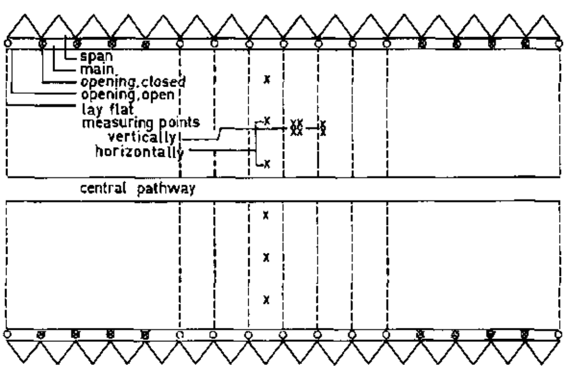

Fig. 1. Plan of a distribution system consisting of two main ducts with lay flats (perforated plastic tubes), showing the position of the CO_2 measuring points. An alternative system may be obtained by installing one main duct above the central pathway, instead of two main ducts along the gables.

measured by us is certainly to a large extent the result of decreasing CO_2 supply at increasing distances from the main duct. Nevertheless, the reduction is often much

toes and at 0.8 m for chrysanthemums. For the vertical measurements in the toma-
toes there were four points at regular intervals between the glasshouse floor and the

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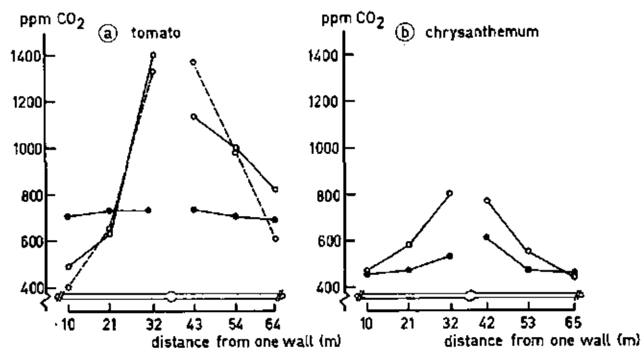

Fig. 4a. Horizontal gradient of the CO_2 levels in a tomato crop, using a central duct with:
●——● lay flats at soil level;
o——o openings at 10 and 20 cm above the crop;
o - - - o openings at half the height of the crop.
Fig. 4b. The same in a chrysanthemum crop with:
●——● lay flats at soil level;
o——o openings 1.2 m above the crop.

greater than may be explained with the values found by Vente. One explanation may be the variation found in the ventilator openings from the gables to the central path or vice versa. The interruption in the CO_2 tubes at the central path may also have an effect on the distribution pattern.

CO_2 distribution via tubes and free openings

As Fig. 4a shows, the gradient of the CO_2 levels measured over a tomato crop was much greater if the CO_2 was released from the main duct than via lay flats. Amongst the crop this effect was even more pronounced. Much the same pattern was found with chrysanthemums, but the variations were not quite as great (Fig. 4b).

The strong gradient obtained with the free release of CO_2 from the main duct as probably partly caused by CO_2 losses to the outside as a result of cross currents from the open ventilators.

The height of the main duct openings and the space between the top of the crop and the glasshouse roof were probably responsible for the greater gradients found with tomatoes than with chrysanthemums. In the case of tomatoes, the CO_2 stream was released at 10 to 20 cm above the top of the crop which may well have caused some resistance. With the chrysanthemums, the CO_2 stream was released at a height of 1.2 m above the crop. The flow path between the glasshouse roof and the top of the crop was also narrower in the case of the tomatoes, about 0.9 m, as against 2.0 m with the chrysanthemums. The CO_2 current must have met with relatively more resistance in the tomato crop than in the chrysanthemums.

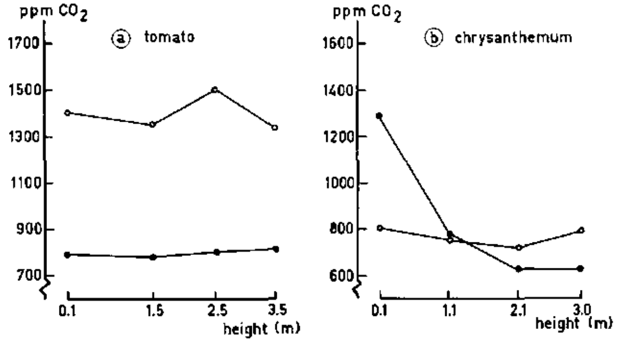

Fig. 5a. Vertical gradient of the CO_2 levels in a tomato crop, using a main duct with:
●——● lay flats at soil level;
o——o openings at 10 and 20 cm above the crop.
Fig. 5b. The same in a chrysanthemum crop with:
●——● lay flats at soil level;
o——o openings at 1.2 m above the crop.

Vertical gradient of CO_2 levels

Again, only the data obtained with open ventilators were used. No clear differences in the levels of CO_2 at various heights were found in the tomato crop, irrespective of whether the CO_2 was applied via lay flats or released directly from the main duct (Fig. 5a). Much the same picture was obtained with chrysanthemums (Fig. 5b), except that where CO_2 was applied via lay flats, the levels amongst the crop at 10 cm were clearly higher than at other points above the crop. The difference in the vertical gradients in tomatoes and chrysanthemums were probably caused by two factors, plant density and position of the heating pipes.

Plant density. With 2.7 plants per m^2, the tomato crop has a low plant density, whereas chrysanthemums have a very high plant density at 58 to 62 plants per m^2. In the case of chrysanthemums this may lead to stagnation of the air amongst the plants and the CO_2 emitted by the lay flats is slow to circulate amongst the plants. The result is a gradient between the measuring points amongst and above the crop.

Position of the heating pipes. The low level of the heating pipes in the tomato crop, 30 to 60 cm, tends to encourage greater movement of the air and therefore better mixing of the CO_2 with the air. This is not the case with the chrysanthemums where the heating pipes are at a height of 1.8 m.

Measurements made at 10 and 80 cm above the path between the chrysanthemum beds showed differences between the CO_2 levels of the same order as those recorded between the measuring points amongst and above the crop. The exchange rate is apparently as low in the paths as it is in the beds. The theory of stagnated air movement in beds and paths is confirmed by the fact that CO_2 levels

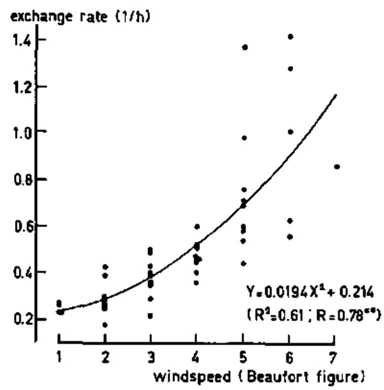

Fig. 6. Relationship between the wind speed (Beaufort figure) and the exchange rate of CO_2 (1/h) in an aluminium-wooden multispan.

recorded amongst the chrysanthemum crop at night were always a little higher than at other measuring points.

With the free release of CO_2 from the main duct there was no gradient from amongst to the outside of the crop. This appears to be the result of slow penetration of the CO_2 stream into the crop.

Exchange rate

With closed ventilators. At the end of the day when the CO_2 supply was stopped, the CO_2 content in a glasshouse decreased gradually, showing a curved pattern. Eventually the minimum level was reached which was more or less above the CO_2 level in the open. The nightly coarse of the CO_2 levels offered the possibility of calculating the exchange rate of a glasshouse.

The calculation was carried out with the aid of the formula worked out by Businger (1963).

$$S = -(1/t) \ln (C_g - C_o)/(C_s - C_o)$$

in which S represents the exchange rate, expressed as the number of air changes per hour (1/h).

t = time in hours

C_g = prevalent CO_2 level (%) in the glasshouse

C_s = the initial concentration (%) in the glasshouse

C_o = the CO_2 concentration outside (%) (for this the value was chosen of the ultimate CO_2 level. The value is the balance between the CO_2 supply as a result of respiration of the soil and the crop and the CO_2 loss through exchange).

For a glasshouse with closed ventilators the exchange rates ranged between the extremes of 0.18 and 1.42. The values appeared to depend on the wind speed (Fig. 6). The relationship may be expressed as $Y = 0.0194 X^2 + 0.214$ in which X represents the wind speed (in Beaufort figures) and Y the exchange rate. The correlation R = 0.78 proved to be very significant ($P < 0.01$), so that 60 % of the variance could be explained with this expression. In other glasshouse values for exchange rates were found of the same order of magnitude as those mentioned above. The lowest value obtained is similar to the lowest value recorded by Okada & Takakura (1973). They found a value of 0.21 for an aluminium glasshouse, but the difference was that with increasing wind speeds they found exchange rates which increased much more sharply than in this case. At a windspeed of 3 Beaufort they recorded values ranging from 1.02 to 1.38, compared with 0.22 to 0.50 in this experiment. Their glasshouse was obviously less air-tight.

The calculated low exchange rates are no doubt the result of developments in glasshouse construction which have taken place in the Netherlands in the past ten or twenty years. During this time there has been a change from the wooden Dutch light houses via the wooden and metal clad houses to aluminium glasshouses. The extent of glass overlaps and leaks has been reduced at the same time with the result that the exchange of glasshouse air has decreased.

At lower exchange rates, the CO_2 levels will tend to be relatively high, as will the levels of possibly harmful gases. On the other hand, in the absence of CO_2 enrichment the CO_2 levels in the glasshouse may easily drop below 0.03 %.

The loss of water vapour is also made very difficult by low ventilation rates. This may lead to high levels of atmospheric humidity, particularly if the difference between the outside temperature and the temperature in the glasshouse is small. In this case the second way of water vapour loss, by condensation against the glass, becomes largely inoperative.

The result then is an increased risk of fungal diseases.

With open ventilators. The CO_2 content drops sharply when the ventilators are opened (Fig. 7). Even a small ventilator opening has a great effect. Continued opening of the ventilators has a relatively smaller effect. As the CO_2 levels in the glasshouse are in fact the result of the difference between supply and loss of CO_2,

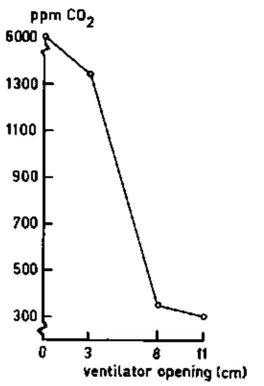

Fig. 7. CO_2 levels in an aluminium clad multispan with closed ventilators and ventilators opened to 3, 8 and 11 cm.

it appears that the exchange rate is greatly increased by opening the ventilators. The first few centimetres of ventilator opening produce the largest relative increase.

Acknowledgments

I would like to thank the Institute for Agricultural Engineering and the Institute for Land and Water Management Research at Wageningen for the loan of the necessary measuring instruments. I would also like to thank C. Mol for his assistence in carrying out the measurements.

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Self-stopping tomatoes - cultural and economic aspects*

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Introduction

The present system of tomato growing, in which the crop is in the glasshouse for up to 10 months, is very labour-intensive. Side-shooting, twisting, leaf picking and harvesting are continually recurring operations. At the Institute for Plant Breeding at Wageningen, work is in progress to develop a crop type which requires little labour for cultural operations. To achieve this the plant must be made self-stopping with little or no lateral growth. The stems must be made sturdy enough to obviate the need for support. The plants must therefore remain low. For single harvesting the fruits should ripen simultaneously and, if this aim cannot be achieved entirely, the fruits, when ripe, should be retained on the plants in good condition for some time (Hogenboom, 1974). If these aims can be achieved, it should become possible to utilize the whole of the glasshouse area for the crop. A plant density of 10 plants per m^2 would become feasible (Buitelaar, 1973). The cropping cycle would be 2 to 3 months, depending on the season, and four crops per year would be possible. Some experience has already been gained in cropping experiments with some prototypes of self-stopping tomatoes.

Cultural aspects

Plant raising and planting

Because of the high density of the crop it will be necessary to raise large numbers of plants. This will require a large propagation area and a great deal of labour. Planting out will also require a lot of labour for a short time and the obvious answer is to mechanize plant raising and planting out. If a smaller plant is required for mechanical planting, this would mean a longer cropping cycle and a higher crop cost.

Cultural operations

In the experiments it was always found necessary to support the crop. The use of chrysanthemum netting or canes requires more labour and makes harvesting difficult. The plants must therefore be made self-supporting which would also increase the possibilities of mechanization (Postel, 1967).

With the present prototypes it is necessary to side-shoot at least twice and to remove the lower leaves to avoid suffocation of the crop. In the self-stoppers of

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the future lateral growth must be limited and suffocation of the lower leaves must be prevented by the application of the right climatic conditions.

Fruit set in the present tomato crop has to be aided by various artificial means. Suitable methods may have to be found to achieve the same with self-stoppers grown at high densities in which fruit set will certainly not become any easier. The use of a high-pressure sprayer has already given good results.

Harvest

The harvesting period in the experiments lasted for 3 to 4 weeks. Single harvesting is of course the ideal, but the high labour requirements over a short period would make mechanisation necessary. The highest yield obtained in the experiments so far was 5 kg per m². The yield was reduced by disease (botrytis) and by magnesium deficiency. The latter in particular is still a big problem, but it may well be possible to developed less susceptible varieties. There also appear to be good possibilities of increasing yields by improved growing methods.

