IV. SOURCES AND QUALITY OF THE IRRIGATION WATER

THE EFFECT OF SALINE IRRIGATION WATER ON SOME VEGETABLES UNDER GLASS

C. Sonneveld and J. van Beusekom
Glasshouse Crops Research and Experiment Station,
Naaldwijk, The Netherlands

Abstract. - For vegetables grown in greenhouses it is necessary to have available irrigation water with a low salt content. Already between 1934 and 1945 in The Netherlands investigations were made on the influence of sodium chloride in the irrigation water. Besides sodium chloride, however, other salts play an important part in the salinisation of greenhouse soils. For this reason there was need of investigations in which both the sodium chloride content and the electrical conductivity could be tested and then used as standards for the quality of the irrigation water. In 1966 such a series of investigations was started at the Experiment Station at Naaldwijk.

During the last years a great number of crops were investigated. The results for lettuce, tomatoes, cucumbers and spinach are discussed. If the electrical conductivity of the irrigation water was increased with 1 mmho/cm (25^{o} C) the yields of lettuce, tomatoes and cucumbers decreased 4, 7 and 14 per cent, respectively. The spinach yields did not show any difference. Sometimes crop quality was affected adversely. In case of lettuce, for instance, addition of sodium chloride to the irrigation water greatly increased the occurence of tipburn.

In the investigation attention was also paid to soil and leaf analysis. It was found that the uptake of several nutrients was influenced by the salt content of the irrigation water

Introduction. - The availability of irrigation water of low salinity is very important for the glasshouse industry. Almost all glasshouse crops are salt sensitive and give reduced yields with increasing salinity of the irrigation water (2, 9, 10)*. As natural rainfall is excluded, the crops are dependent almost entirely on water applied by irrigation. (*:see p. 80)

The glasshouse industry in the West of The Netherlands depends heavily on the surface water for irrigation of the crops. Ground water is unsuitable in this part of the country as its salinity is very high. Also the surface water in the West of The Netherlands contains a lot of salt, especially as a result of the increasing salinity of the Rhine. This river is used to replenish and clean the waterways in the polders in the West of The Netherlands. The quality of the surface water in this part of the country is therefore very dependent on the quality of the Rhine water.

The water from the Rhine was quite satisfactory in the days when its salt level was low. However, growing industrialization in Western Europe has caused a sharp increase in the salinity of the Rhine in recent decades (3). At low water the chloride contents measured now may exceed exceed 350 mg per litre. In spite of its high salt content the Rhine water is still used to supply the polders as there is no other water available. This has some important consequences for the glasshouse industry which should realize its implications.

As long ago as in the years between 1934 and 1945, pot experiments were carried out at the Naaldwijk Research Station in which the harmful effects of sodium chloride in the irrigation water were demonstrated (8). Other Dutch scientists also conducted experiments in which the relationships were shown between the sodium chloride content of irrigation water and the development of various horticultural crops (4. 5, 13). However, apart from sodium chloride there are other salts which play an important part in the increasing salinity of the surface water in the West of The Netherlands (17). This made it necessary to carry out a comparative study of the effects of sodium chloride on various crops and of other kinds of salt occurring in the surface water. An experiment could be started in 1966 in which these effects were investigated under practical conditions. The results achived with some of the crops grown in the experiment are discussed.

Methods.

Experimental design. - The crops in the experiment were irrigated with mains water to which were added different quantities of a salt mixture and different quantities of sodium chloride, The salt mixture consisted of calcium chloride, magnesium chloride, magnesium sulphate, sodium sulphate and sodium bicarbonate in such proportions as to resemble the average salt composition of the surface water in the West of The Netherlands (17). Application of the salt mixture and the sodium chloride took place on the basis of equal electrical conductivity. Previous research had shown that 1,000 mg of sodium chloride and 1, 340 mg of the salt mixture per litre produced an equal increase in conductivity (15, 17). In order to study the effects of reduced levels of salt accumulation in the soil as a result of leaching during the growing season, variations were made in the amounts of water applied. A normal rate of application was compared with 1½ times the normal amount.

