Effect of Simulated Acid Rain on seed germination and on growth and mineral nutrition of *Lycopersicon esculentum* var. Red Kaki

by

Frans A. Marsh

Submitted in partial fulfilment of the requirements for the degree
of M.Sc in the Department of Botany,
University of the Western Cape.

Promoter: Dr. L.M. Raitt

Joint Promoter: Mr. J. Aalbers

November 1993

Dedicated to :

* my parents, John and Maria.

* my wife, Mathilda and

* my son, Enrique

ACKNOWLEDGEMENTS

The author wishes to acknowledge the invaluable assistance and support provided by Dr. L.M. Raitt in carrying out the research upon which this thesis is based. I am also very grateful for his endurance and patience. His understanding, guidance and expertise helped to make the writing of this thesis a worthwhile experience.

To my joint promoter, Mr. J. Aalbers, I extend my sincere appreciation for the time sacrificed to read my document, and also for the useful advice and suggestions he gave me.

A special word of appreciation is also extended to my wife, Mathilda and Karen Harris who helped with the typing of this document. I wish to thank Edward Smith for his technical assistance and the styling of the document.

Finally, I extend my sincere gratitude to Mathilda and my son, Enrique for their understanding, support and great patience during the many months in which I was unable to devote the necessary time and attention they needed because of my work.

INDEX

CHAPTER 1

ACID RAIN - AN INTRODUCTION

The phenomenon of acid rain is not new. It has been active for more than a billion years (Abelson, 1983). The term "acid rain" was introduced as early as 1872 by Robert Angus Smith, the world's first air pollution control inspector, who measured pH values of precipitation considerably lower than 5,6 (the pH of distilled water in equilibrium with atmospheric CO_2) in and around northern English industrial cities. At this time relatively little interest was shown in the topic (Anon, 1984; Bell, 1988). Widespread interest in the topic began in the mid - 1970's, when Scandinavian studies identified a downward trend in pH of precipitation in southern Norway and Sweden, accompanied by an increase in acidity of lakes and rivers (Bell, 1988). At the same time, predictions were made that Swedish soils would become progressively acidified, with a concommitant fall in timber production. Initially there appeared to be little evidence to support the latter contention and research concentrated on the causes of the loss of fish, untill the early 1980's when a serious forest decline was observed in Central Europe, which has been popularly ascribed to acid rain (Bell, 1988).

The acidic nature of rain is now seen to be due to the emission of oxides of both sulphur and nitrogen. These oxides are discharged into the atmosphere and are transformed into sulphuric and nitric acid, which eventualy fall to the earth as acid rain - but not just rain, for acid snow, fog, mist, and dew are also known (Likens, 1976; Likens et al.1979; Cowling and Linthurst, 1981). Sources such as power stations, industrial and commercial users of coal and oil, such as factories, smelters and oil refineries account for most of these oxides, while comparatively small but important amounts of nitrogen oxides are produced by motor vehicles (Likens, 1976).

Previously, it was believed that most man-made emissions were removed from the atmosphere near the site of emissions. Now it is recognised that these substances and their reaction products are dispersed by meteorological processes and may be deposited hundreds or even thousands of kilometers from the original source (Cowling and Linthurst, 1981).

Acid rain has become a cause for concern in many countries such as southern Scandinavia, northeastern United States, central Europe, Britain, Norway, Sweden, West Germany, Canada, West Germany, Switzerland, and many more (Likens, 1976; Anon, 1984; Blank, 1985; Bell, 1988). It is only recently that acid rain has attracted attention in South Africa, as shown in the work of Bohm (1983). The rainfall acidity recorded in the Eastern Transvaal Highveld and adjacent regions is similar to that for northeastern North America and Europe. As has been found in these countries, the pH in the Eastern Transvaal Highveld and adjacent regions is lower than that recorded in areas which are relatively free from man-made pollution (Tyson et al.1988).

Research programmes on the acid rain issue are increasing in countries where there is conclusive proof of the damaging effects of acid rain. In Britain, substantial contributions have been made by its nationalized Central Electrical Generating Board and the National Coal Board (Anon, 1984). The National Academy of Science's research council as well as the Environmental Protection Agency of the United States are also actively involved in acid rain research.

The effects of acid rain are widespread. Acid rain effects range from corrosion of constructing material (Rentz and Weibel, 1984) and loss of animal and plant life in lakes and streams (Anon, 1984; Evans,1984; Tamm and Cowling, 1977), to direct and indirect effects on terrestrial vegetation (Blank, 1985; Wood and Bormann, 1977; Evans and Lewin, 1981; Lee et al.1981; Chang and Alexander, 1983; Rathier and Frink, 1984; van Loon, 1984; Rorison, 1986; Ohno et al.1988).

It is well documented that terrestrial plants have been affected by simulated acid rain at pH levels lower than those which occur in ambient rain (Heagle et al.1983). The effects include increased leaching of nutrients from leaves (Fairfax and Lepp, 1975; Ferenbaugh, 1976; Wood and Bormann, 1975), erosion of leaf cuticles (Evans et al.1977; Ferenbaugh, 1976; Lee et al.1981), growth inhibition (Lee et al.1981; Evans et al.1982) or growth stimulation (Lee et al.1981; Wood and Bormann, 1975; Evans and Lewin, 1981; Raynal et al.1982). Dicotyledenous plants, with their broader leaf systems prove to be more susceptible to acid rain treatments of lower pH levels than monocotyledenous plants, with thinner, longer leaf systems (Banwart et al.1990; Pell and Puente, 1987).