Technical equipment

As a crop of self-stoppers will cover practically the whole of the ground area, the equipment will have to be adapted to this growing method. Overhead irrigation of the crop provides a favourable climate for all kinds of diseases (Vriesenga, 1972). The use of a low-level irrigation system beneath the crop would therefore be preferable. The heating pipes would also have to be accommodated beneath the crop as far as possible, as with other bed systems of growing, in order to obtain satisfactory heat distribution. If the heating pipes are installed in the path, they may also be used as rails for a transport system.

Economic aspects

Introduction

The most obvious feature of the cropping system described is the high plant requirement. For four crops a year this is 40 plants per m² of glasshouse. For the normal two-crop system – a heated crop from mid-December until 1 July and an autumn crop from 5 July until 20 November – 5 plants are required per m². This large number of plants has consequences for plant raising in terms of space and labour requirements, as well as for planting out when a great deal of labour is required in a short time. With the figures known for plant requirements and labour, an assessment was made of the production costs of year-round cropping with self-stoppers.

There is, of course, also the question whether it would be economically justified to use self-stoppers in summer. In other words, will the gross returns expected be sufficient to cover the direct costs like the cost of the plant material, pesticides, fertilizers, transport costs and the labour costs for planting, harvesting, grading and supervision? With some other glasshouse crops which have relatively high plant costs, such as irises and pot chrysanthemums, the crops costs are often not covered in summer by the gross returns. From an economic point of view it is then more

Table 1. Labour requirements for a crop of self-stopping tomatoes in minutes per 100 kg (= 100 plants).

Operation	With present methods of planting and harvesting	After mechanization of planting and harvesting
Planting and watering in	20	10
Harvesting	50	20
Grading	15	15
Packing	3	3
Transport	2	2
Crop clearance	5	0
	75	40
Supervision	5	5
Total labour requirements per 100 kg	100	55
Total labour requirements for 1000 m²	167 hours	92 hours

attractive to grow a crop with a better cost/return relationship, such as lettuce, or to leave the glasshouse empty.

The labour requirements

In consultation with Ing. A. T. M. Hendrix[1] an estimate was made of the labour requirements expected in self-stopping tomato crops. The calculations were based on the assumption that yields of 1 kg per plant would be obtained.

The labour requirements in minutes per 100 plants were assessed for two situations:

1. with the present methods for planting, harvesting and crop clearance;
2. after mechanization of planting, harvesting and crop clearance.

The labour saved by mechanized harvesting was estimated at 30 minutes per 100 kg. It was also assumed that the harvesting machine clearing the crop gives a saving of another 5 minutes per 100 kg. The cost of the harvesting machinery was estimated to be equal to two-thirds of the value of the labour saving. This means that at an hourly rate of *ƒ* (Dutch guilders) 12.40 (on 1 July 1974) the machine costs for harvesting and crop clearance would be

$$2/3 \times 35/60 \times f\ 12.40 = f\ 4.82 \text{ per 100 kg.}$$

The labour saving in planting was assessed at 10 minutes per 100 kg, and here also it was assumed that the machine costs would be equal to two-thirds of the labour saving expected. This would give a machine cost for planting of:

$$2/3 \times 10/60 \times f\ 12.40 = f\ 1.38 \text{ per 100 plants (100 kg).}$$

Table 1 shows that the labour requirements for four crops of self-stopping toma-

[1] Labour specialist of the IMAG at Wageningen, stationed at the Glasshouse Crops Research and Experiment Station, Naaldwijk, the Netherlands.

toes, with the present techniques, would be 4 × 167 = 668 hours + 10 % for miscellaneous jobs = 735 hours per 1000 m^2. The normal-heated tomato crop with a yield of 15 kg per m^2 and the autumn crop with a yield of 10 kg per m^2 have a labour requirement of 820 hours per 1000 m^2, including the allowance for miscellaneous jobs. Substitution of the normal crops with four self-stopping crops would produce a 10 % reduction in total labour requirements. Labour productivity would be greatly improved and would be increased from 31 kg per labour hour with the normal two-crop system to 54 kg per labour hour with the four self-stopping crops with the present-day growing methods. After mechanization of harvesting and planting labour, productivity is further increased to 99 kg per labour hour.

Substantial labour savings are achieved by mechanization of planting and harvesting. Four mechanized self-stopping crops have a labour requirement of 4 × 92 = 368 hours + 10 % miscellaneous jobs = 405 hours per 1000 m^2 compared with 735 hours with present growing techniques and 820 hours for the present two-crop system. Mechanization of planting and harvesting would give a 45 % reduction in the labour requirements compared with the present growing techniques for self-stoppers and a reduction of 51 % compared with the present two-crop system.

Estimate of production costs

Basis for calculations

The hourly rate for labour used in the calculations was *f* 12.40, the level on 1 July 1974. All operations were carried out by casual labour and the grower. The net cost of gas for heating was taken as *f* 0.08 per m^3, the price level on 1 October 1974. The annual cost of fixed equipment, overheads and that portion of the grower's labour which could not be attributed directly to the crop, was assessed in all cases at *f* 12 per m^2. These are the so-called fixed costs.

The normal cropping system was assumed to consist of a heated crop from mid-December until 1 July with a yield of 15 kg per m^2, followed by an autumn crop from 5 July until 20 November with a yield of 10 kg per m^2.

The harvest dates of the four self-stopping crops were presumed to be on 15 March, 31 May, 31 July and 15 October.

In apportioning the fixed costs, the net margins of the second, third and fourth crop were deducted from the fixed costs of the four crops. The remainder of the fixed cost was apportioned to the first crop in every case.

Table 2. Production costs of self-stopping tomato crops with four harvest dates and two different growing systems.

Growing system	Production costs in Dutch guilders per m^2				
	15/3	31/5	31/7	15/10	total
Present methods	22	11	7	8	48
Mechanized method	20.50	11	7	8	46.50

Results of the estimate

With the normal two-crop system the production costs for the heated crop until 1 July amount to *f* 24.75 per m² and for the autumn crop to *f* 8.25 per m². Table 2 shows the estimated production costs for self-stoppers with the present growing techniques and for self-stoppers after mechanization of planting and harvesting. Table 2 shows that the profitability of year-round cropping with self-stopping tomatoes depends on the financial returns obtained for the first crop. If the financial returns of the present system amount to *f* 22 per m² for the first crop and the yield of this crop is 8 kg per m², the average price would be *f* 2.75 per kg. It would seem that with increasing supplies reaching the markets in March, this price level would be the maximum, even without any self-stopping effects. In other words, the yield obtained on 15 March must be at least 8 kg per m² at a price level of *f* 2.75 per kg if the costs are to be covered. With a supply of 20 000 tons, the average price obtained for tomatoes in April was about *f* 2.75 per kg in recent years.

If it is assumed that the demand for tomatoes in March will be the same as it is in April, it would mean that in March 250 ha of self-stopping tomatoes could be harvested with an average production of 80 tonnes per hectare. This would of course also assume that only self-stopping crops are being grown.

Direct costs in the summer months

Table 3 contains an estimate of the direct costs in guilders per m² (per 10 kg of tomatoes), again for two growing systems (Anon., 1973):

1. with the present techniques for planting, harvesting and crop clearance;
2. with mechanized planting, harvesting and crop clearance.

At an hourly labour rate of *f* 15 and a gas price of *f* 0.12 per m³, the direct costs per kg tomatoes would be respectively *f* 0.67 and *f* 0.63 at a yield of 10 kg per m². In most years the average price of tomatoes during three or more successive weeks

Table 3. Direct costs in guilders per m² for self-stopping tomatoes harvested in the period July to September.

Factors	Present techniques	Mechanized techniques
Labour costs (see Table 1)	10/60 × *f* 12.40 = *f* 2.07	5.5/60 × *f* 12.40 = *f* 1.14
Machine costs:		
for planting		*f* 0.14
for harvesting		*f* 0.48
Plant material		
10 plants at *f* 0.30	*f* 3.00	*f* 3.00
Other materials and cultivation	*f* 0.20	*f* 0.20
Energy, 6 m³ gas at *f* 0.08	*f* 0.48	*f* 0.48
Auction costs	*f* 0.25	*f* 0.25
Total direct costs	*f* 6.00	*f* 5.69
Direct costs per kg at a yield of 10 kg per m²	*f* 0.60	*f* 0.57

in August has been below ƒ 0.50 per kg. The slack period starts usually in week 32 (second week in August).

If ƒ 0.60 per kg tomatoes is regarded as the minimum price, average prices usually start to drop below this level in week 31, and this period lasts for five weeks or more. Cropping for the harvest period from the beginning of August until mid-September is therefore economically justified only if the labour costs are much lower than those given in Table 3. This may be achieved by using very cheap labour or by using permanent workers for whom no more productive work is available. If Dutch supplies are reduced in August and supplies from other sources remain the same, it could be that limited production for the August period might become economically justified again as average prices would tend to rise.

The supply pattern

If it is assumed that there are four crops of self-stopping tomatoes per year, then the harvest of the first crop should take place before 1 May, the harvest of the second crop before 15 July, of the third crop before 15 September and of the fourth crop before 30 November. On the basis of the present supply of tomatoes until the end of April (in 1974, 25 000 tons, of which 2000 tons in March), it would be feasible to use 250 ha for year-round cropping. It would mean that the supply in November would increase from 4000 to 23 000 tons and the remaining 2000 tons of the fourth crop would come in in October.

The supply until the end of April would also be much greater if self-stopping crops were to be introduced on a large scale into the present tomato acreage of 1200 ha (acreage on 1 February). Table 4 shows the monthly Dutch tomato supplies in 1973, the total imports of the UK, West Germany and France (average over the years 1969/73), as well as a prediction of the fortnightly supplies in the Netherlands if Dutch growers were to change over on a large scale to four self-stopping crops a year.

The supply until May would increase from 21 000 tons in 1973 to 125 000 tons, the first crop from 1250 hectares.

Table 4 shows that the harvest of the first crop would start on 15 February and that the harvest of the fourth crop would end at the end of November at the latest. Table 4 also shows that for the supply prediction used, it was assumed that four crops a year would be grown on 1050 ha, three crops on 100 ha, two crops on 150 ha and one crop on 400 ha.

For the two-crop system (150 ha), the first crop would be harvested in the second half of April and the second crop in July. This opens up the possibilities of combinations with autumn cucumbers, chrysanthemums, several lettuce crops and even freesias. However, the technical problems of cropping programmes which include self-stopping tomato crops will be left out of the discussion.

It was assumed that it would be technically possible to obtain a complete crop of 1 kg per plant or 10 kg per m² in the second half of February. To achieve this there should be very few problems in fruit setting at the beginning of January. It must be stressed that year-round cropping with four crops of self-stopping tomatoes – from December until March, from March until May, from May until July and

Table 4. Monthly Dutch tomato supplies, imports into the UK, West Germany and France and a prediction of Dutch tomato supplies from self-stopping crops with corresponding acreage to be harvested.

Period		Dutch supplies[1]	Imports into UK, etc.[2]	Predicted supplies[3]	Acreage in ha harvested			
					1st crop	2nd crop	3rd crop	4th crop
January			36					
February	2		31	20	200			
March	1	1	44	20	200			
	2			25	250			
April	1	19	54	30	300			
	2			30	300			
May	1	66	106	35	150	200		
	2			35	150	200		
June	1	66	114	35	100	250		
	2			35	50	300		
July	1	70	85	35		200	150	
	2			35		150	200	
August	1	72	55	25			250	
	2			30			300	
September	1	33	36	20			200	
	2			20			50	150
October	1	20	40	20				200
	2			20				200
November	1	3	51	25				250
	2			25				250
December			40					
Total		350	693	520	1700	1300	1150	1050

[1] Present supplies of Dutch glasshouse tomatoes in 1973 × 1000 tonnes (Anon., 1974b).
[2] Combined imports of tomatoes in the UK, West Germany and France, (average over the years 1969/73) × 1000 tonnes (Anon., 1974a).
[3] Predicted supplies of Dutch glasshouse tomatoes × 1000 tonnes.

from August until November – is possible only on a large scale if there is practically a full first crop coming in from mid-February onwards.

Mention should also be made of the big changes in the supply after July which may be expected. The supply in August was assumed to be lower than the present supply because of the low prices and the relatively high direct costs of self-stoppers. The supply from September onwards becomes appreciably greater if the acreages mentioned are planted (see Table 4).

The changes in the supply before 1 May and after 1 September – as shown in Table 4 – are particularly great and from a marketing point of view they may become possible only by substitution, i.e. by replacing the outdoor tomatoes in the European market.

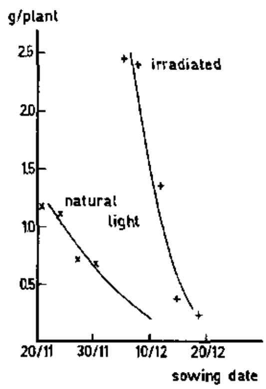

Fig. 1. The effect of the sowing date (20 November – 20 December 1972) on the weight of lettuce plants in g per plant on 17 January 1973. + denotes irradiated plants and × plants grown with natural light only. Night temperature 7 °C, day temperatures 21 – 24 °C.

which were given supplementary light, compared with the untreated plants, was remarkable (see Fig. 1).

Lettuce sown on 28 November (unlit) and on 13 December (lit) reached an average weight of 0.8 g per plant on 17 January. According to crop physiologists, the lit plants had sturdier and broader leaves than the unlit. With supplementary irradiation, good marketable lettuce plants weighing about 1.3 g each could be obtained on 17 January from an 11 December sowing, whilst on this date unlit plants from a 28 November sowing weighed only 0.7 g each.