The factors salt mixture, sodium chloride and water rate were incorporated in the experiments as follows:

factor a	salt mixture	: 0 - none 1 - 670 mg per litre 2 - 1, 340 mg per litre
factor b	sodium chloride	: 0 - none 1 - 500 mg per litre 2 - 1, 000 mg per litre
factor c	water rate	: 0 - normal amount 1 - 1½ times normal amount

The treatments were duplicated in the experiment. The 36 experimental plots were arranged in a 6 by 6 quasi latin square in which the interaction of factors a and b was partially confounded with the rows and columns (18).

Table 1 shows the composition of the irrigation water in the different treatments. It can be calculated from the results of this table that about 60% of the ions in the salt mixture consist of sodium and chloride.

The yield reduction through saline irrigation water was so great in the first cucumber crop that it was decided to halve the salt level for the second cucumber crop. The levels of factors a and b are denoted in this case by 0 - ½ and 1.

Cropping conditions. - The experiment was housed in a Venlo block with light pipe heating. The soil type in the glasshouse consisted of loamy sand containing 11% clay particles ($\measuredangle$ 16 mu) and 0. 5% $CaCo_3$. The pH was 6. 8. At the beginning of the experiment the organic matter content of the soil was 3% which increased to 6% in the course of the experiment by regular dressing of organic manure.

From the beginning a relatively large number of crops was included in the experiment. Most crops were grown more than once. Table 2 shows the seasons in which the crops mentioned in this publication were grown. The varieties used are given in the final column of this table. Lettuce was grown in autumn or winter, tomatoes and cucumbers in spring and summer and spinach in winter.

The crops were watered with the aid of spray lines. Lettuce and spinach were irrigated overhead, tomatoes were irrigated overhead first and by low level spray lines later on and cucumbers were irrigated the whole time by low level spray lines. The moisture tension of the soil was kept at a low level, usually less than 5 cm Hg. Slightly higher values occurred occasionally in the tomato crops at the lowest watering rates.

The following quantities of water were applied in the course of the growing season:

	Watering rate in mm	
	0	1
Lettuce	65	100
Tomatoes	300	450
Cucumbers	450	675
Spinach	10	15

Once a year - at the end of the main crop - the soil was flooded. For this purpose the quantity of salt added to the water was the same as in the experimental design. The quantity of water used for flooding was the same in all treatments, viz. 200 to 300 mm a time.

The nutrient level in the soil was adjusted to the crops. Supplementary feeding in the tomato and cucumber crop was carried out via the spray lines. This way the treatments which received more water during the growing season also received proportionately more nutrients. This compensated for the losses of nutrients as a result of leaching through high watering rates (16).

Soil analysis. - The soil was sampled and an lysed regularly. With lettuce and spinach this was done immediately before or after the crop and with tomatoes and cucumbers in the middle of the growing season. Samples were taken from a depth of 0 to 30 cm. After drying of the soil samples a saturation extract was prepared (14) of which the chloride content and electrical conductivity were determined. The chloride content and was expressed in me per litre and the concuctivity in mmho/cm at 25°C.

Crop analysis. - Crop samples were collected from the second lettuce crop. With lettuce the samples consisting of whole heads were collected at harvest. With tomatoes leaf samples were taken at the level of the fourth truss a fortnight after the beginning of picking and with cucumbers young fully-grown leaves were taken four weeks after the beginning of picking. Crop samples of spinach were collected at harvest.

The samples were dried and analysed for sodium, chloride and the main nutrient elements. Reference is made to Den Dekker and Van Dijk for the analytical methods used (7).

Results.