Acid rain may also affect terrestrial plants indirectly via the soil. The most widely accepted initial hypothesis was based on a suggestion that acid rain deposition affects the soil by destroying its buffering system (Blank, 1985). This would lead to the leaching of nutrients (for example Ca, Mg, K) and mobilization of toxic aluminium ions, which would damage the fine root system of the tree, eventualy resulting in its death (Ulrich, 1983). On the other hand soils with a high buffering capacity (ie. soils containing excess base such as calcium carbonate) the effects of acid inputs will be very slow or even negligible (McFee, 1983), causing less damage to plant systems.

The purpose of the following experiments was to investigate the effects of simulated acid rain with pH levels 2,0; 3,2; 4,4 and 5,6 (control) on :

a) Seed germination

b) suphur deficient tomato plants, and

c) tomato plants grown in a base-rich- and an acidic soil.

Since acid rain is responsible for the acidification of soil it is evident that seed germination will be affected by the afore-mentioned. With this in mind the response of various seeds, subjected to simulated acid rain, was investigated and the following questions posed:

(a) How would the individual species' seeds respond to the simulated acid rain treatment?

(b) Was there a particular pH level which would affect seed germination significantly?

(c) Would seed germination be inhibited, promoted or unaffected by the simulated acid rain treatment?

As for the tomato plants with adequate sulphur and those with sulphur deficiency we were particularly interested in finding out if the simulated acid rain would act as a fertilizer in the case of the sulphur deficient plants. How would plant growth be affected by the various pH levels? Was there a particular pH level at which plant growth would be significantly promoted/ reduced/unaffected? How would the plants, containing adequate sulphur compare with the sulphur deficient plants after simulated acid rain treatment? Finally, how would nutrient uptake be affected by simulated acid rain treatment in both the plants containing adequate sulphur and the sulphur deficient plants.

Finally tomato plants grown in a base-rich soil, containing free lime were compared with tomato plants grown in a poorly buffered soil after simulated acid rain treatment. Plant growth, cation-, heavy metal- and sulphate content in particular were investigated. Could the base-rich soil serve as a suitable buffer against acid rain inputs.

From the above it was expected that the results obtained would help to answer the questions posed, and would serve as a contribution to research on the acid rain issue as a whole.

REFERENCES

ABELSON, P.H. 1983. Acid Rain. Science 221(4606)

ANON. 1984. How to neutralize acid rain. Nature. 310: 611-612.

BELL, J.N.B. 1988. Recent developments in acid rain research. Journal of Biological Education 22(2): 93-98.

BANWART, W.L., ZIEGLER, E.L. & PORTER, P.M. 1990. Field corn response to acid rain - drought stress interaction. Journal Environ. Qual. 19(2): 321-324.

BLANK, L.W. 1985. A new type of forest decline in Germany. Nature 314: 311-314.

BOHM, M. 1983. Acid Rain: towards automated monitoring. Symposium on Atmospheric Sciences in South Africa. CSIR, Pretoria.

COWLING, E.B. & LINTHURST, R.A. 1981. The acid precipitation phenomenon and its ecological consequences. Bio Science 31: 649-654.

CHANG, F.H. & ALEXANDER, M. 1983. Effects of simulated acid precipitation on growth and nodulation of leguminous plants. Bull. Environ. Contam. Toxicol. 30: 379-387.

EVANS, L.S. & LEWIN, K.F. 1981. Effects of simulated acid rain on growth and yield of soybeans and pinto beans. Ann. Arbor Science: 299-308.

EVANS, L.S., CURRY, T.M. AND LEWIN, K.F. 1982. Response of leaves of Phaseolus vulgaris L. to simulated acid rain. New Phytol. 88: 403-420.

EVANS, L.S., GMOR, N.F. & DA COSTA, F. 1977. Leaf surface and histological perturbations of leaves of Phaseolus vulgaris and Helianthus annuus after exposure to simulated acid rain. Am. J. Bot. 64: 904-913.

EVANS, L.S. 1984. Botanical aspects of acidic precipitation. The Botanical Review 50: 449-490.

FERENBAUGH, R.L. 1976. Effects of simulated acid rain on Phaseolus vulgaris L. Am. J. Bot. 63: 283-288.

FAIRFAX, J.A.W. & LEPP, N.W. 1975. Effectof simulated acid rain oncation loss from leaves. Nature 255: 324-325.

HEAGLE, A.S., PHILBECK, R.B., BREWER, P.F. & FERRELL, R.E. 1983. Response of soybeans to simulated acid rain in the field. J. Environ. Qual. 12(4): 538-543.

LEE, J.J., NEELY, G.E., PERRIGAN, S.C. & GROTHAUS, L.S. 1981. Effects of simulated acid rain on yield, growth and foliar injury of several crops. Environ. Exp. Bot. 21: 171-185.

LIKENS, G.E. 1976. Acid precipitation. Chem. Eng. News. 54 : 29 - 44

LIKENS, G.E., WRIGHT, R.F., GALLOWAY, J.N. & BUTLER, J.J. 1979.