Fig. 2 shows the effect of plant weight on the yields obtained on 13 and 22 March. During the harvest of 22 March the lit and unlit plants were recorded separately. Irradiated lettuce plants of the same weight as unlit plants at planting out, yielded slightly heavier heads at harvest. The difference was not statistically significant and amounted to 6 g per head at most. A comparison of the yields on 13 and 22 March

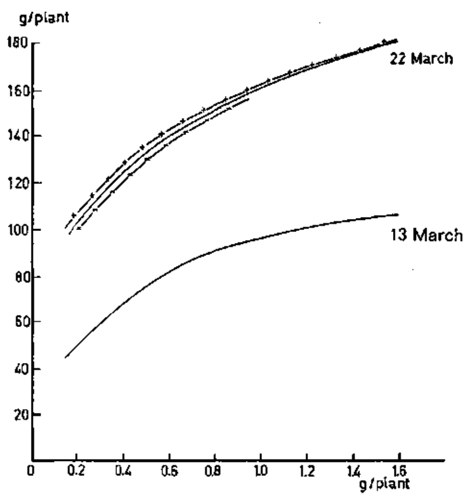

Fig. 2. The effect of plant weight in g per plant at the time of planting out (17 January 1973) on the yield in g per head of lettuce on two harvesting dates, 13 and 22 March 1973. The crop harvested on 22 March was divided into the plants raised with irradiation (–+–) and those raised with natural light only (–×–). Night temperature 7 °C. The day temperature treatments, 12 – 21 °C, were recorded together.

shows that the weight of a lettuce plant is increased by 60 to 70 g in 9 days, a weight increase of 7 g in less than one day! There was no significant difference at harvest in the plants raised at different temperatures, but which were of the same weight at the time of planting out. It may be concluded from these data that the pre-planting history of lettuce plants has little or no effect on the ultimate harvest as far as irradiation is concerned, provided the plants are of equal weight at the time of planting out.

3 Economic aspects

The calculations have been based on a number of assumptions. The daily cost of the glasshouses has been fixed at *f* (Dutch guilders) 50 per 1000 m^2 which is the equivalent of the net income a grower could expect from a winter crop.

The gas price is *f* 80 per 1000 m^3 and the gas consumption has been calculated according to the method worked out by Kostelijk et al. (1966). A transmission figure of 9 for the cropping house and a figure of 10.8 for the propagation house is used. One m^3 natural gas produces 7500 kcal at an efficiency of 80 %. The periods of plant raising and cropping may be found in the first part of this paper. Of the total glasshouse area 5 % has been allocated to plant raising, assuming that 4-cm soil blocks are used. Per 1000 m^2 21 000 plants are propagated and 20 000 are planted out. Two examples are examined in closer detail.

3.1 Cost comparison of lit and unlit plants of the same weight

The difference of the costs of propagating space and energy between a lit and an unlit plant of the same weight (0.8 g) on 17 January is examined. The lit plant was sown on 13 December, the unlit on 28 November. For irradiation to be viable proposition the plant raising costs with irradiation should be the same – or less – as the plant raising costs without irradiation.

Costs: Irradiation (13/12 – 17/1) + propagating space (13/12 – 17/1) + energy for propagating space (13/12 – 17/1)
< propagating space (28/11 – 17/1) + energy for propagating space (28/11 - 17/1)

Costs of irradiation < 5 % cropping space (28/11 – 13/12) + 5 % energy (28/11 – 13/12)
< 0.75 days cropping space + 250 m^3 gas
< *f* 37.50 + *f* 20.

This means that a maximum of *f* 57.50 for 20 000 plants or *f* 0.0029 per plant is available for irradiation. The electricity consumption for irradiating the plants, based on 600 plants per m^2 propagating space and 200 W per m^2 for 16 hours a day, works out at (21 000/600) × 16 × 0.2 = 112 kWh per day.

The consumption over 35 days is 3920 kWh. At a kWh cost of *f* 0.06 the cost of electricity works out at *f* 235.20 for 20 000 plants or *f* 0.0118 per plant. The calculation shows that only 25 % of the cost of electricity is covered.

Fig. 1. Before planting, netting with a mesh size of 12.5 by 12.5 cm^2 is laid out over the bed.

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Plant density of year-round chrysanthemums*

A. P. VAN DER HOEVEN, C. P. MOL AND J. A. VAN DER STEEN

on the quantity and quality of the yields of year-round spray chrysanthemums, an investigation was started in 1972.

Materials and methods

The experiments were carried out with the variety Spider grown on loam in Venlo glasshouses on two specialized chrysanthemum nurseries. In 1972-1973, 14 treatments were compared with plant densities of 40, 54, 60, 64, 70 and 80 plants per meter bed of 1.25 m wide. The plants were distributed as evenly as possible over the beds. In 7 of the 14 trials the crop was cut in January and in the other 7 the flowers were cut during the period July to October.

During the winter months of 1973-1974, 12 trials were performed with plant densities of 27, 32, 40, 48, 54 and 60 plants per meter bed. The flowers in these trials were harvested between the beginning of December and the beginning of April. To harvest the flowers the plants were pulled up. The time lapse between the beginning and the end of the harvest was always less than 8 days. The roots were cut off and the number of flowers, the length and the weight of each stem were recorded. The sprays were arbitrarily graded into three quality classes, depending on the weight and strength of the stem and the number of flowers per stem. Stems without flowers, stems which were not salable for one reason or another and cuttings which had not developed a stem were recorded as waste. In each trial plot a bed area of two times 1.00 × 1.25 m^2 was used for the determination of quantitative and qualitative yields. The data recorded were averaged.

Results 1972-1973

Table 1 shows the data obtained from the trials in winter and summer/autumn. Table 1 shows that as plant density increases, the average stem weight and number of flowers per stem decrease. The differences are greatest at low plant densities.

In Fig. 2 the visual quality assessments are given of the trials during the winter months. At increasing plant densities the percentage of first quality decreases and

Table 1. Average stem weight, stem length and number of flowers per stem at increasing plant densities in the winter of 1972-1973 and the summer and autumn of 1973.

Number of plants per 1 m by 1.25 m bed	Stem weight (g)		Stem length (cm)		Number of flowers per stem	
	1972/73	1973	1972/73	1973	1972/73	1973
40	77	151	96	95	6.8	20.7
54	63	121	94	100	5.6	15.0
60	59	112	96	101	5.6	14.5
64	58	105	94	102	5.5	13.2
70	54	98	94	103	5.2	12.0
80	53	89	94	104	5.1	11.5

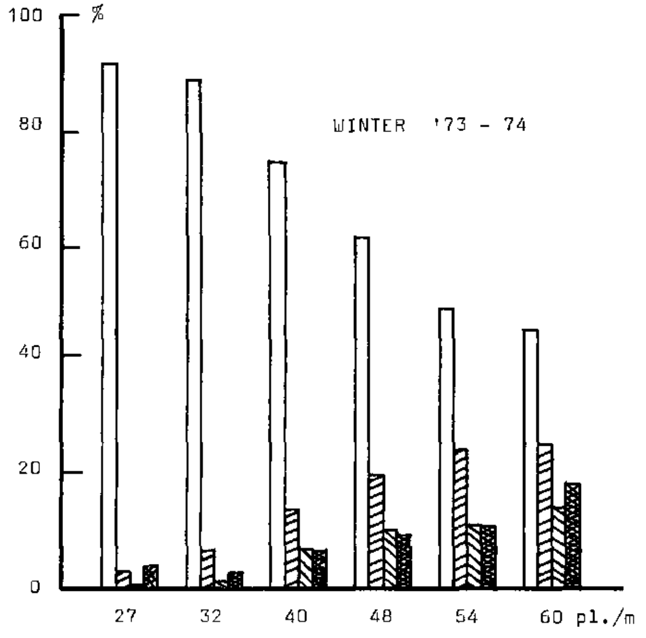

Fig. 2. Average percentages of first, second and third quality and waste at different densities (first, second, third and fourth column, respectively).

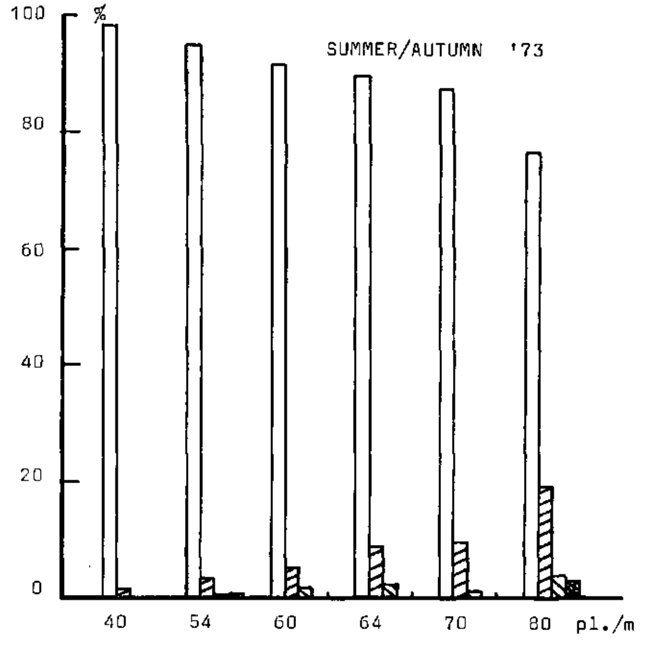

Fig. 3. Average percentages of first, second and third quality and waste at different densities (first, second, third and fourth column, respectively).

Table 2. Average stem weight of quality Class I with increasing plant densities (winter 1972-1973)

Average stem weight (g) at a density of .. plants per bed					
40	54	60	64	70	80
84.2	74.2	74.6	72.6	72.2	69.3

the percentage waste increases. The same applies to the summer months (Fig. 3).

Table 2 shows the average stem weight of the first quality. The figures show that the stems of quality Class I increased in weight and were therefore better as the plant density decreased. The differences in stem weight between the stems of the outer rows and those of the inner rows were greater at high plant densities than at low plant densities.

Results winter season 1973-1974

Some of the results recorded are shown in Table 3. Stem weight and number of flowers per stem increase with decreasing plant densities. Stem length was again hardly affected by plant density. Compared with the winter of 1972-1973, the stems in the following winter were heavier and carried more flowers.

The results of the division into quality classes and waste are given in Fig. 4.

Discussion and conclusions

Up to 1973, growers usually planted 60 plants per meter bed of 1.25 m wide for winter cropping. However, the results obtained with 40 plants in the winter crops were so good that it was decided to include even lower plant densities in the experiments. Particularly in winter the stems remain too light and too thin at the higher plant densities. Differences in quality are reflected more clearly in the returns in winter than in the summer. In summer the average stem weight is more than 100 g,

Table 3. Average stem weight, stem length and number of flowers per stem at increasing plant densities during the winter of 1973-1974.

Number of plants per 1 m by 1.25 m bed	Stem weight (g)	Stem length (cm)	Number of flowers per stem
27	119	105	11.4
32	105	105	10.4
40	92	104	9.1
48	80	103	8.1
54	76	103	7.7
60	76	102	7.5

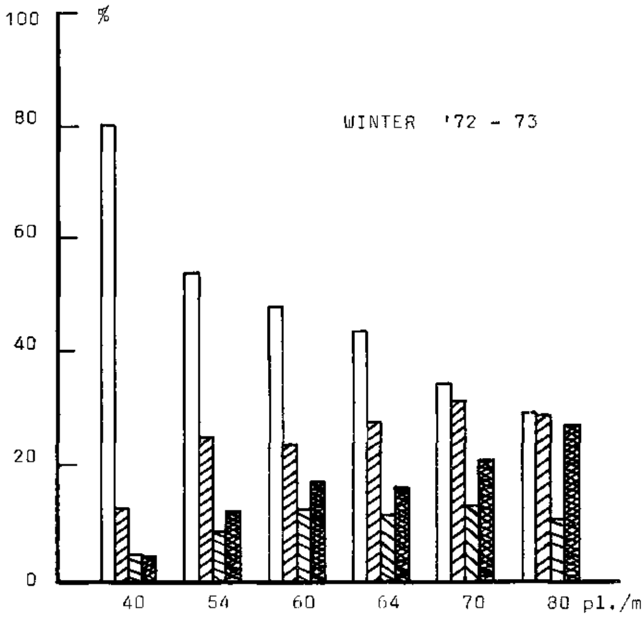

Fig. 4. Average percentages of first, second and third quality and waste at different densities (first, second, third and fourth column, respectively).

and the stems are strong enough. At the lowest plant density most of the stems were too heavy and too big in summer to be bunched easily. In winter the stems are usually much lighter and weaker than in summer.

Economically the optimum plant density depends mainly on the price of the cuttings and the price differences between the quality classes. Table 4 shows an example of the calculation of the financial returns. It is assumed that the cuttings cost *ƒ* 0.10 each (*ƒ* = Dutch guilder) and that stems of first, second and third quality give returns of *ƒ* 0.60, *ƒ* 0.30 and *ƒ* 0.15 each, respectively. The possible differences in labour for the different plant densities have been ignored. This

Table 4. Calculated returns in guilders per m bed (winter 1972-1973).