Yield. - The yield of lettuce, tomatoes and cucumbers showed a negative linear correlation with the salt content of the irrigation water. No significant differences were found in spinach. Table 3 shows the average yields of the four crops during the different growing seasons. It shows that for yield cucumbers are most salt sensitive, followed by tomatoes and then lettuce. The application of sodium chloride produced a slightly greater yield reduction in lettuce than the salt mixture. With tomatoes there were no clear differences between the sodium chloride and salt mixture treatments. With cucumbers the yield reduction as a result of the sodium chloride treatment was considerably greater than that obtained from the salt mixture treatment.

In Figure 1 the relationship is shown between the conductivity of the irrigation water and the yields of lettuce, tomatoes and cucumbers. It may be concluded from the regression equations calculated that the yields of the three crops mentioned will show a reduction of 4, 7 and 14% per mmho respectively with increasing conductivity.

The rate of irrigation produced on the whole no significant effects on the yield of lettuce and spinach which is understandable as sufficient water was being applied at the low rate and accumulation of salts was very small during the cropping periods. However, the effects of the rate of irrigation were on the whole significant in the tomato and cucumber crops (See Table 4). The beneficial effect of the higher watering rate showed no interaction with the salt content of the water.

Quality. - The salinity of the irrigation water is not only important for the yield but also for the quality of the crops. For instance, the quality of lettuce may be badly affected by the occurrence of tipburn. Several research workers have shown that salts have a profound effect on the occurrence of this disorder (6, 11). As a rule, tipburn increases with the salinity of the soil, although the increase may become proportionately smaller the more the salt level is raised. At very high salt concentrations the percentage lettuce heads affected by tipburn may sometimes even decrease.

With the autumn crops in our experiment it was also found that the increase in tipburn was less at high salt levels than at low levels. With the first two winter crops there was a linear increase in tipburn. Hardly any tipburn was found in the last winter crop. There appeared to be a particularly strong relationship between tipburn and the sodium chloride content of the irrigation water. Figure 2 shows the relationship between the chloride content of the irrigation water and percentage lettuce heads affected by tipburn. Separate equations have been calculated for the two autumn crops as the relationships were very different from those recorded for the two winter crops.

Generally salts in the irrigation water will not have harmful effects on the fruit quality of tomatoes. The smaller fruits picked at the higher salinity levels are usually good in shape and colour. However the occurrence of blossom end-rot is promoted by increased salt concentrations, although little was found of this in our experiment.

A quality examination was carried out during the cucumber season of 1971. In this examination the storage characteristics of the fruit after harvest were used as the criterion of its quality. A clear relationship was found between storage quality and dry matter content of the fruits. Higher dry matter content meant better storage quality. Table 5 shows that the dry matter content of the fruits was increased by the addition of salts to the irrigation water and it was decreased by the higher watering rates.

Soil analysis. - There was a close correlation between the chloride content of the saturation extract. This was also the case with the electrical conductivity. Table 6 shows the regression equation which were found in the different crops. The average results obtained with the different crops of the same species were used for the calculation of the equations.

The equations show that the salt accumulation during the tomato and cucumber crops were greater than during the lettuce and spinach crops. They also show that the chloride content of the saturation extract undergoes a proportionately greater increase than the conductivity. This is probably the result of precipitation of less soluble salts in the soil like calcium sulphate.

The chloride content and the conductivity during the tomato and cucumber crops were on average 15% lower at the high rate of watering than at the low rate. In the lettuce crops the difference was about 10% and there were hardly any differences in the spinach crops. This may be explained by the fact that spinach was hardly watered during the growing season.

Crop analysis. - The sodium and chloride contents were generally increased by the application of salts, but the potash content on the other hand was decreased. The results obtained with the calcium content are somewhat remarkable: in cucumbers the calcium content was increased by the application of salts and in the other crops it was decreased. The magnesium content was also increased in cucumbers. However, application of the salt mixture also increased the magnesium content of tomatoes. Generally the effect of the salt applications on the sulphur, phosphor and nitrogen contents is not significant. Table 7 shows the results of the crop analyses, averaged over the highest and lowest levels of factors a and b.