Acid rain. Sci. Am. 241: 43-51.

McFEE, W.W. 1983. Sensitivity ratings of soils to acid deposition: A review. Environ. Exp. Bot. 23: 203-210.

OHNO, T., SUCCOF,E.I., ERICH, M.S., BLOOM, P.R., BUSCHENA, C.A. & DIXO, N.R.K. 1988. Growth and nutrient content of Red spruce seedlings in soil amended with Aluminum. J. Environ. Qual. 17(4): 666-672.

PELL, E.J. & PUENTE, M. 1987. Impact of simulated acid rain on yield of a field-grown oat crop. Environ. Exp. Bot. 27(4): 403-408.

RATHIER, T.M. & FRINK, C.R. 1984. Simulated acid rain: Effects n leaf quality and yield of broadleaf tobacco. Water, Air and Soil Pollution 22: 389-394.

RAYNAL, D.J., ROMAN,J.R. & EICHENLAUB, W.M. 1982. Response of tree seedlings to acid precipitation. ii. Effect of simulated acidified canopy throughfall on sugar maple seedling growth. Environ. Exp. Bot. 22: 385-392.

RENTZ, O. & WEIBEL, M. 1984. Acid rain, the international problem. 6th International Conference on Air Pollution. C.S.I.R. Pretoria.

RORISON,I.H. 1986. The response of plants to acid soils. Experentia 42: 357-361.

TAMM, C.O. & COWLING, E.B. 1977. Acidic precipitation and forest vegetation. Water, Air and Soil Pollution. 7: 503-512.

TYSON, P.D., KRUGER, F.J. & LOUW, C.W. 1988. Atmospheric pollution and its implications in the Eastern Transvaal Highveld. South African National Scientific Programmes Report(150). Council for Scientific and Industrial Research, Pretoria.

ULRICH, B. 1983. Interaction of forest canopies with atmospheric constituents: SO_2, alkali and alkaline earth cations and chloride. In: Effects of Accumulation of Air Pollutants in Forest Ecosystems: 34-45.

VAN LOON, G.W. 1984. Acid rain and soil. Can. J. Physiol. Pharmacol. 62: 991-997.

WOOD. T. & BORMANN, F.H. 1975. Increases in foliar leaching by acidification of an artificial mist. Ambio 4: 169-171.

WOOD, T. & BORMANN, F.H. 1977. Short-term effects of a simulated acid rain upon the growth and nutrient relations of Pinus strobus L. Water, Air, and Soil Pollution 7: 479-488.

CHAPTER 2

THE EFFECT OF ACID SOLUTIONS ON SEED GERMINATION

ABSTRACT

Seeds of nineteen species, including crop-, weed-, and indigenous species were exposed to simulated acid rain, with pH levels 2,0 ; 3,2 ; 4,3 and 5,6. Seeds were examined daily in a laminar flow cabinet and germinating seedlings were removed.

The success rate of germination for Dimorphotheca pluvialis (L.) Moench (disc florets), Acacia saligna (unscarified) and Otholobium fruticans (L) Stirton and Conicosia pugioniformis (L.) N.E.Br. was below 35%, while the success rate of the rest ranged from 76% - 100%. Simulated acid rain of pH 2,0 resulted in the promotion of 5,3% of the total number of species: 52,6% were not affected and the germination of the remaining 42,1% was inhibited.

2.1 INTRODUCTION

Most research on acid rain has focussed on shoot growth and leaf damage because shoots and leaves are directly exposed to the precipitation (Stroo and Alexander, 1985). Acid rain is widely believed to be responsible for acidifying soil. In the process the soil chemistry is affected, ranging from a change in soil buffering capacity, depletion of nutrients, and the mobilization of toxic metals (Krug and Frink, 1983; McFee, 1983). These indirect effects of acid rain undoubtedly affect root growth, mycorrhizae, soil micro-organisms and seed germination (Stroo and Alexander, 1985; MacDonald et al.1986). Lee & Weber (1979) reported that crops were most likely to be affected by acid rain and Blum and Tingey (1977) suggested that reduced root development is a general response to atmospheric pollutants. It has been shown that endomycorrhizae of soybeans were sensitive to simulated acid rain (Stroo and Alexander, 1985).

Seed germination and seedling establishment are critical life stages of plants, and acid rain seems to be an additional stress during these early life stages that may affect regeneration by impacting seedbed properties, seed germination, seedling nutrient relations, and seedling growth (MacDonald et al.1986). Turner et al.(1988) have shown seed germination to be affected by substrate acidity, caused by acid rain inputs. Effects of acid rain on seed germination have varied with species and method of treatment, producing inhibition of germination in some species, but stimulation of germination in others (MacDonald et al.1986)

The objective of this study was to investigate the effect of acid solutions on seed germination of some crop, weed and indigenous species. Since it has been said that acid rain is an additional stress during the early life stages of the plant, our hypothesis is that acid solutions will inhibit seed germination, rather than stimulating it. Our null hypothesis then is that seed germination is unaffected by acid treatment.

2.2 MATERIALS AND METHODS

2.2.1 Preparation of acid solution

Acid solutions were prepared by dilution of reagent grade sulphuric acid with distilled water (Ferenbaugh, 1976; Phillips et al.1985; Hindawi et al.1980; Hodgkin and Briggs, 1981) with nutrients added (Irving et al.1981; Evans et al.1982) to correspond to the values of Van Wyk (1985) for local conditions.