Number of plants per 1 m by 1.25 m bed	Gross returns	Costs of cuttings per m²	Returns after deduction of cutting costs
40	20.90	4.00	16.90
54	22.20	5.40	16.80
60	22.80	6.00	16.80
64	22.30	6.40	15.90
70	22.40	7.00	15.40
80	23.10	8.00	15.10

2 Transport systems

In the glasshouse industry, the term 'transport systems' covers transport in the growing area by means of more or less permanent equipment, such as rail systems and conveyor belts. This is different from the normal concept of transport which does not necessarily take place via fixed pathways. Because of the fixed installation transport systems are subject to limitations (see Section 3). The nature of the transport system will depend on its purpose (transport of the operator, of the operator and produce, or of produce alone), the nature of the produce and the production methods. Because of these combination of factors, it may happen that several systems are used for one and the same crop. In the harvest of pot chrysanthemums, for instance, both conveyor belts (Anon., 1973b) and rail systems (Anon., 1973c) are used. The various systems available may be classified as follows:
- conveyor belts
- rail systems which travel over the crop, travel alongside or between the crop, or move the whole crop.

2.1 Conveyor belts

A conveyor belt is an installation consisting of rollers or wheels of which one roller or two wheels are driven by a motor. A belt or cords run over the rollers or wheels powered by the driver roller. For economic reasons conveyor belts are used only with crops which are single harvested. They have been constructed in such a way that they are mobile and may be moved within easy reach of the operator (van Mullem, 1972).

The capital cost of conveyor belts is too high to make it economically justified to equip the whole of the production area with more or less permanently fixed belts. On a year-round lettuce nursery producing 7 successive crops at a rate of 18 heads per m^2, the labour saved by using a permanently fixed conveyor belt would be about 4 h a year per 100 m^2. In 1974 labour costs were *f* (Dutch guilders) 12.50 per hour which would make up a money saving of *f* 50 per 100 m^2. However, the annual cost of a conveyor belt for this area would be about *f* 250 (Hendrix, 1973). These figures show clearly that conveyor belts must be mobile to be a viable proposition. Moving the belt on this lettuce nursery takes about 2 h per 100 m^2 per year (Hendrix, 1972), leaving a saving in labour for transport of 100 minutes per 100 m^2 per year.

For selectively harvested crops the use of conveyor belts is seldom economically attractive. On the one hand there is the high cost of the system compared with the savings in transport, on the other hand continually moving the belt takes more time than the possible savings in transport obtained from the use of the belt. In the case of harvesting cucumbers or tomatoes, the time taken to move the produce from each picking out of a glasshouse bay is 2 and 2½ minutes, respectively. If one were to use the mobile lettuce belt for this purpose, it would take about 17 minutes to move the belt from one bay to the next. Other transport systems must therefore be used for these crops (see Section 2.2.2).

Apart from lettuce (Fig. 1), conveyor belts are also used for pot chrysanthemums

Fig. 1. Transport of harvested produce by means of mobile conveyor belts.

(Anon., 1973b) and cut flower chrysanthemums (van Gaalen & Hendrix, 1973). Other possible areas of application may be endive, celery and pot plants which are cleared in the lump such as saintpaulias and zygocactus. With cut chrysanthemums the conveyor belt is used for two purposes: saving in labour for transport (van Gaalen & Hendrix, 1973) and the possibility of using machines (Fig. 2) which may speed up certain operations. Bunching is done by machine in this instance. The conveyor belt is necessary to carry the cut crysanthemums to the bunching machine on the main path.

Fig. 2. The conveyor belt with cords enables mechanizing certain operations such as deleafing and bunching.

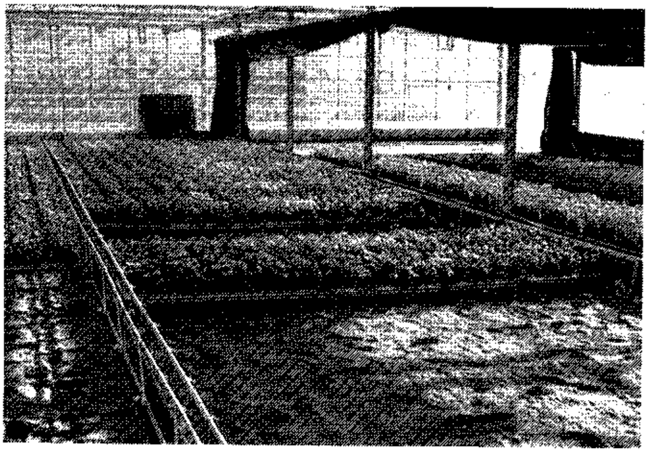

Fig. 6. Transport grids with pot chrysanthemums in the glasshouse. No loss of growing space through paths.

3 Advantages and disadvantages of transport systems

The magnitude of the advantages which may be gained by the use of a transport system depends on the system and the manner in which it is used. The cost of a transport system (see Sections 2.2.1 and 2.2.2) in which the heating pipes are used as rails, is relatively low compared with the system in which the whole crop is made mobile (see Section 2.2.3).

The disadvantages of transport systems are:

- extra capital investment;
- relatively many operators – 3 to 5 persons – are required to achieve the correct distribution – and therefore savings – of labour;

Fig. 7. Transport grid on the operating line. Better working position and the elimination of unnecessary handling may be achieved.

– the work becomes more monotonous as each worker is allowed to do only one operation in the chain.

The advantages of transport systems are:

– labour savings because:

• larger quantities of produce can be transported and handled at the same time (rail systems);

• manual transport of produce can be eliminated entirely (conveyor belt);

• the system may be combined with certain machines, such as a bunching machine at the end of a conveyor belt for chrysanthemums;

• a better work posture may be created; the system described in Section 2.2.2 gives a labour saving of 15 % in the harvest of tomatoes and a 20 % saving in the side-shooting and trimming of the crop;

– less tiring work as there is less lifting to do and because transport over rails is easier than over paths or the soil states that transport over a good path and over an uneven path is 1.2 and 5.7 times as heavy as transport on rails, respectively (Grandjean, 1965);

– greater possibilities of using unskilled labour as operations may be divided; in harvesting chrysanthemums, for instance, the only skilled operation is the shaping of the bunch;

– greater possibilities of employing female labour as the work becomes lighter;

– less risk of damage as there is less handling of produce;

– the use of conveyor belts with lettuce makes it possible to use lighter grade cardboard boxes as they are handled less and they remain dry (van Esch, 1973);

– with certain systems (see Sections 2.2.1 and 2.2.3) a higher degree of glasshouse utilisation may be achieved by the elimination of paths. In some cases, such as with pot chrysanthemums, the cultivated area may be increased by more than 10 %.

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The climate glasshouse at Naaldwijk*

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Summary

The technical outfit of a glasshouse of 24 compartments is described. A process computer with peripheral units is used to control the glasshouse climate and to record the climatic data inside and outside the glasshouse. The analysis of the results of the experiments is discussed.

Introduction

For many years there has been a need for climatically controlled rooms in which the effects of climatic factors such as light and temperature on the growth and development of the plant could be studied. In the 1950's this led to the introduction of the phytotrons or growth chambers (e.g. Went, 1957; Chouard et al., 1972; Doorenbos, 1964; Commissie Fytotrons TNO, 1972). However, all the information obtained in this way (Lang, 1963) was valid only for individual plants growing under certain constant conditions.

The task of applied agricultural research is to relate this information to the crop as it is produced in agriculture under often sharply fluctuating conditions. In the case of glasshouse horticulture this crop research should be carried out in glasshouses in which the environmental conditions can be controlled by methods which are within the present and future economic reach of growers.

In England compartmented glasshouses were built to study the interaction of a number of climatic factors (Sheard, 1965). The scope of an existing glasshouse with six compartments at the Naaldwijk Research Station proved to be too limited, and it was decided to build the climate glasshouse described in this article. During the 1960's the glasshouse temperature control equipment used in practical horticulture developed into glasshouse climate control equipment. The control actions of this equipment are determined by climatic factors in and outside the glasshouse (Germing, 1969; Bokhorst et al., 1972; Strijbosch et al., 1973; Heyna, 1973). It became necessary to find an answer to the question which control procedures are most likely to provide the optimum climate for the crop. This means that the relationship between the climate outside, the glasshouse climate and the growing crop needs to be studied.

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Lay-out

A climate glasshouse should consist of several compartments in which crops can be grown under practical conditions. The new climate glasshouse at Naaldwijk has 24 compartments, each with a surface area of about 50 m^2. The compartments were built in a Venlo block bordered on two sides by corridors and by other glasshouse compartments on the other two sides to eliminate fringe effects. Each compartment is regarded as a separate unit, equipped with flexible heating and irrigation systems suitable for both flower and vegetable crops, ventilators on two sides, CO_2 equipment, facilities for artificial irradiation and permanent underground steam sterilization and soil heating systems (Anon, 1972b). A computer system was found to be necessary to control the climatic conditions in each of the 24 compartments.

This system is also used for continuous recording of a number of climatic factors and for the daily control of the glasshouse climate and the positions of the final control elements (Anon., 1972a).

Construction

The climate glasshouse was built on the site of the Glasshouse Crops Research and Experiment Station, Zuidweg 38, Naaldwijk. The soil consists of light loam drained

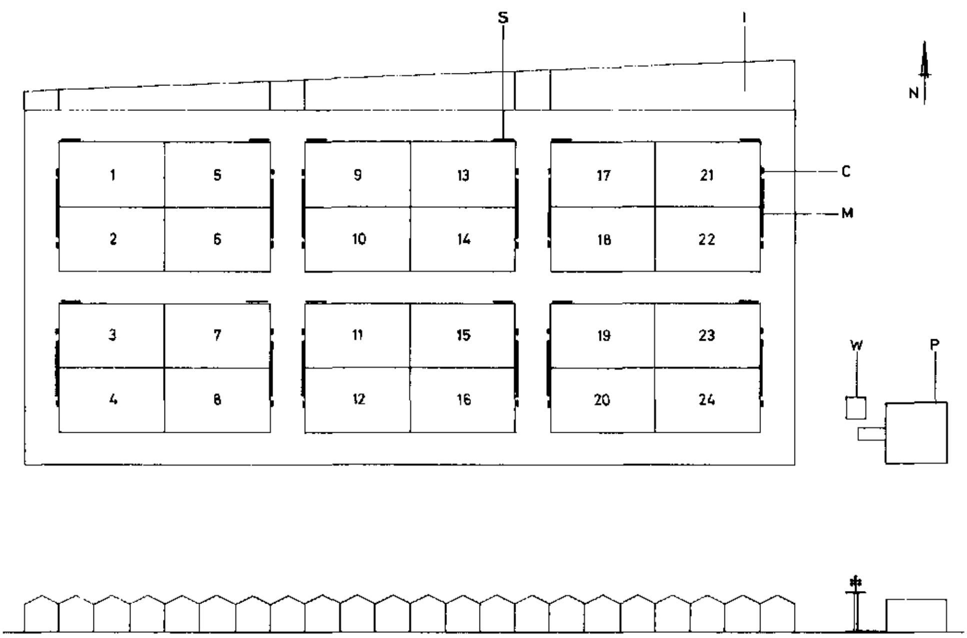

Fig. 1. Plan and front view of the climate glasshouse with computer centre (P) and weather mast (W). Also shown are the position of the irrigation installation (I), manifolds (M), the control and switch cabinet (S) and the connection cabinets for mV signals (C).

Fig. 4. View of process computer and peripheral units.

(Fig. 1) and consists of a process computer with peripheral equipment (Fig. 4, Table 1; Offer et al., 1973).

Each growing compartment has a surface area of 56 m². Tile drainage has been installed consisting of clay pipes with a diameter of 50 mm. The soil heating system consists of a double network of 13-mm galvanized steel pipes and the permanent steam sterilization system consists of 50-mm clay pipes.

The drainage system, connected to a central pump, maintains the water-table at a constant level. The water temperature of the soil heating system in each compartment is separately controlled by a regulating valve and a thermostat with a range of 0 to 40 °C. The steam sterilization system in each compartment can be connected

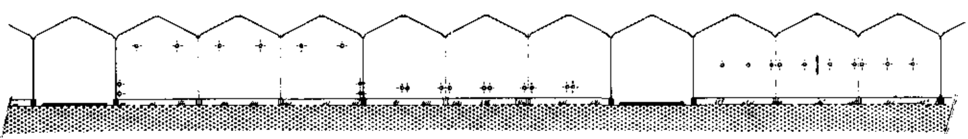

Fig. 5. Possible combinations of the heating systems.