Conclusions. - In the range of 0. 9 to 4. 5 mmho, the yields of lettuce, tomatoes and cucumbers showed a linear decrease with increasing salt concentrations of the irrigation water. The yields of these crops decreased by 4, 7 and 14% per mmho respectively. Spinach suffered no harmful effects of saline irrigation water. The yield reduction of lettuce and cucumbers was greater if the conductivity was increased with sodium chloride (Na and Cl) than if a salt mixture (Na, Cl, Ca, Mg, SO_4 and HCO_3) was used. With tomatoes no differences were found between the application of sodium chloride and the salt mixture.

With lettuce the salt accumulation during the growing season was appreciably less than with tomatoes and cucumbers. This makes it partly possible to explain the slight yield reduction in lettuce. On the other hand, the results of the experiment have shown that although saline irrigation water does not result in great yield reduction in lettuce, it may have a great effect on quality. By the application of sodium chloride to two autumn crops, the percentage heads affected by tipburn increased by 4% per me in the lower salt range. The other salts added to the irrigation water showed no clear effects on tipburn. The results of crop analysis showed that the calcium content of lettuce decreased proportionately to the sodium chloride content of the irrigation water. Tipburn in lettuce could therefore be connected with a low calcium content of the crop. Other research workers have already pointed to this possibility (1, 12).

The conductivity of the irrigation water in the treatments with the lowest salt content was 0. 9 mmho. The results of the experiment seem to indicate that the use of irrigation water with a conductivity of less than 0. 9 mmho may increase the yields of lettuce, tomatoes and cucumbers. Bierhuizen and Ploegman have calculated that for maximum yield of cucumbers not more than 75 mg chloride may be present per litre soil solution (13) and for tomatoes not more than 360 mg chloride (4). From the results of the soil analyses and the relationship between the chloride content of the soil solution and the chloride content of the saturation extract, it may be concluded that in our experiment the chloride content of the soil solution during the tomato and cucumber crops was about twice as high as in the irrigation water. This would mean that the irrigation water for cucumbers may contain no more than 37 mg chloride per litre and for tomatoes no more than 180 mg per litre. However, further research into the relationship between the salt content of irrigation water and the yield of various crops in the range below 0. 9 mmho is required. Apart from the yield at these low salt concentrations, quality aspects like uneven ripening of tomatoes and the storage quality of cucumbers should also be studied. The loss of quality which can take place in some crops at very low salt concentrations should be prevented by adjustment of the nutrition.

*The reference-figures are mentioned in the alphabetical, combined list of references before the name of the author.

Table 1 - Salt composition (me/litre) and electrical conductivity (mmho/cm at 25°C) of the irrigation water used.

Treatment	Na^+	Ca^{++}	Mg^{++}	Cl^-	SO_4^{--}	HCO_3^-	E. C.
a_0b_0	3. 0	4. 8	1. 0	3. 6	1. 3	2. 9	0. 9
a_0b_1	11. 5	4. 8	1. 0	12. 1	1. 3	2. 9	1. 8
a_0b_2	20. 0	4. 8	1. 0	20. 6	1. 3	2. 9	2. 7
a_1b_0	7. 7	9. 1	2. 4	8. 6	4. 9	4. 7	1. 8
a_1b_1	16. 2	9. 1	2. 4	17. 1	4. 9	4. 7	2. 7
a_1b_2	24. 7	9. 1	2. 4	25. 6	4. 9	4. 7	3. 6
a_2b_0	12. 3	13. 4	3. 9	13. 7	8. 5	6. 5	2. 7
a_2b_1	20. 8	13. 4	3. 9	22. 2	8. 5	6. 5	3. 6
a_2b_2	29. 3	13. 4	3. 9	30. 7	8. 5	6. 5	4. 5

Table 2 - Growing periods of the crops and varieties used.