Table 2.1 Ions additions to acid solution (g.dm^{-3}) in stock solution.

Nutrients	Amounts (g)
NaCl	17,024
KCl	2,580
CaCl	4,802
MgCl	4,668
NH_4Cl	0,926
Total mass (g)	30,00

Four acid treatments, viz pH 5,6 ; 4,4 ; 3,2 and 2,0 were used. Acid solutions were prepared by adding 1 cm^3 of the nutrient stock solution to each dm^3 of dilute sulphuric acid solution. pH's were tested and adjusted with dilute NaOH or H_2SO_4 solutions.

2.2.2 Germination Procedure

Germination studies were carried out in 9cm petri dishes, with filter paper under "Autumn-like" conditions (12h day 20° C; 12h night 10° C) in an incubator. The five replicates by four treatments were arranged in a random block design. Petri dishes were examined daily in a laminar flow cabinet, recordings of germination were made and germinating seedlings were removed.

2.3 RESULTS AND DISCUSSION

The first germination results were recorded the second day after initiation of the experiment. The results were expressed as percentage for each level of acid treatment and referred to as the initial germination (IG). Recordings of germination results continued on a daily basis until maximum germination had been obtained. The latter was referred to as final germination (FG). The duration of germination varied with species, but most of the germination had been completed during the first week of sowing. In a few cases where germination had not been completed within this period, seeds became infected with fungi and ultimately died of fungal attack. This was especially evident in the case of Geissorrhiza sp. where all the seeds were attacked by fungi at pH 2,0, resulting in the death of these seeds and giving rise to zero germination at this pH. This is similar to results obtained by Moore and Gillette (1989) with Fraser fir (Abies fraseri).

Germination results were obtained for each acid rain solution for the species chosen and were expressed as initial and final percentage germination (Table 2.3) The results show no significant difference between the control pH and pH levels 4,4 and 3,2, while seed germination was significantly affected by pH treatment 2,0. Since this was the case, results of the lowest pH, viz 2,0 were compared with that of the control (pH 5,6). This is consistent with studies performed by McColl and Johnson (1983) with seed germination of Douglas-fir (Pseudotsuga menziesii).

According to the initial germination (IG) results in Table 2.3, species such as Phaseolus vulgaris var. Topcrop and Lycopersicon esculentum var. Red Kaki were significantly promoted by acid treatment, while species such as Brassica oleracea var. Glory of Enkhuizen, B. oleracea var. gemmifera, B. rapa var. rapa, Bromus diandrus, Erucastrum strigosum, Geissorrhiza sp. and Otholobium fruticans (L.) Stirton were significantly inhibited by acid treatment (ie pH 2,0). The remaining species were initially not affected by acid treatment.

Results indicating the final germination, show that Conocosia pugioniformis (L.) N.E. Br was the only species that was significantly promoted by acid treatment. Acid treatment also caused the promotion of seed germination of Pinus strobosus (Raynal et al.1982), balsam fir (Abies balsemea L.) and yellow birch (Betula alleghaniensis Britt.) (Scherbatskoy, et al. 1987).

Germination of B. oleracea var. Glory of Enkhuizen, B. oleracea var. gemmifera, B. rapa var. rapa, Bromus diandrus, Erucastrum strigosum, A. saligna (unscarified), Geissorhiza sp. and Otholobium fruticans (L.) Stirton was significantly inhibited by acid treatment. Similar results were obtained with Douglas-fir at pH 2,0 treatment (McColl and Johnson, 1983), Betula lutea at pH 3,0 (Raynal et al. 1982), and jack pine (Pinus banksiana Lamb.) at pH 2,0 (Macdonald et al. 1986). In the case of Paulownia tomentosa seed germination failed to occur below pH 4,0 (Turner et al. 1988). Zammit and Zedler (1988) found that the germination responses of seven species were significantly reduced by a single acid rain deposition of pH 1,0.

The rest of the species were not affected by acid treatment. This was also the case with red spruce (Picea rubens) (Moore and Gillette, 1989). No significant treatment effects were detected during germination studies on seven species (Evans, 1984).

By comparing the initial germination with the final germination, it is clear that acid treatment increased the rate of seed germination of P. vulgaris var. Topcrop and L. esculentum var. Red Kaki, rather than promoting germination of these species. The results in Table 2.4 can thus be expressed in terms of no effect, promotion and inhibition. 52,6% of the total number of species investigated were not affected by acid treatment with pH as low as 2,0, while 42,1% were inhibited and only 5,3% showed promotion.

Table 2.3 Effect of acid solution on seed germination for total number of species.

Effect on germination	INITIAL GERM.	FINAL GERM.
No effect (0)	52,6 %	52,6 %
Inhibition (-)	36,8 %	42,1 %
Promotion (+)	10,5 %	5,3 %

Table 2.4 The effect of simulated acid rain on the progress of germination of seeds of selected species.