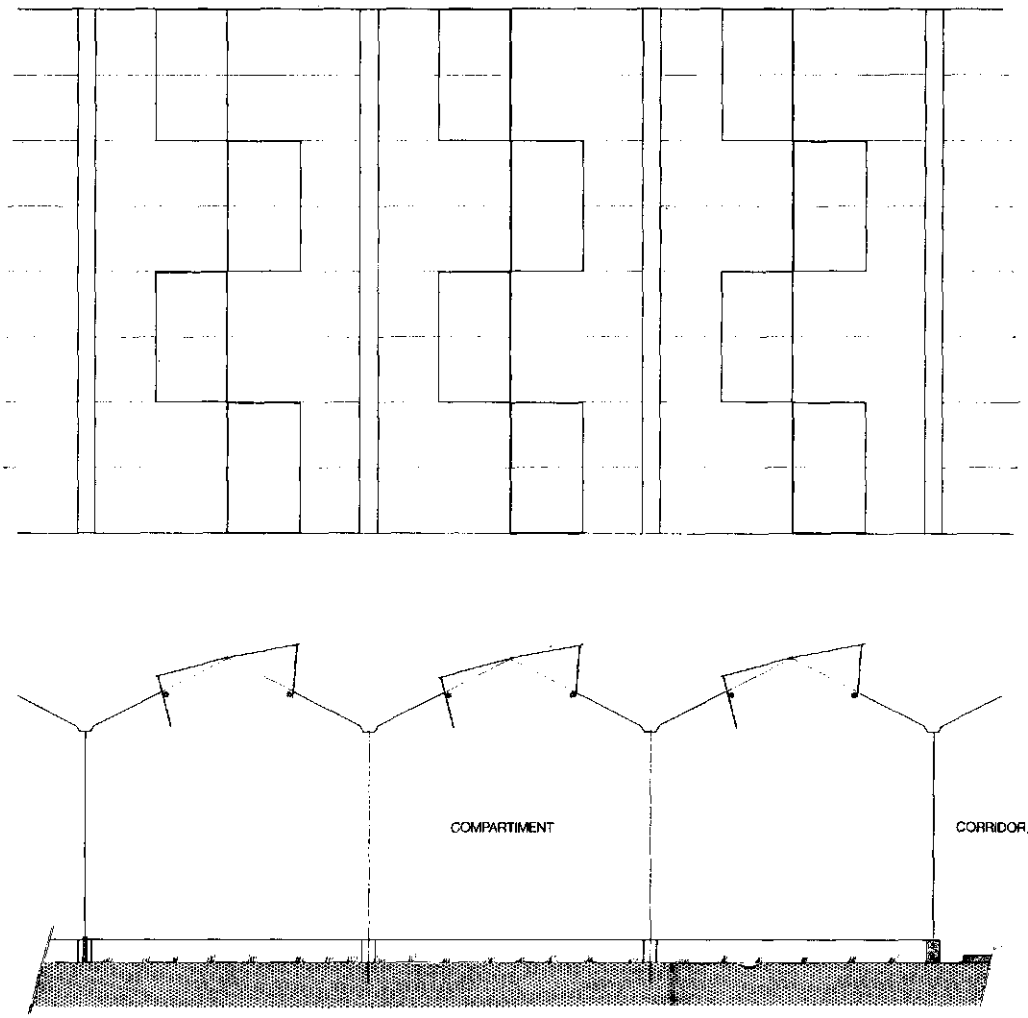

Fig. 6. Configuration of ventilators in one compartment.

to a mobile steam generator. Two pipe heating systems – made of 51-mm steel pipes – have been installed in each compartment, fixed pipes along the gables and at gutter level and a vertically and horizontally adjustable pipe system lower in the house (Fig. 5).

The water temperature in the heating system is controlled with the aid of regulating valves operated by the computer system. This type of control system is known as direct digital control (DDC). Both the upper and lower pipe heating systems are activated with on/off valves by DDC. The ventilation system consists of 12 ventilators (Fig. 6).

Table 2. List of signals recorded.

Variable	Signal	Method	Location	Number	Physical unit
Time	digital clock	digital	computer	1	d, h, s
Radiation	solarimeter	analog 0-10 mV	weather st.	1	$J\ cm^{-2}\ h^{-1}$
Outside temperature	thermo-couple	analog 0-10 mV	weather st.	1	°C
Wind speed	*tachogenerator*	analog 0-10 mV	weather st.	1	m/s
Relative atmospheric humidity outside	potentiometer	analog 0-10 mV	weather st.	1	%
Wind direction	potentiometer	analog 0-10 V	weather st.	1	°
Rain	relais	digital	weather st.	1	–
Glasshouse air temp. dry bulb	thermo-couple	analog 0-10 mV	compartment	72	°C
Glasshouse air temp. wet bulb	thermo-couple	analog 0-10 mV	compartment	72	°C
Glasshouse air temp.	thermo-couple	analog 0-10 mV	compartment	48	°C
Pipe temperature supply	thermo-couple	analog 0-10 mV	compartment	24	°C
Pipe temperature return	thermo-couple	analog 0-10 mV	compartment	24	°C
Soil temp. at 0-50 cm	thermo-couple	analog 0-10 mV	compartment	120	°C
Plant temperature	thermo-couple	analog 0-10 mV	compartment	24	°C
CO_2 content	infra-red gas analyser	analog 0-10 V	compartment	24	% v/v
Setting heating valve	potentiometer	analog 0-10 V	compartment	24	%
Setting western vents.	potentiometer	analog 0-10 V	compartment	24	%
Setting eastern vents.	potentiometer	analog 0-10 V	compartment	24	%
Setpoint heating back up controller	potentiometer	analog 0-10 V	compartment	24	°C
Setpoint vent. back up controller	potentiometer	analog 0-10 V	compartment	24	°C
Spare 1		analog 0-10 mV	compartment	72	μV
Spare 2		analog 0-10 V	compartment	48	V
Valve setting lower pipe network	relais	digital	compartment	24	–
Valve setting upper pipe network	relais	digital	compartment	24	–
Lighting on/off	relais	digital	compartment	24	–
Test signal 1	DC power supply	analog 0-10 mV	computer	8	μV
Test signal 2	multiplex	analog 0-10 mV	computer	8	μV

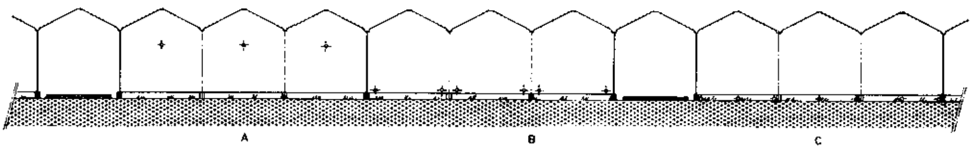

Fig. 7. Possible configurations of the irrigation systems.

The ventilators are operated by the computer system via two ventilator motors installed in each compartment. If necessary, the ventilators can also be opened and closed manually. There is a choise of two irrigation systems. One consists of a 32-mm aluminium pipe fitted with five stem nozzle sprinklers per bay, the other system consists of two 32-mm PVC tubes fitted with 7 bow sprinklers (Fig. 7).

Enrichment with pure CO_2 is applied through 13-mm perforated tubes, one of which is installed in each bay. The time of enrichment is controlled with on/off valves by DDC.

Power points have been fitted for crop irradiation at a capacity of 175 W/m^2. The switches are operated by DDC or, if necessary, manually. Many climatic factors are measured and recorded (Table 2).

Temperatures are measured with copper constantan thermo-couples. The relative and absolute atmospheric humidity is calculated from dry and wet bulb measurements. The weather station measures the relative atmospheric humidity with a hair hygrometer, the wind speed with a cupanemometer, the wind direction with a wind vane and global radiation with a Kipp solarimeter. The CO_2 levels in the 24 compartments will be measured by three infra-red analysers. The synchronization of

Table 3. List of digital output signals.

Variable	Location	Number
Heating computer back up controller	compartment	24
Heating control valve, opening	compartment	24
Heating control valve closing	compartment	24
Valve lower heating network open/closed	compartment	24
Valve upper heating network open/closed	compartment	24
Setpoint heating back up controller higher	compartment	24
Setpoint heating back up controller lower	compartment	24
Ventilation computer back up controller	compartment	24
Ventilation east/west	compartment	24
Ventilators opening	compartment	24
Ventilators closing	compartment	24
Setpoint ventilation back up controller higher	compartment	24
Setpoint ventilation back up controller lower	compartment	24
Valve CO_2 enrichment open/closed	compartment	24
Valve CO_2 measurement open/closed	compartment	24
Lighting on/off	compartment	24
Alarm on/off	computer	1

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The relationship between plant quality and yields of glasshouse tomatoes*

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Summary

Experiments in plant raising and early cropping of tomatoes under glass showed that the quality of the plant material, measured by the subsequent crop yield, was largely determined by plant size and was therefore a question of quantity. A further investigation covering 55 nurseries in the South Holland glasshouse district showed that there was a wide variation in the tomato plants used for planting out in December for the early 1969/70 crop. In all cases the plants were too small.

For earliness and yields until 18 April 1970, multiple regression equations could be formulated with correlation coefficients of R = 0.92 and R = 0.86, respectively. According to these equations the effect of plant size on earliness was considerable, but the effect on the yield was less. Further it was found that a higher NO_3 level in the plant material resulted in a later date of the first pick, whilst a higher Na level caused a lower yield. With the data available, an explanation for these statistically reliable relationships could not be advanced. It was also shown that when the same plant material was used there was no relationship between the yields in one cropping experiment and those on the nurseries.

1 Introduction

Earlier investigations into the propagation of tomatoes under glass showed the existence of a relationship between plant size and yield (Spithost, 1969) which could be quantified. Apart from the size of the plant material there was little indication of specific quality effects. The variations in the plant material were caused mainly by soil conditions. It was considered desirable therefore to examine the effect of specific plant quality, brought about by, for instance, climatic conditions, on the earliness and yield of tomatoes under glass.

There was also another problem. It was suggested that there were wide variations in the size of the plant material used on commercial nurseries and that this could have an effect on the yield, earliness and profitability of the nurseries. Between 1969 and 1971 a number of investigations were carried out into the following aspects:

1. does the quality of the plant material depend partly on inner properties?

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2. to what extent does the quality of the plant material used for the early heated tomato crop in the South Holland glasshouse district vary and how much effect does this have on earliness and yield?

2 Methods of investigation

Samples of the plant material were obtained by cutting off the plants just below the cotyledons. The samples were put into sealed plastic bags to limit transpiration losses during transport to a minimum. As soon after collection as possible, the length, the number of leaves larger than 3 cm, the fresh weight and the dry matter weight of the samples were recorded and chemical analyses were carried out. The number of plant tops used varied between 18 and 50 per sample, depending on the size of the plants.

Uncut samples of plant material were also collected for inclusion in cropping experiments. The yields of these plants were determined be weighing the fresh fruits.

On the nurseries a number of factors were recorded which were considered to have a bearing on the variations in yield. The growers supplied the information on night temperatures and the minimum and maximum day temperatures, supplemented sometimes by our own recordings.

The relative light transmission of the glasshouses was determined by carrying out a number of light measurements with a lux meter inside and outside the glasshouse, after which the average inside reading was calculated as a percentage of the light level outside the glasshouse.

Experimental designs and statistical analyses were carried out according to well-known methods (Cochran & Cox, 1957) and multiple regression equations were selected by the stepwise regression procedure (Draper & Smith, 1966).

3 Experiment with commercial plant material 1969/70

Besides the investigation into the relationship between plant quality and earliness and yield on commercial nurseries (Section 5), a cropping trial was organized at the research station for which 21 nurseries contributed plant material. There were also four plots in the trial containing plants propagated on the research station. The trial was conducted in a heated glasshouse block, laid out as a 5 by 5 lattice square with 6 replications and 20 plants per plot. Planting out in the glasshouse borders was done between 15 and 24 December 1969. Each of the six replicates was housed in a separate compartment with its own temperature regime. In three of the compartments the temperature of the air was set at a higher level than in the other three compartments, with the result that beween 24 December 1969 and 9 May 1970, the average temperature in one set of compartments was 20.9 °C and in the other 20.3 °C. The difference was caused mainly by the difference in maximum day temperatures.

The data on the plant material are shown in Table 1. It is clear that the variation in the plant material was very wide. The fresh weights showed much wider vari-

Table 6. Variations present in important factors in a study of 55 commercial nurseries with and early heated tomato crop.

Factor	Minimum	Mean	Maximum
First picking (week in 1970)	8	12	15
Fruit yield until 18 April (kg per 100 m^2)	3	98	192
Sowing date (days after 30 September)	22	35	52
Plant age (days)	42	55	70
Plant length (cm/plant)	8.7	16.4	32.8
Leaves over 3 cm (number per plant)	4.8	7.2	9.2
Na content plant material (% Na_2O in dry matter)	0.3	0.8	1.5
NO_3 content plant material (% N in dry matter)	0.9	1.8	2.2
Row spacing (cm)	40	48	55
Soil temperature (°C)[1]	15.2	17.2	18.8
Relative light transmission (% of light outside)[1]	53	69	84
Roof sprinkler (0 = no; 1 = yes)	0	0.4	1
Paraffin usage for CO_2 (kg/100 m^2)	0	197	441

[1] On 17 February after the effect of date of survey has been removed.

Section 3 was much larger than the commercial plants which made a poor impression.

Earliness, expressed as the week in 1970 when the first fruit was picked, varied between 8 and 15, or almost two months (Table 6). The average was 12 which is equivalent to the period of 22 to 28 March 1970. It should be noted that the earlier the crop, the lower was the assessment figure awarded. Earliness as a function of a number of factors is illustrated in Table 7. The independent factors have been included in the same order of sequence as with the regression analysis with the exception of the leaf numbers which will be explained later.

The multiple correlation coefficient was calculated as $R = 0.92$ so that only 15 % of the total variance remained unexplained. However, it is not only the regression coefficients which are important to obtain an impression of the effects of the factors included in the equation, but also the respective distributions which

Table 7. Multiple regression equation for earliness of the yield (expressed as the week of first picking) in a study of 55 commercial nurseries with an early heated tomato crop.

First picking (week in 1970) =		Standard error	F to remove
0.15	sowing date (days after 30 September)	0.01	105.96
0.10	plant age (days)	0.02	28.93
— 0.33	soil temperature (°C) (% N_{NO_3} in dry matter)	0.11	8.37
1.0	NO_3 content plant material	0.3	10.81
— 0.0024	paraffin usage (kg/100 m^2)	0.0009	7.56
— 0.08	in row spacing (cm)	0.03	6.76
— 0.5	leaves over 3 cm (number per plant)	0.1	21.16
+ 13.2			

$R = 0.92$

are shown in Table 6.