Crop		Year	Growing period				Variety
			Beginning		End		
Lettuce	1	1966	September	1966	November	1966	Deciso
	2	1966-1967	December	1966	March	1967	Rapide
	3	1967	September	1967	November	1967	Deciso
	4	1967-1968	December	1967	March	1968	Rapide
	5	1968-1969	December	1968	March	1969	Noran
Tomatoes	1	1966	March	1966	August	1966	Maascross
	2	1967	March	1967	August	1967	Maascross
	3	1969	March	1969	September	1969	Money Globe
Cucumbers	1	1968	March	1968	August	1968	Sporu
	2	1971	March	1971	August	1971	Briljant
Spinach	1	1970-1971	December	1970	March	1971	Subito
	2	1971-1972	December	1971	March	1972	Subito

Table 3 - Crop yields in per cent of the control.

Treatment	Lettuce	Tomatoes	Cucumbers	Spinach
a_0	100	100	100	100
$a_{\frac{1}{2}}$			90. 6	
a_1	96. 5	94. 6	85. 0	104. 5
a_2	93. 7	85. 4	72. 3	103. 0
b_0	100	100	100	100
$b_{\frac{1}{2}}$			84. 4	
b_1	95. 9	92. 5	77. 0	96. 1
b_2	91. 7	86. 1	65. 2	101. 4

Table 4 - Crop yields in per cent of the control.

Crop	Water quantity	
	0	1
Lettuce	100	101. 0
Tomatoes	100	105. 6
Cucumbers	100	117. 6
Spinach	100	100. 3

Table 5 - Index figures for storage quality and dry matter content of cucumber fruits. The index figures are higher the better the storage quality.

Treatment	Quality index	Per cent dry matter
a_0	75. 4	3. 36
$a_{\frac{1}{2}}$	87. 6	3. 53
a_1	108. 4	3. 62
b_0	73. 6	3. 33
$b_{\frac{1}{2}}$	90. 2	3. 62
b_1	107. 8	3. 56
c_1	104. 8	3. 64
c_2	76. 2	3. 36

Table 6 - Regression equations for the relationships between: chloride content of the irrigation water (x) and chloride content of the saturation extract (y); electrical conductivity of the irrigation water (x) and electrical conductivity of the saturation extract (y).

Crop	Chloride		Electrical conductivity	
	Regression equation	r	Regression equation	r
Lettuce	$y = 1.064\,x + 4.32$	0.991	$y = 0.938\,x + 2.75$	0.987
Tomatoes	$y = 1.336\,x + 5.88$	0.995	$y = 1.157\,x + 3.54$	0.994
Cucumbers	$y = 1.263\,x + 7.66$	0.983	$y = 1.036\,x + 3.63$	0.910
Spinach	$y = 0.918\,x + 2.15$	0.986	$y = 0.922\,x + 2.33$	0.992

Table 7 - Results of leaf analyses, given as average values of the lowest and highest level of the factors a and b. The elements are expressed in per cent of the dry matter.

Crop	Treatment	Na	K	Ca	Mg	S	P	N	Cl
Lettuce	a_0	1.08	6.86	1.18	0.36	0.34	0.93	5.33	3.64
	a_2	1.36	6.65	1.07	0.34	0.35	0.85	5.26	3.62
	b_0	0.76	7.09	1.26	0.37	0.33	0.87	5.30	3.24
	b_2	1.60	6.50	1.02	0.33	0.34	0.90	5.27	3.92
Tomatoes	a_0	0.96	3.34	6.29	0.76	1.93	0.51	3.44	3.60
	a_2	1.19	2.63	6.16	0.90	1.80	0.45	3.22	4.50
	b_0	0.79	3.35	6.39	0.83	1.94	0.48	3.35	3.45
	b_2	1.41	2.72	6.17	0.84	1.80	0.45	3.31	4.70
Cucumbers	a_0	0.37	1.82	7.40	0.84	0.46	0.47	4.22	3.16
	a_2	0.52	1.43	8.02	1.15	0.54	0.42	4.03	4.39
	b_0	0.24	1.97	7.31	0.90	0.50	0.46	4.31	2.79
	b_2	0.60	1.30	8.34	1.10	0.51	0.42	3.84	4.64
Spinach	a_0	1.23	10.42	0.85	0.95	0.37	1.03	5.75	1.22
	a_2	1.37	9.75	0.80	0.96	0.34	1.00	5.78	1.67
	b_0	0.87	10.24	0.86	0.99	0.36	1.01	5.77	1.18
	b_2	1.70	9.85	0.81	0.94	0.34	1.02	5.75	1.72