SPECIES	Time of germ.	Simulated acid rain pH (% germination)				LSD	
		5,6	4,4	3,2	2,0	$P_{0,05}$	$P_{0,01}$
P. vulgaris var. Topcrop	IG	46,4	54,4	39,2	77,6	17,7	24,8
	FG	100	98,4	96,0	100	3,9	5,5
L. esculentum var. Red Kaki	IG	28,0	16,8	17,6	44,0	25,1	35,3
	FG	100	99,2	96,8	97,6	4,5	6,4
Raphanus sativus var Cherry Bell	IG	29,6	32,0	34,4	20,8	16,9	23,7
	FG	89,6	92,8	91,2	91,2	5,7	8,0
Lactuca sativa var. Great Lakes	IG	98,4	92,8	93,6	94,4	7,5	10,5
	FG	99,2	99,2	96,8	96,8	3,4	4,8
B. oleracea var. Glory of Enkhuizen	IG	88,8	93,6	92,8	68,0	11,0	15,7
	FG	99,2	98,4	99,2	85,0	3,4	4,7
B. oleracea var. Botrytis f. asparagoides	IG	91,2	87,2	92,8	94,4	5,8	8,2
	FG	99,2	98,4	98,4	96,8	3,4	4,8
B. oleracea var. gemmifera	IG	88,8	83,2	84,8	76,0	11,3	15,9
	FG	95,2	99,2	100	84,8	4,6	6,4
B. oleracea var. botrytis	IG	74,4	82,4	67,2	76,8	9,6	13,5
	FG	95,2	96,8	94,4	88,8	7,1	9,9
B. rapa var. rapa	IG	80,8	90,4	92,8	52,8	11,5	16,2
	FG	98,4	97,6	97,6	67,2	6,7	9,4
Bromus diandrus	IG	98,4	99,2	97,6	56,0	15,3	21,4
	FG	98,4	99,2	97,6	90,4	6,1	8,5
Erucastrum strigosum	IG	72,0	74,4	79,2	3,2	9,7	13,6
	FG	88,8	92,8	93,6	4,0	8,1	11,3
Acacia saligna (scarified)	IG	87,2	83,2	80,0	80,8	12,7	17,8
	FG	95,2	93,6	91,2	94,4	4,9	6,9
Acacia saligna (unscarified)	IG	2,4	2,4	2,4	0,8	4,3	6,1
	FG	19,2	16,0	15,2	6,4	12,1	17,0
Medicago sativa	IG	88,8	96,0	92,8	88,8	9,4	13,2
	FG	96,8	99,2	100	95,2	4,1	5,7
Dimorphotheca pluvialus (L.) Moench (Ray florets)	IG	50,4	61,6	50,4	60,0	17,8	24,9
	FG	76,0	80,0	78,4	76,8	14,6	20,4
Dimorphotheca pluvialus (L.) Moench (Disc florets)	IG	7,2	12,0	3,2	8,8	8,6	12,0
	FG	20,8	24,8	20,0	23,2	14,6	20,4
Conicosia pugioniformis (L.) N.E.Br	IG	4,8	5,6	2,4	7,2	7,9	11,0
	FG	11,2	12,0	7,2	34,4	18,2	25,5
Geissorrhiza sp.	IG	17,6	26,4	31,2	0,0	17,1	24,0
	FG	92,0	93,6	94,4	0,0	5,9	8,4
Otholobium fruticans (L.) Stirton	IG	13,6	13,6	12,0	2,4	10,7	15,1
	FG	27,2	20,8	19,2	12,0	20,3	28,5

IG = Initial Germination; FG = Final Germination

Table 2.5 Effect of simulated acid rain compared with the control (pH 5,6) on crop germination.

CROPS	INITIAL GERMINATION			FINAL GERMINATION		
	-	0	+	-	0	+
P. vulgaris var. Topcrop			**		/	
L. esculentum var. Red kaki			/		/	
B. oleracea var. Glory of Enkhuizen	**			**		
Lactuca sativa var. Great Lakes		/			/	
Raphanus sativus. var. Cherry Bell	/				/	
B. oleracea var. Botrytis f. asparagoides		/			/	
B. oleracea var. gemmifera	*			**		
B. oleracea var. botrytis		/		/		
B. rapa var. rapa	**			**		
Total species affected	4	3	2	4	5	0
Percentage affected	44,4	33,3	22,2	44,4	55,6	0,0

/ = No significance ; * = Significant ; ** = Highly significant

According to the results in Table 2.5 Phaseolus vulgaris var. Topcrop showed initial stimulation by acid treatment, while the final germination showed no difference from the control, suggesting that acid treatment increased the rate of germination of bean seeds, rather than stimulating it. In contrast to this, seed germination of B. oleracea var. Glory of Enkhuizen, B. oleracea var.

gemmifera and B. rapa var. rapa were significantly and highly significantly inhibited by acid treatment, while seed germination of the other species remained unaffected by acid treatment.