The sowing date which was on average on 4 November 1969 had a regression coefficient of 0.15. This means that one week later sowing resulted in one week later picking. The sowing dates ranged over a period of 30 days which shows what a large effect the sowing date has on the time of picking.

The age of the plant material had a positive regression coefficient which indicates that the use of an older plant is detrimental to earliness. In view of the maximum age difference of the plants of 28 days, the difference in picking date amounted to almost three weeks.

The nitrate content of the plant material ranged from 0.9 to 2.2 % N of the dry matter and was therefore rather high (Ward & Miller, 1971). An increase in the nitrate content was accompanied by a decrease in yield with a maximum effect of 9 days. The nitrate content was significant and was positively correlated with the K content ($r = + 0.41$). In view of the positive correlation coefficient of K content and yield (Table 3), the NO_3 effect cannot be explained as part of a general relationship between the mineral content of the plant material and the subsequent development of the crop.

Finally, there is the plant material variable of the number of leaves larger than 3 cm. An increase in the number of leaves has a beneficial effect on earliness with a maximum effect of more than 2 weeks. In view of the high F value there is a strong correlation between this plant property and earliness. Plant weight was included initially at the third stage of the analysis as a factor in plant size, but is was eliminated at a later stage of the analysis through the inclusion of the leaf number because of the strong interrelationship between these two factors.

Earliness was of course also encouraged by factors other than the plant material such as higher soil temperatures, increased CO_2 enrichment (van Berkel, 1967) and wider planting in the rows. However, these factors will be left out of the discussion.

The yields until 18 April, i.e. the 15th week in 1970, were on an average 98 kg per 100 m² (Table 6) and depended on 8 factors (Table 8). The multiple correlation coefficient was $R = 0.86$ which means that 75 % of the total yield variance could be explained. Five of the eight factors are connected with the plant material, viz

Table 8. Multiple regression equation for yield until 18 April.

Yield (kg/100 m²) =		Standard error	F to remove
+ 0.20	paraffin usage (kg/100 m²)	0.04	22.30
— 2.5	sowing date (days after 30 September)	0.7	12.95
— 78	Na content plant material (% Na_2O in dry matter)	23	11.97
+ 2.2	relative light transmission (% of outside)	0.7	10.78
— 4.6	plant age (days)	0.9	25.62
+ 31	leaves over 3 cm (number per plant)	8	14.54
— 4	plant length (cm/plant)	1	9.87
+ 17	roof sprinklers (0 = no; 1 = yes)	8	3.98
+ 151			

$R = 0.86$

sowing date, Na content of the plants, age of the plants, number of leaves over 3 cm and length of the plants. One day earlier sowing increased the yield from 100 m^2 by 2.5 kg of fruit. With the sowing dates ranging over a period of 30 days, the maximum yield difference was 75 kg per 100 m^2.

An increase in the Na_2O content of 1 % caused a yield reduction of 78 kg per 100 m^2, with a maximum reduction of 94 kg per 100 m^2. This effect is practically the same as that achieved in the cropping trial with commercial plant material for the yields recorded until 9 May. On the other hand, in the compartments with the higher temperature regime (Table 3) there is no similarity with these results.

A decrease in the age of the plants of one day, increased the yield by 4.6 kg per 100 m^2 and the yield difference between the shortest plant raising period and the longest was 129 kg.

An increase in the number of leaves larger than 3 cm increased the yield per leaf by 31 kg and by 136 kg per 100 m^2 at most. Both factors, age of the plants and leaf number, had an effect on production which was similar to the effect on earliness. The effect of plant length was opposite to the effect of leaf number. An increase in plant length of 1 cm was equivalent to a yield reduction of 4 kg per 100 m^2. The regression equation length (cm/plant) = 3.5 leaves > 3 cm (number/plant) — 8.6 (r = + 0.72) shows that the detrimental effect of increasing plant length is more than compensated for by the yield increase as a result of the increasing number of leaves. In the computation the plant length was included immediately after the introduction of the number of leaves in the regression equation, after which the regression coefficient of the leaf number was also increased appreciably. Apart from the plant properties mentioned above, there was only one independent factor in the comparisons which had a bearing on the crop, viz the paraffin usage for CO_2 enrichment. For every 5 kg increase in the usage of paraffin, the yield was increased by 1 kg per 100 m^2. The maximum effect amounted to 88 kg per 100 m^2.

Finally, there were two factors connected with the technical equipment of the nursery: the relative light transmission expressed as a percentage of the light outside the glasshouse and the presence or absence of roof sprinklers for keeping the glass clean. The regression coefficient of the relative light transmission indicated that for every % light loss the yield decreased by a little over 2 kg per 100 m^2. This is not a great deal in itself, but the distribution within this factor was so great that the maximum difference was still as much as 68 kg per 100 m^2. The use of a roof sprinkler increased the yield by 17 kg per 100 m^2.

The financial results of the yields until 18 April obtained on the commercial nurseries investigated, varied between 6 and 492 guilders per 100 m^2, with an average of 229 guilders. There was a high correlation between the financial results in guilders per 100 m^2 and the crop yield in kg per 100 m^2, expressed by the following equation:

financial results in guilders = 2.55 kg — 19 (r = + 0.99). The standard error of the regression coefficient amounted to s = 0.05. The presence of the constant is a result of reducing prices as the season progressed which, if this had been the case, would have given nurseries with earlier yields higher average returns. More-over, the high correlation coefficient shows that the financial results can be explained almost entirely by the yields and that differences in grade and quality, as well as the auction to which the fruit was supplied, had practically no effect on the financial results.

6 Discussion and conclusions

The results of both cropping trials showed the strongest correlation between early yield and plant length which confirmed the results of previous investigations (Spithost, 1969). In the first experiment (Section 3) there were no significant differences in the regression coefficients of the plant length in the equations for the higher and the lower temperature regimes. This indicates that there was no specific interaction between plant length and the cropping temperature. This would mean that the effect of plant size on subsequent yield is independent of the climatic conditions during the cropping period.

According to the plant raising and cropping trial described in Section 4 an internal quality effect was found which was an effect resulting from the plant raising temperature. However, in relation to the overall effect it was practically negligible. In other words, the quality of the plant material for an early heated crop is almost entirely a question of plant size or plant quantity.

Besides plant size, the mineral composition of the plant material proved an important factor in the experiment with commercial plant material. However, the various regression equations all included different mineral contents, viz magnesium, potassium or sodium. In assessing whether there is question of a functional effect, it should be borne in mind that the potassium content correlated with both the magnesium content ($r_{K,Mg} = -0.62$) and the sodium content ($r_{K,Na} = -0.54$). There was also a significant relationship between the potassium content and the length of the plant ($r_{K,l} = +0.53$). Although there were no significant correlations between plant length and the contents of sodium and magnesium, the other intercorrelations make it difficult to give accurate interpretations of the presence of the contents in the multiple regression equations.

The same was true for the NO_3 content or the Na_2O content in the regression equations for earliness and the yields obtained on the nurseries. According to the correlation matrix, there was a most significant correlation between the Na content and all the factors connected with crop development, in the sense that a higher Na_2O content in the plant material had a detrimental effect on subsequent growth of the crop. It is probable that the correlations between the chemical composition of the plant material and the crop results are partly true and partly the result of indirect relationships. For example, varietal differences could play a rôle as the nursery investigations were not limited to one and the same variety. Further work may shed more light on this aspect.

With regard to the commercial plant material it could be said that generally wide variations were found. Compared with an investigation carried out in 1960 (Spithost, 1969), there was little difference in the range of plant weights recorded in spite of an interval of nine years. Taking into account that there must be an optimum plant size from the point of view of handling, one cannot escape the conclusion that on the whole commercial plant material was much too small, particularly if one considers the effect of the plant material on the subsequent yields.

Amongst the variables of the plant material the sowing date was most important, and its effect needs no further explanation. Increasing plant age had an unfavourable effect. As the aftereffects of poor conditions during plant raising are less if the plants are planted out in a younger stage (Spithost, 1964), the relationships found in the experiments could be an indication that conditions during plant raising were often below the optimum.

An increase in the number of leaves over 3 cm had a beneficial effect.

The close correlation between plant length and the number of leaves generally and the fact that in linear regressions the variable with the highest correlation coefficient is selected, merely shows that in principle there is no antagonism between plant length and the number of leaves over 3 cm.

However, in the regression equation of the nursery returns a complication cropped up through the inclusion of the plant length with a negative regression coefficient. Nevertheless, the beneficial effect of increasing plant size on the yield was retained. It is possible that the inclusion of plant length should be seen more as a result of the computation method used than as a true effect.

The effect of the plant material on yields was much greater in the experiments than in the nursery investigation. As there were 19 treatments in both projects, it was determined whether there was a correlation between the respective yields. After the data had been divided into high and low temperature treatments, it was found that the correlation coefficients of the experimental yields and the commercial yields for the harvest period until 18 April were $r = + 0.05$ and $r = + 0.07$, respectively. There was therefore no relationship whatsoever, although it might have been expected to exist. Apparently there were one or more factors which prevented this. There might be a kind of countereffect on the nurseries which could have worked like this: after planting out larger plants there was rapid growth which the growers purposely controlled on the supposition that controlled vegetative growth is beneficial for flower formation and fruit set. Besides this there may have been other factors which were not covered by the investigation but which were connected with the fact that on the nurseries included in the investigation the possibilities of good plant material were not used to the best advantage.

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Growth rates of tomato seedlings and seasonal radiation*

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Summary

During the years 1970 to 1972, 34 batches of tomatoes were sown at regular intervals. Until the plants flowered, their fresh weight was determined once or twice a week. The data were used to calculate daily growth percentages and the number of days required by the plants to develop from 0.1 to 10 g fresh weight per plant. For each of the growing periods the radiation totals and the average radiation per day were calculated. The data obtained were related to each other and compared with the information obtained by other research workers.

The growing methods used resulted in substantially higher growth rates and higher light efficiency than were known from previous work carried out under natural light conditions (Brouwer, 1973). However, the same very high relative growth rates have been recorded more recently in growth chambers with artificial irradiation (Hurd & Thornley, 1974).

Nevertheless, there are still unknown factors which have caused a disproportionate reduction in the light efficiency of many batches during the summer period. Further investigations into these aspects are necessary.

Introduction

Plant growth, and especially the rate of growth of young tomato seedlings, varies with the time of year. This well-known phenomenon has been described and quantified by a number of research workers (Blackman et al., 1955; Bunt, 1972; Cooper, 1966, 1967; Hegarty, 1973; Hodgson, 1967; Voldeng & Blackman, 1963). Apart from the effects of temperatures, the amount of daily radiation is generally regarded as the direct cause of growth variations.

The data are presented as annual growth curves and occasionally as light efficiency curves. There are very large variations in the absolute growth rates recorded by different workers (Warren Wilson, 1966).

The data in this publication are of a similar nature, although the aim has been to achieve maximum growth rates in all seasons. A plentiful supply of water and automated fertilization proved to be crucial for this. The temperature regime was also found to be very important.

Thirty-four sowings were made between 1970 and the end of 1972. In many

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cases the treatment giving the quickest growth was chosen from an experiment as the basis for the annual cropping programme. The starts of the treatments were also selected in such a way that an evenly distributed annual cycle was obtained (see also de Lint & Klapwijk, 1973, 1974).

Samples were taken from the different batches, twice a week in summer and once a week in winter. This means that five to eight observations were made for each sowing from the moment of emergence until the first truss came into flower. The data obtained were used for plotting growth curves. Those sections of the growth curves representing the development of the plants from 0.1 g to 10 g fresh weight per plant were analysed further and related to the amounts of light received.

The information obtained is discussed and compared with the data obtained by other research workers.

Materials and methods

Tomatoes of the cv 'Moneymaker' were sown directly into 3-litre black plastic pots filled with peat compost. The compost consisted of a mixture of 85 % sphagnum peat and 15 % black sedge peat. To each cubic metre of the mixture were added 5 kg of ground dolomite lime stone, 1.5 kg compound fertilizer (14-14-14), 0.5 kg Sporumix PG (25 % MgO, 0.3 % Cu, 0.1 % B, 0.6 % Mo and 0.5 % Mn), and 25 g Fe 138 (chelated iron).

After emergence, the seedlings were thinned to 8 to 10 per pot, leaving a uniform stand of plants in each pot. When the plants developed they were thinned again to avoid overcrowding. The thinnings were used as samples for the determination of fresh weights. Other growth characteristics were not measured as these can be deduced adequately from the fresh weight figures (de Lint & Klapwijk, 1974).

The plastic pots were placed on glasshouse staging in 2 cm of liquid feed in which they remained for the duration of the experiment. Root development was satisfactory even in the layer of peat which was submerged in the nutrient solution (de Lint & Klapwijk, 1974). The nutrient solution was prepared from a compound fertilizer (13-5-13-5) and its concentration was automatically controlled at about 1 atm osmotic pressure by resistance measurement. The pH and electric conductivity of the nutrient solution were determined in the laboratory once a week. The solution in the glasshouse staging was replaced twice a day in summer and once a day in winter.

The glasshouse used for the experiments was a Venlo type block of average height, metal clad, with a bay width of 4.8 m and two-sided half-length ridge ventilation. Light transmission was 70 % maximum.

Between May and September 1970 and 1971, the average maximum day temperature was 35 to 37 °C. In 1972, the thermostat was moved from between the plants to an insulated, aspirated screen. As a result the summer temperature dropped to 30 to 32 °C. During the winter months the temperatures gradually dropped to an average maximum day temperature of 22 to 24 °C. The average minimum night temperature was 20 to 22 °C between March and October and gradually decreased in winter to 14 to 16 °C. No CO_2 enrichment was applied.