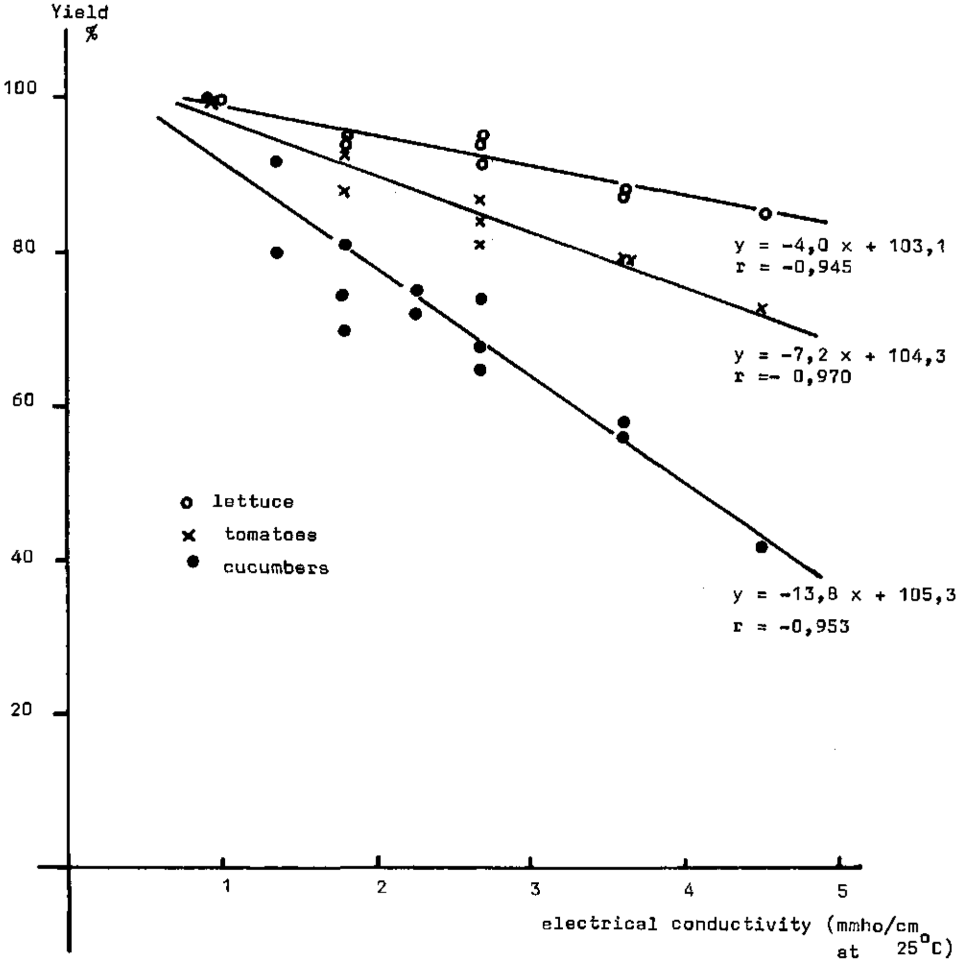

Figure 1 - Relationship between the electrical conductivity of the irrigation water and the yield of some vegetable crops.