Table 2.6 Effect of simulated acid rain, compared with the control (pH 5,6) on weed germination

WEEDS	INITIAL GERMINATION			FINAL GERMINATION		
	-	0	+	-	0	+
Acacia saligna (scarified)	/				/	
Acacia saligna (unscarified)	/			*		
Bromus diandrus	**			*		
Erucastrum strigosum	**			**		
Medicago sativa		/			/	
Total species affected	4	1	0	3	2	0
Percentage affected	80,0	20,0	0,0	60	40	0

/ = No significance ; * = Significant ; ** = Highly significant

\- = Inhibition ; 0 = Unaffected; + = Promotion

The results in Table 2.6 show that Bromus diandrus Roth and Erucastrum strigosum and Acacia saligna (unscarified) were the three weed species that were significantly inhibited by acid treatment. Likewise Geissorhiza sp. and

Othololobium fruticans (L.) Stirton. of the indigenous species (Table 2.7) were also significantly inhibited by acid treatment, while Conicosia pugioniformis (L.) N.E.Br. was the only one of the latter group that was significantly promoted by acid treatment.

Table 2.7 Effect of simulated acid rain, compared with the control (pH 5,6) on indigenous species germination

INDIGENOUS SPECIES	INITIAL GERMINATION			FINAL GERMINATION		
	-	0	+	-	0	+
C. pugioniformis (L.) N.E. Br.			/			*
D. pluvialus (L.) Moench (Disc Florets)			/		/	
D. pluvialus (L.) Moench (Ray Florets)		/			/	
Geissorrhiza sp.	*			**		
Otholobium fruticans (L.) Stirton	*			*		
Total species affected	2	1	2	2	2	1
Percentage affected	40	20	40	40	40	20

/ = No significance ; * = Significant ; ** = Highly significant

\- = Inhibition ; 0 = Unaffected; + = Promotion

The overall pattern shows that of the nineteen species investigated, promotion of seed germination by acid treatment scarcely occurred, while inhibition of seed germination was slightly above 40%, and a little more than 50% of the species were not affected by acid treatment.

2.4 CONCLUSION

Seeds that did not germinate during the first week of germination were the only ones that became fungal infected, and died eventually. The *Geissorrhiza sp*. was the only species of the selected nineteen that showed zero germination at pH 2,0 acid treatment. *Conicosia pugioniformis*. (L.) N.E.Br. was the only species that was promoted by acid treatment, while *B*. *oleracea* var. Glory of Enkhuizen, *B*. *oleracea* var. gemmifera, *B*. *oleracea* var. botritis, *B*. *rapa* var. rapa (crops); *B*. *diandrus* Roth., *E*. *strigosum*, *A*. *saligna* (unscarified) (weeds); *Geissorhiza sp*., and *O* *fruticans* (L.) Stirton (indigenous species) were all inhibited by acid treatment and *P*. *vulgaris* var. Topcrop, *L*. *esculentum* var. Red Kaki, *L*. *sativa* var. Great Lakes, *R*. *sativus* var. Cherry Bell, *B*. *oleracea* var. botrytis f. asparagoides (crops); *A*. *saligna* (scarified), *M*. *sativa* (weeds); *D*. *pluvialis* (L.) Moench (ray florets), and *D*. *pluvialis* (L.) Moench (disc florets) (indigenous species) were all unaffected by acid treatment.

The results thus did not favour our hypothesis that acid treatment inhibits seed germination, but favoured the null hypothesis that acid treatment does not affect seed germination.

REFERENCES

ABRAHAMSEN, G., HORNTVEDT, R. & TVEITE, B. 1977. Impacts of acid precipitation on coniferous forest ecosystems. Water Air and Soil Pollution. 8: 57-73.

ALEXANDER, M. 1977. Introduction to soil microbiology, 2nd ed. John Wiley and Sons. New York.

ALEXANDER, M. 1980. Effects of acidity on microorganisms and microbial processes in soil: 363-374. In: Effects of Acid Precipitation on Terrestial Ecosystems. Hutchinson, T.C. & Havas, M. (eds). Plenum Press, New York.

BJOR,K. & TEIGEN, O. 1980. Effects of acid precipitation on soil and forest. Proc. Int. Conf. Ecol. Impact acid precip. SNSF - project, 200-201, Norway.

BLUM, U. & TINGEY, D.T. 1977. Atmos. Environ. 11: 737.

DOCHINGER, L.S. & SELIGA, T.A. 1976. Proceedings of the first international symposium on acid precipitation and the forest ecosystem. USDA Forest Service General Technical Report NE-26. Northeastern Forest Experimental Station, Upper Darby, P.A.: 18.

EVANS, L.S. 1984. Botanical Aspects of Acidic Precipitation. The Botanical Review 50: 449-490.

EVANS, L.S., CURRY, T.M. & LEWIN, K.F. 1982. Response of leaves of Phaseolus vulgaris L. to simulated acid rain. New Phytol. 88: 403-420.

EVANS, L.S., LEWIN,K.F, CUNNINGHAM, E.A. & PATTI, M.J. 1982a.

Effects of simulated acidic rain on yields of field-grown crops. New Phytol. 9: 429-441.

FERENBAUGH, R.W. 1976. Effects of simulated acid rain on Phaseolus vulgaris L. (Fabaceae). Amer. J. Bot. 63: 283-288.

HINDAWI, I.J., REA, J.A. & GRIFFIS, W.C. 1980. Response of bushbean exposed to acid mist. Am. J. Bot. 67: 168-172.

HODGKIN, S.E. & BRIGGS, D. 1981. The effect of simulated acid rain on two populations of Senecio vulgaris L. New Phytologist 89: 687-691.

IRVING, P.M., MALEY, J.A. & GRADERT, C.M. 1981. Rainfall Acidity interlaboratory study - Rains. In: Radiological and Environmental Research Division Annual Report, ANL - 80 - 115: 1-4.