Table 1. Sowing dates, fresh weights (g/plant) and days after sowing of the observations.

Experiment No.	Sowing date	Fresh weights after . . . days															
		days	g	days	g	days	g	days	g	days	g	days	g	days	g	days	g
1	14 Jan. '72	6	0.0176	13	0.0478	20	0.141	28	0.616	34	2.50	42	8.80	49	29.9	56	84.3
2	3 Feb. '72	6	0.0133	8	0.0251	14	0.136	22	0.560	29	3.40	36	14.5	43	62.1	50	108
3	25 Feb. '72	7	0.0172	14	0.214	21	2.21	28	21.4	32	44.8	34	64.6				
4	26 Feb. '71	14	0.164	18	0.567	21	1.14	24	3.25	27	7.43	38	89.5				
5	17 March'72	7	0.0249	13	0.155	18	0.895	21	2.63	28	27.2	35	121				
6	19 March'70	6	0.0235	13	0.285	18	1.57	21	4.37	25	13.4	34	113				
7	7 April '72	6	0.0191	14	0.270	19	2.43	21	4.13	28	34.2	35	130				
8	26 April '71	11	0.118	16	0.540	18	1.31	22	3.69	28	28.5	36	101				
9	6 May '70	5	0.0113	9	0.0950	14	0.622	16	4.42	19	4.42	22	12.7	33	162		
10	10 May '71	11	0.120	16	0.458	22	2.75	29	20.8	36	75.8						
11	28 May '71	12	0.200	14	0.480	18	2.32	25	19.7	31	78.2						
12	15 June '70	7	0.0305	14	0.455	18	2.11	24	15.3	37	207						
13	18 June '71	10	0.105	14	0.613	17	1.50	21	5.37	31	69.2						
14	9 July '71	10	0.123	14	0.535	19	4.29	24	13.3	31	65.7	35	108				
15	20 July '72	15	0.310	19	1.88	22	4.99	27	21.2	41	221						
16	29 July '71	11	0.114	15	0.416	19	1.67	25	13.7	32	53.3	39	152				
17	30 July '71	11	0.177	12	0.232	14	0.436	21	5.79	25	20.3	28	41.6	38	166		
18	13 Aug. '70	8	0.0459	13	0.320	15	0.844	18	2.41	22	8.65	35	134				
19	18 Aug. '71	12	0.263	15	0.800	19	3.68	22	11.5	26	33.7	29	62.1				
20	20 Aug. '71	10	0.0810	13	0.289	17	1.20	20	4.01	24	12.6	32	61.6	38	98.1		
21	31 Aug. '72	11	0.139	14	0.236	18	0.806	21	2.64	25	9.55	28	20.3	32	47.2	36	86.2
22	10 Sept. '71	6	0.0233	11	0.130	14	0.337	17	0.845	21	2.88	31	28.8	38	62.8	42	98.6
23	21 Sept. '71	13	0.0800	18	0.433	22	1.57	27	5.20	29	7.50	35	25.5	39	45.7	43	84.4
24	1 Oct. '70	6	0.0740	8	0.0264	11	0.0732	15	0.234	19	0.651	22	1.33	29	4.85	56	66.0
25	1 Oct. '71	10	0.0990	14	0.255	17	0.625	21	1.70	26	6.00	30	19.9	35	30.8	41	60.8
26	5 Oct. '72	15	0.0857	18	0.170	25	1.01	29	3.20	34	6.92	43	26.1	49	53.3	57	104
27	19 Oct. '72	11	0.0364	15	0.125	20	0.235	29	1.33	35	3.36	43	12.5	47	27.4	54	45.5
28	2 Nov. '72	15	0.130	21	0.290	26	0.900	29	1.54	33	3.50	40	8.90	49	20.6	60	51.9
29	5 Nov. '71	13	0.0453	20	0.116	27	0.295	34	0.665	42	1.86	52	4.52	62	10.3	76	28.0
30	17 Nov. '72	14	0.0375	24	0.124	32	0.513	40	1.42	46	4.47	53	7.30	60	12.4	67	24.2
31	18 Nov. '70	15	0.0420	23	0.134	30	0.277	36	0.453	43	1.09	51	3.36	70	28.6		
32	2 Dec. '71	15	0.0489	25	0.125	35	0.361	49	1.62	56	3.17	63	8.18	71	24.6	77	53.3
33	3 Dec. '70	7	0.0124	14	0.384	19	0.0629	36	0.520	55	5.28	84	90.6				
34	23 Dec. '71	14	0.0327	28	0.154	35	0.408	42	1.06	50	3.92	56	9.05	64	34.1	71	90.6

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Brouwer with maize are about as high as those from Australia.

The data obtained by Hurd & Thornley (1974) however, obtained in growth chambers, are directly comparable. Their plants also achieved about 45 % maximum relative growth rates. It is therefore feasible to achieve very high growth rates in glasshouses with natural light as well as in growth chambers with artificial irradiation. These growth rates are of the same order as those achieved with duckweed (*Lemna minor*), viz 35 % (Hodgson, 1970) and 68 % (J. Rombach, pers. commun., 1974).

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The relationship between the Aphis gossypii Glover group and cucumber mosaic virus in autumn cucumbers*

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Summary

The wide-spread damage caused by cucumber mosaic virus (CMV) to autumn cucumbers in 1963, led to an investigation into aphids which are the vectors of this virus. In the South Holland glasshouse district *Aphis gossypii* Glover is the only aphid occurring as a pest of glasshouse cucumbers. Yellow water traps were set up in various places. There appeared to be no relationship between the extent of the cucumber crop in an area and the number of *A. gossypii* caught in the traps. The peak month for flight of these aphids is August. More aphids were caught in the yellow traps outside the glasshouse than in the traps placed inside the glasshouse beneath the ventilators. However, percentage-wise a larger proportion of the aphids caught in the traps inside the glasshouses belonged to the *A. gossypii* group than was the case in the outside traps, and more of these aphids were caught in cucumber houses than in tomato houses.

A. gossypii rapidly colonized cucumber and gherkin plants placed outside and under frame lights for 24 hours. *A. gossypii* plays an important part in the infection of CMV which occurred most frequently in August. However, only a small percentage of the aphids was responsible for transmission of the virus.

Introduction

Although cucumbers are grown in glasshouses the whole year round, cucumber mosaic virus (CMV, Cucumis virus 1) causes damage virtually only to the autumn crop. In 1963, the virus caused so much damage that it was considered necessary to carry out research into the vectors of the virus, aphids. The only species of aphid which is a pest of glasshouse cucumber crops in the South Holland glasshouse district is *Aphis gossypii*. Cucumber mosaic virus is non-persistent. It may be found in many cultivated plants as well as in weeds. According to Kennedy et al. (1962) this virus may be transmitted by many species of aphids. Tjallingii (1952) and van Koot & van Dorst (1959) state that cucumber crops grown in the early part of the year escape infection as they will have reached a mature stage by the time the aphids take to the wing. Börner (1952) reports that (*Cerosipha*) *Aphis gossypii* Glover from cucumber nurseries was found to be anholocyclic. However,

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in his studies of the *A. frangulae-gossypii* problem, Böhm (1966) comes to the conclusion that part of the population on crops of the cucumber family is holocyclic (overwintering on Rhamnaceae), a smaller part is anholocyclic (overwintering in glasshouses) and a considerable part is killed by frost together with the host plant. Thomas (1968) sees a close relationship between the holocyclic *A. frangulae* Kaltb. and the anholocyclic *A. gossypii,* and suggests that the latter hibernates in glasshouses and other sheltered places. Maison (1966) comes to the conclusion that in S.E. France *Myzus persicae* transmits CMV from weeds into the melon crop in spring and that *A. gossypii* plays an important rôle in the subsequent spread of the virus. According to McClanahan (1964) it is possible under practical conditions for *M. persicae* to transmit the virus into cucumber crops and for *A. gossypii* to spread the disease.

In breeding experiments by Passlow & Roubiceck (1969) with *A. gossypii* on cotton seedlings (temperature 16 to 26 °C), there were found to be four larval stages, each lasting about two days. The adult stage was reached after 7½ days. The adult had an average life span of 16 days (maximum 46 days) during which they produced a progeny of 50 on average and 166 as maximum. Wyatt (1970) reported that *A. gossypii* on cucumber crops multiplied at rates of 5.4, 8.8 and 6.5 times a week at average temperatures of 19.7, 25 and 26 °C, respectively.

As *A. gossypii* plays such an important rôle in the cucumber crops in the South Holland glasshouse district, an investigation was carried out to establish whether there is a relationship between the flights of these aphids and the incidence of CMV. Transmission of this virus by aphids was also studied and the numbers of aphids entering the glasshouses through the ventilators were recorded.

Materials and methods

In order to establish the relationship between the flights of aphids of the *A. gossypii* group and the incidence of cucumber mosaic virus, yellow water traps (36 × 53 cm) were used for several years. The traps were set out at a height of 50 cm. In each season one trap was installed at the Research Station at Naaldwijk where cucumber crops were grown regularly. For a number of years there were also three yellow water traps distributed over a cucumber growing area in the South Holland glasshouse district. In a nursery growing peppers at Poeldijk one trap was placed in a sheltered site between glasshouses at 2 to 7 m distance from the glasshouses. Another one was placed at a cucumber nursery at Delft and a fourth trap on an allotment at Maasdijk. For comparison a fifth trap was placed in an area where no cucumbers were grown. This was on meadowland of a farm at Negenhuizen near Schipluiden. The traps at Poeldijk, Delft, Maasdijk and Negenhuizen were 4.2 km NE; 9.7 km E; 3.4 km S and 9.3 km SE, respectively, of the Research Station at Naaldwijk.

In 1965 and 1966 some yellow water traps were placed in a few glasshouses right under the ventilators, in order to obtain information about the numbers of aphids entering the glasshouse. Ventilators and traps were isolated from the rest of the glasshouse by fine gauze and the crops were kept free of aphids so that no

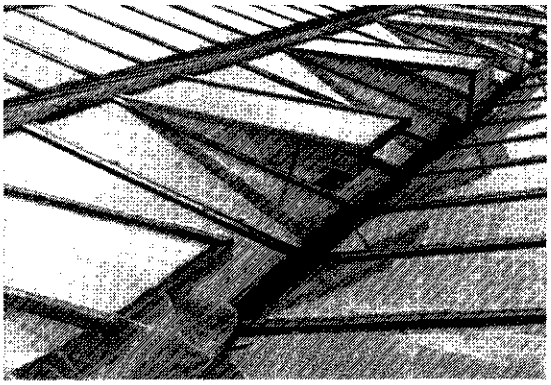

Fig. 1. Yellow water traps under ventilators, some of which are covered by nylon gauze.

aphids could enter the traps from the glasshouse. Half of the traps were covered on top with nylon gauze of 0.9 mm mesh (see Fig. 1). The ventilators could be closed if necessary, but this rarely happened in summer.

A preliminary investigation was carried out into the possibility that aphids penetrate into the glasshouse through crevices between the panes. This was done by fixing on the inside of the glasshouse sticky tape over four crevices between the panes and over a few crevices between the concrete foundations and the lowest pane of glass. It should be pointed out that in well-maintained glasshouses the latter crevices are usually sealed.

As cucumber mosaic virus is non-persistent, it is not easy to determine which aphid species are responsible for transmitting the virus to cucumber crops under practical conditions. Nevertheless, an attempt was made to find out more about the agents of infection by placing young cucumber (Sporu) and gherkin (Baarloo Non-Spot) plants in the open and under frame lights (permanently opened to 25 cm) for 24 h. This was done several times a week in several summers. The plants were marked and all the aphids removed at the end of the 24-hour period and before the plants were taken back to the glasshouse. The aphids collected from the plants consisted of alatae, their larvae and other apterous aphids. Few of the latter were found. Only the alatae were counted and identified. After the exposure the plants were grown on for three weeks in an aphid-proof glasshouse to determine which plants, and how many, had been infected with CMV during exposure. Gherkins were also used as cucumbers are susceptible to bad weather. At the time of the exposure all the plants were in the first true leaf stage. Although they had been sown on the same days, the total leaf area of the young plants (cotyledons, first leaf and youngest leaf) was on average 76 cm^2 for cucumbers and 54 cm^2 for gherkins. For comparison a yellow water trap with a yellow surface area of 1908 cm^2 was placed near the plants.

A. gossypii belongs to a group of aphid species which are very difficult to identify when they are not living on their host plants. In this publication the name *A. gossypii* is used, but the authors are well aware that it would be more correct to refer to the *A. gossypii* group. Identification of the aphids to determine which

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Table 4. CMV infection of cucumber and gherkin plants.

Year	Crop	Number of plants used	Number of plants with aphids		Number of plants with aphids and CMV	Number of plants without aphids but with CMV	Percentage plants with aphids and CMV	Percentage plants without aphids but with CMV
			total	*A. gossypii*				
1966	cucumbers	820	117	109	38	6	32.5	0.9
	gherkins	820	344	266	56	6	16.3	1.3
1967	cucumbers	1560	326	266	5	1	1.5	0.1
1969	cucumbers	880	314	238	5	0	1.6	—
	gherkins	880	221	169	0	0	—	—
1970	cucumbers	720	177	139	10	1	5.6	0.2
	gherkins	720	145	104	4	4	2.8	0.7
Total		6400	1644	1291	118	18	7.2	0.4

185 *A. gossypii* were found on the 20 cucumber plants in the frame, but even so, 70 % of these plants also became infected. On that day 216 *A. gossypii* and 7 *M. persicae* were caught in the yellow water trap in the open. Except for 11 August, the average number of aphids per plant was about the same as in the other years.