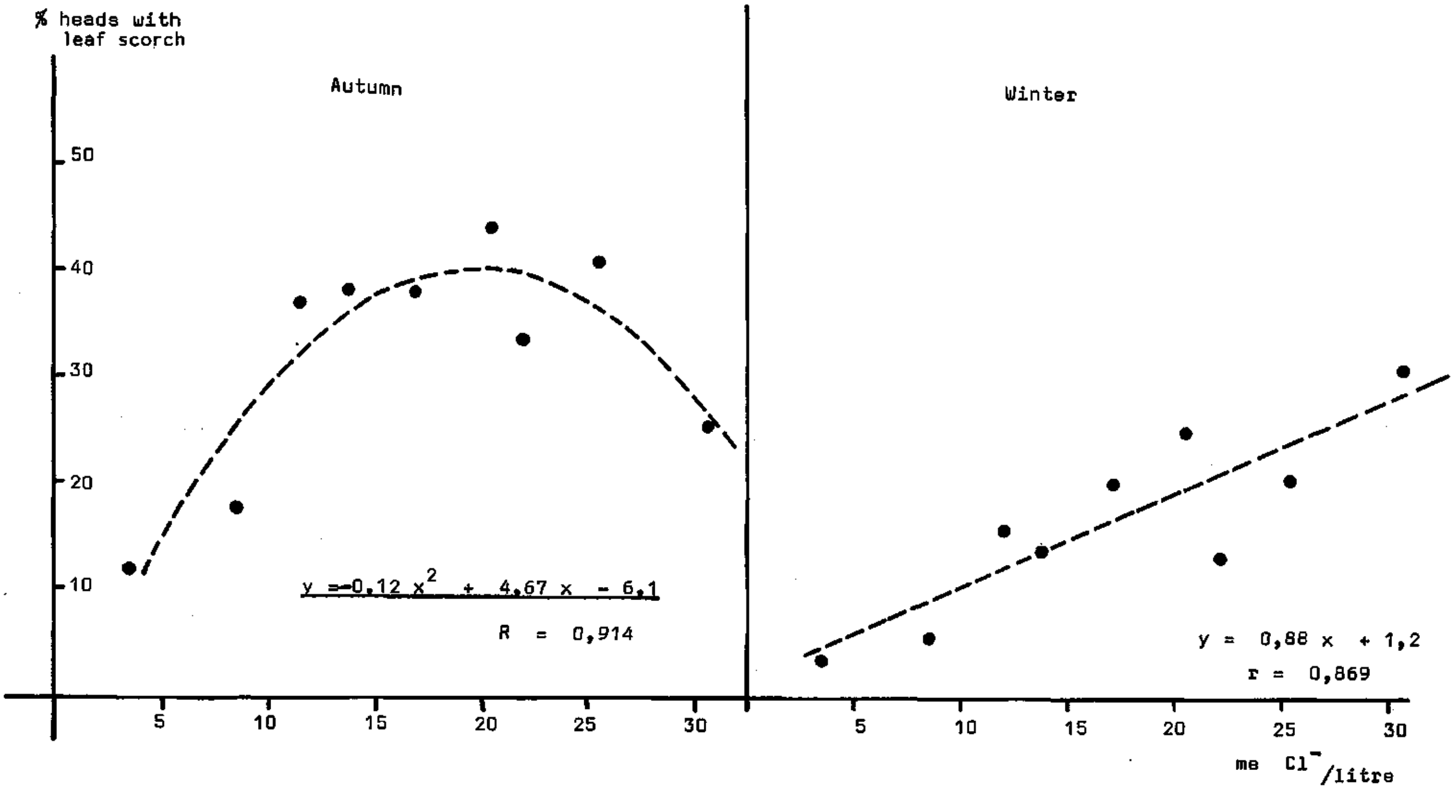

Figure 2 - The relationships between the chloride content of the irrigation water and the percentage lettuce heads affected by tipburn.

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