KRUG, E.C. & FRINK, C.R. 1983. Acid rain on acid soils: a new perspective. Science 221: 520-525.

LEE, J.J. & WEBER, D.E. 1979. The effects of simulated acid rain on seedling emergence and growth of eleven woody species. Forest Sci. 25: 393-398.

MACDONALD, N.W., HART, J.B., Jr. & PHU, V.N. 1986. Simulated acid rain effects and jack pine seedling establishment and nutrition. Soil Sci. Soc. Am. J. 50: 219 - 225.

McFEE, W.W. 1983. Sensitivity ratings of soils to acid deposition: A review. Environ Exp. Bot. 23: 203-210.

McCOLL, J.G. & JOHNSON, R. 1983. Effects of simulated acid rain on germination and early growth of Douglas-fir and ponderosa pine. Plant and Soil. 74: 125-129.

MOORE, A.M. & GILETTE, A. 1989. Germination of red spruce and frase fir seeds exposed to simulated acid rain. J. Elisha Mitchell Sci. Soc. 104(3) : 137 - 140.

PHILLIPS, G.M., RAITT, L.M. & AALBERS, J. 1985. Effect of simulated acid rain and sulphur nutrition on the growth, sulphate and cation content of Bromus diandrus Roth. S.Afr.J.Plant Soil,2: 98-100.

RAYNAL, D.J., ROMAN, J.R. & EICHENLAUB, W.M. 1982. Response of tree seedlings to acid precipitation. II. Effect of simulated acidified canopy throughfall on sugar maple seedling growth. Environ Exp. Bot. 22: 385-392.

SCERBATSKPY, T., KLEIN, R.M. & BADGER, G.J. 1987. Germination response of forest tree seed to acidity and metal ions. Environ. Exp. Bot. 27(2) : 157 - 164.

STROO, H.F. & ALEXANDER, M. 1985. Effect of simulated acid rain on mycorrhizal infection of Pinus strobus L. Water, Air, and Soil Pollution 25(1): 107-114.

TURNER, G.D., LAU, R.R. & YOUNG, D.R. 1988. Effect of acidity on germination and seedling growth of Pawlownia tomentosa. Journal of Applied Ecology 25 : 561 - 567.

VAN WYK, D.B. 1985. The influence of catchment management on erosion and subsequent sediment and nutrient in South African mountain streams, Jonkershoek Forestry Research Centre Report J13/85, South African Forestry Research Institute, Stellenbosch.

WOOD, T. & BORMANN, F.H. 1975. Increase in foliar leaching by acidification of an artificial mist. Ambio. 4: 169-171.

ZAMMIT, C.A. & ZEDLER, P.H. 1988. Germination response to extreme acidity : impact of simulated acid deposition from a single shuttle launch. Environ. Exp. Bot. 28(1) : 73 - 81.

CHAPTER 3

EFFECTS OF SIMULATED ACID RAIN AND SULPHUR NUTRITION ON THE GROWTH, SULPHATE AND CATION CONTENT OF Lycopersicon esculentum var. Red Kaki

ABSTRACT

Tomato seedlings (Lycopersicon esculentum var. Red Kaki) grown in an acid-washed sandculture, and subjected to sulphur deficient Hoagland nutrient solution (-S) and complete Hoagland nutrient solution (+S), respectively, were exposed to 5,6 mm simulated acid rain per day twice weekly for 4 weeks at pH levels 2,0 ; 3,2 ; 4,4 and 5,6 (control). Injury, characterized by leaf necrosis and curling under of leaflets occurred at pH 2,0. This resulted in parameters such as plant height, number of leaves on plants, fresh and dry mass of shoots and dry mass of roots being significantly lower compared with the control (pH 5,6). Plants at this level (pH 2,0) also contained greater quantities of root Na, Ca, Mg and $SO4^{-2}$, shoot Na and $SO4^{-2}$, and lower quantities of shoot Ca and Mg, and root K relative

to pH 5,6. Growth of tomato plants increased at pH 3,2 (with sulphur deficient plants growing more rapidly than the control plants), compared with the control pH. Significantly higher growth was obtained in plants with a complete Hoagland nutrient solution (+S). Root K was significantly higher at pH levels 3,2 ; 4,4 ; 5,6 and root Ca was significantly higher at pH levels 2,0 and 4,4 for the sulphur deficient plants.

3.1 INTRODUCTION

In many parts of the world rain can no longer be regarded as a beneficial solution that keeps plant life fresh and fair (Anon, 1984). Acid rain is one of the most significant environmental problems confronting all of eastern North America and much of western and northern Europe (Likens, 1976; Likens & Bormann, 1974). These trends are thought to be linked to increasing levels of sulphur and nitrogen oxide pollutants. Areas most notably affected include southern Scandinavia and northeastern United States where the annual weighted mean pH's for precipitation measured 4.0 to 4.5 in 1966 and 4.0 to 4.2 in 1974 (Likens & Bormann, 1974). The rainfall acidity recorded in the Eastern Transvaal Highveld and adjacent regions is similar to that for north eastern North America and Europe. As has been found in these countries, the pH in the Eastern Transvaal Highveld and adjacent regions is lower than that recorded in areas which are relatively free from man-made pollution (Tyson et al.1988).