The aphid density was calculated only for the plants on which aphids were found. The average in 1966 was 1.6 aphids per plant under the frame lights and 2.4 for plants in the open. In subsequent years these averages varied between 1.0 and 1.6, and 2.7 and 3.5, respectively. From this one may conclude that in 1966 a higher percentage of the aphids was infected with CMV than in later years. As in 1966 a very high percentage of the aphids found on the cucumber and gherkin plants consisted of *A. gossypii*, viz 97 % and 93 %, respectively (Table 3), it may be concluded that this aphid played an important part in the transmission of the virus.

The aphids found on the 118 CMV-infected plants were identified: 28 plants had one *A. gossypii*, 55 more than one, 30 had *A. gossypii* together with other species, and 5 other species only. The latter occurred only in plants which had been in the open. *A. gossypii* was therefore by far the most prevalent species. Other aphids found on cucumbers and gherkins varied according to the season. None of the species was dominant, not even *M. persicae*. Of the 136 plants 12 became infected at a time when *M. persicae* was not found in the trap in the open.

Of the 136 CMV-infected plants, 4 infections were recorded in June, 7 in July, 83 in August, 37 in September and 5 in October.

Yearly observations were made of the extent of CMV infection in autumn cucumbers in practice which was found to vary from light to moderate infections. In 1966, the most cases of CMV infection were recorded, both in the experiments and in practice, but the rate of infection was not as severe as in 1963.

Discussion

Autumn cucumbers are sown in July and planted in the beginning of August. The crop is cleared in November. The flight observations show that in the South Holland glasshouse district *A. gossypii* occurs mainly during the period of the autumn crop. The records for two years show that proportionately more *A. gossypii* were found in yellow water traps in glasshouses (55 %) than in traps in the open (15 %). Also, more *A. gossypii* were found in a trap in a cucumber house (69 %) than in a tomato house (36 %). These differences were not found in the case of *M. persicae* for which the figures were 5 %, 6 %, 4 % and 6 %, respectively. It would be desirable to analyse in how far the rate of aphid penetration in cucumber and tomato houses is caused by differences in crop attraction or by differences in the climatic conditions near the ventilators.

At the time of the investigation it was usual for growers to protect the crop against bees by screening the ventilators with gauze, in order to prevent fertilization of the cucumbers. Since the introduction of the all-female flowering varieties, gauze screening is not used any more. The type of gauze used was insufficient to exclude

The fungicide thiram is widely used in the glasshouse lettuce crops. It is applied as a 10 % dust for the control of *Botrytis cinerea.* Formerly this fungicide was applied regularly right up to the stage when the crop covered the whole of the soil surface. Later on, only a single treatment was given with a higher dosage rate shortly after planting.

The following factors may have a bearing on the residue levels:

1. the amount applied per treatment;
2. the time of application;
3. the number of treatments;
4. the growth of the plant;
5. irrigation.

Results and methods

A number of experiments were carried out to analyse the influence of these factors. The experiments were usually carried out in normal lettuce crops in which the thiram dust was applied with a small type dust applicator. For factors 1 and 2, the residue levels were determined at crop harvest only, with samples of 3 to 5 heads per treatment. For factors 3, 4 and 5 the residue levels were monitored throughout the growing period. Depending on the size of the lettuce, samples consisting of a certain number of heads were analysed at weekly intervals. The thiram residue levels were determined colorimetrically and in a later stage of the investigation with the CS_2 method. The analyses were carried out by the Central Institute for Nutrition and Food Research at Zeist.

Amount applied per treatment

The results achieved in the control of fungal diseases depend, amongst other things, on the amount of fungicide applied. The following treatments, applied under identical conditions, were designed to determine whether the residue levels found in the crop are proportionate to the amount of fungicide used:

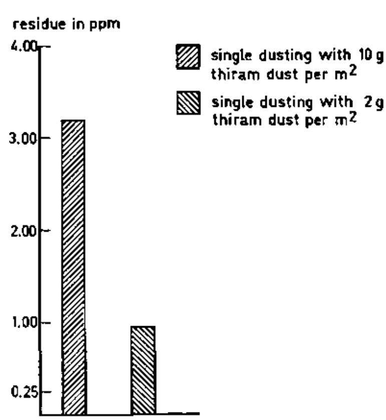

Fig. 1. Effect of the amount of fungicide applied on the final residues found in lettuce.

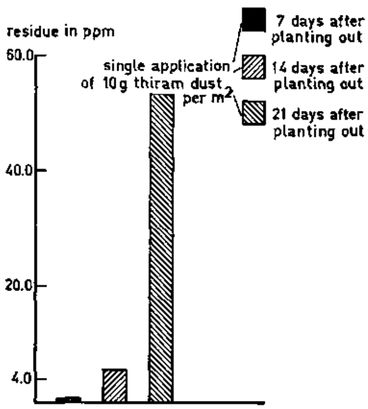

Fig. 2. Effect of the time of application of the fungicide on the final residues found in lettuce.

A. a single application of 10 g thiram dust per m^2;
B. a single application of 2 g thiram dust per m^2.

Fig. 1 gives the results of the residue determinations carried out for the two treatments 18 days after application of the fungicide. The graph shows that on the whole the amounts of fungicide applied are reflected in the residue levels. This might indicate that thiram is relatively stable on the plant.

Time of application

The time of application may be an important factor in the control of the disease as well as in the residue levels. In order to determine the latter aspect the following treatments were applied:
A. a single application of 10 g thiram dust per m^2 at 7 days after planting;
B. a single application of 10 g thiram dust per m^2 at 14 days after planting;
C. a single application of 10 g thiram dust per m^2 at 21 days after planting.
The results are shown in Fig. 2. The time of application obviously has a great effect on the residue levels. The treatment at 21 days after planting out – in this case equivalent to a treatment at 6 days before harvest – resulted in a very high residue level.

Number of treatments

The residue levels found after a series of fungicide applications are the result of the amounts applied and of the times of the treatments. To obtain more information about these aspects the following treatments were applied:
A. a single application of 10 g thiram dust per m^2 at 7 days after planting;
B. a single application of 10 g thiram dust per m^2 at 14 days after planting;
C. a single application of 10 g thiram dust per m^2 at 21 days after planting;
D. three applications of 3.3 g thiram dust per m^2 at 7, 14 and 21 days after planting.
Fig. 3 shows the results. In this experiment the residue levels were determined at

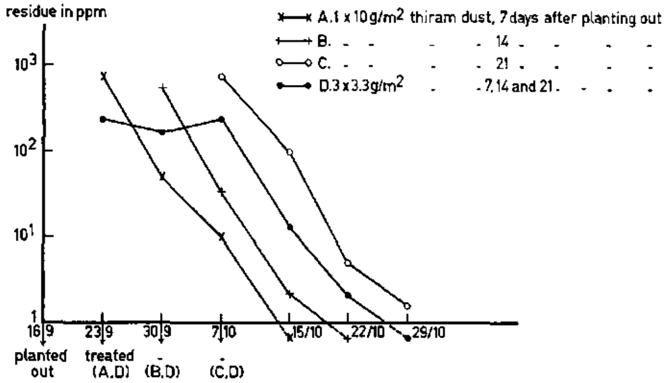

Fig. 3. Effect of a number of successive threatments on the residue levels in lettuce compared with a single treatment.

weekly intervals. As was to be expected, the highest levels were found with 10 g per m^2 at 21 days after planting.

However, where in total 10 g per m^2 was applied in three stages, high residue levels were also found, higher than those resulting from the single application of 10 g per m^2 at 14 days after planting.

With successive treatments it is almost inevitable that one or more of the treatments are applied at a late stage in the growing period, resulting in high residue levels, higher than are obtained usually with a single application at a greater dosage rate carried out at an early stage of the crop.

Growth of the plant

If one supposes that factors like breakdown of the compound and cultural operations have no bearing on the eventual residue levels, it could be postulated that the residue levels decrease in proportion to the growth of the plant. It would then become possible to calculate the residue level at any given time by determining the plant weight and relating it to the residue level immediately after application. This could be done with the equation

$$R_x = (G_1/G_x) \times R_1$$

in which G_1 represents the original weight of the plant and R_1 the original residue level. G_x represents the weight of the plant determined at stage x. R_x will be defined as 'growth residue'. Fig. 4 shows the growth curve of a lettuce plant, the 'growth residue' calculated from an experiment in which 10 g of thiram dust per m^2 was applied 7 days after planting, and the actual residue found in this experiment. As the experiment was started late in autumn, growth was relatively slow and the crop took more than two months to mature. Under more favourable conditions the growing period would have been reduced to 5 weeks. However, the 'dilution' of the fungicide by crop growth is not affected by the rate of growth.

If the calculation is based on the increase in crop weight, the initial residue of

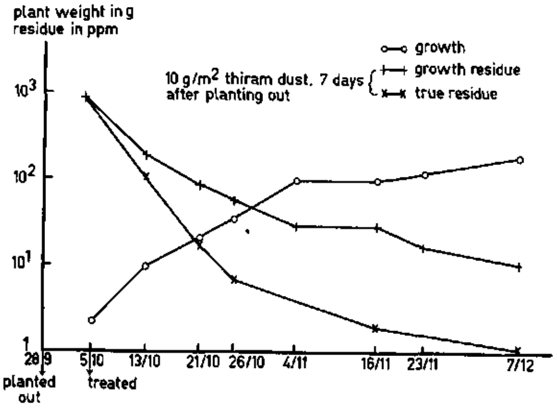

Fig. 4. Effect of the growth of the crop on the residue levels in lettuce.

1000 ppm immediately after application of the fungicide should have decreased to 10 ppm at the moment of harvest. In fact, it was only 1 ppm. This shows that crop growth is the most important factor in the disappearance of the fungicide. Other factors which play a part are relatively unimportant in this type of fungicide. Nevertheless, they have practical importance in meeting the legal residue tolerances. Amongst other factors, the effect of irrigation during the growing season was further investigated.

Irrigation

If the fungicide is applied actually to the plant, as is the case with dusting, crop irrigation would have a direct effect on the residues. However, irrigation is an operation which is applied in accordance with the crop's requirements and not as a means of regulating pesticide residues. It follows that the grower may apply little irrigation, that he may use irrigation at the start of the crop or more towards the end.

An attempt was made in a number of experiments to gain more information on the effect of irrigation under different conditions. For this purpose comparisons were made between two experimental plots which had been dusted with 10 g thiram per m². One plot was watered several times with the aid of spray lines and the other with trickle irrigation which excluded washing off of the residues.

The capacity of the spray lines was about 55 mm per hour and for each watering the lines were switched on for 10 to 15 minutes. Comparable quantities of water were applied with the trickle irrigation system. The irrigation frequencies used were:

A. seven applications of water, the first one two days after dusting;
B. five applications of water, the first one 45 days after dusting.

Fig. 5 shows the residue levels during the growing period. In order to distinguish between the two types of irrigation, reference is made to 'residue spray' and 'residue trickle'.

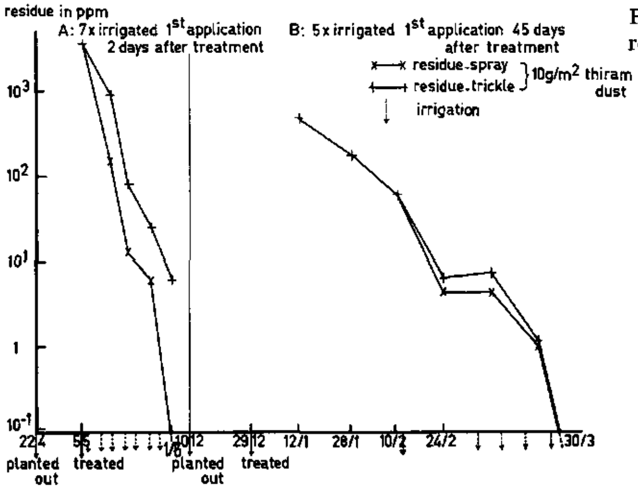

Fig. 5. Effect of irrigation on residue levels in lettuce.

In all the experiments a certain amount of the residue disappears as a result of irrigation.

In Experiment A a great deal of irrigation was applied right through the growing season. A difference in residue levels was found at the second sampling between the spray line treatment and the trickle irrigation treatment. This difference remained about the same throughout the growing season.

In Experiment B no water was applied in the early stages of the crop. Although some difference in residue levels was found after the first watering, the difference was much smaller compared with that found in Experiment A. It is probable that the fungicide is partly removed from the young plant only and that there is hardly any washing off of the fungicide from older plants or that the fungicide is merely washed to the heart of the lettuce.

How much effect irrigation has on the final residue levels depends on the reduction in residue levels caused by irrigation at the beginning of the season. In other words, it depends on how often irrigation is applied in the early stages of crop development.

Effects of other factors on residue levels

The investigation has shown that there must be other factors which have an effect on the residue levels. In experiments in which water was applied by trickle irrigation, excluding the possibility of washing off of the chemical, consistently lower residue levels were found than could have been expected as a result of crop growth. Very little is known about the cause of this, but it is supposed that chemical and physical processes may be involved. More information about these processes might well produce a more complete explanation of the thiram residue levels in lettuce.