It is only recently that acid rain has attracted attention in South Africa, as shown in the work of Böhm (1983).

The effects of acid precipitation on terrestrial ecosystems, particularly plants, are less well known than those on aquatic ecosystems (Tamm & Cowling, 1977; Keever, 1982). Laboratory and field studies have indicated that numerous potential effects, suggested by studies under simulated conditions, are often species-specific; some plants show enhanced growth (Wood &

Bormann, 1977; Evans & Lewin, 1981; Lee et al.1981; Raynal et al. 1982 and Troiano et al.1982), some no effect (Lee et al. 1981; Evans & Lewin, 1981; Raynal et al. 1982 and Johnston et al. 1982), and some reduced growth (Evans & Lewin, 1981; Lee et al. 1981). These growth responses have been attributed mainly to direct effects of acid rain on foliage.

Altered rates of nutrient leaching have been demonstrated to occur if foliage is exposed to acidic rainwater compared with more neutral rain-water (Fairfax & Lepp, 1975; Wood & Bormann, 1975; Evans & Lewin, 1981; Rathier & Frink, 1984). According to Tukey (1970) leaching results in the removal of large amounts of inorganic nutrients from plants, and this loss may be increased by acid rain (Wood & Bormann, 1975).

Visible symptoms of foliar injury characteristic of acid mist deposition have been described by Middleton et al.(1950); Thomas et al. (1952); Oden (1968); The Swedish Preparatory Committee (1971); Likens et al. (1972); Ottar (1972);Almer et al. (1974); Likens and Bormann (1974). Lesions on leaves may result after foliage is exposed to pH levels below 3.5 (Evans & Lewin, 1981).

Apart from the detrimental and the leaching effects of acid rain it could also have a buffering effect (Mellanby, 1980). While sulphur deficiencies are rare in industrial countries (Bould & Hewitt, 1963), such deficiencies occur in some parts of South Africa as in the Swartland and adjacent Cape Flats (Beyers, 1977). Maugh (1979) has shown that where such deficiencies do occur, acid rain can have the beneficial effects of supplying the sulphur required. Where the underlying rocks and soil do not provide a buffering effect, as would be the case in much of the south-western Cape (Truswell, 1970), effects are detrimental.

The aim of this research was to investigate the effects of sulphur nutrition and simulated acid rain on Lycopersicon esculentum var. Red Kaki. Our hypotheses then is that:

(a) Sulphur deficient plants subjected to the correct level of simulated acid rain will show normal growth; thus for the null hypothesis, growth of sulphur deficient plants would be worse than that of the control.

(b) Plants with adequate sulphur will be damaged by acid rain, thus for the null hypothesis they would show no difference.

3.2 MATERIALS AND METHODS

Lycopersicon esculentum var. Red Kaki seedlings were grown in sand culture (Hewitt, 1966). The seedlings were planted in acid-washed sand in 15 cm pots and grown at a density of one plant per pot as used by Evans & Lewin (1981). These plants were subjected to a two-factor randomized block experiment (Norby and Luxmoore, 1983) in a growth chamber (Phillips et al.1985). The experiment was carried out under controlled conditions, with temperature (20° C night & 27° C day), relative humidity (60% day & 70% night), light intensity (app 90 umol.$m^{-2}.s^{-1}$) and a photoperiod of sixteen hours (Evans et al. 1981).

The seedlings were initially treated with sulphur deficient Hoagland nutrient solution (Hewitt, 1966) to the age of six weeks (Evans et al. 1981). After this two levels of sulphur nutrition, complete Hoagland nutrient solution (+S) and nutrient solution without sulphur (-S) (Hewitt, 1966) were applied once a week. Plants were also watered with distilled water once a week (Phillips et al. 1985).

Four simulated acid rain treatments, viz pH 5,6; 4,4; 3,2 and 2,0 were used. The latter solutions were prepared by dilution of reagent grade sulphuric acid with distilled water (Ferenbaugh, 1976; Phillips et al.1985; Hindawi et al. 1980 and Hodgkin and Briggs, 1981) with nutrients added (Irving et al.1981; Evans et al.1982 and Evans & Lewin, 1981) according to the values of van Wyk (1983) for local conditions. Plants were sprayed twice weekly on a turntable to ensure even distribution, for ten minutes, giving an average simulated rainfall of 5,6 mm as measured with rainfall gauges at plant height. Treatments were replicated five times (Phillips et al.1985).

Simulated acid rain treatments were carried out for four weeks before harvesting. Then plant symptoms were noted; heights were measured and the number of leaves were determined.

After harvesting, the fresh- and dry mass of the shoots and dry mass of the roots were determined. The ground dry material for both shoots and roots was acid digested and analysed for sulphate using the turbidometric method

(Jackson, 1962), and for sodium, potassium, calcium and magnesium with a Pye-Unicam atomic absorption spectrophotometer (Phillips et al. 1985).

3.3 RESULTS AND DISCUSSION

3.3.1 External effects of Sulphur Nutrition and Simulated Acid Rain on *Lycopersicon esculentum* var. Red Kaki.

The tomato plants treated with sulphur deficient Hoagland nutrient solution showed chlorosis (fig. 3.1a). Sulphur deficiency typically causes a general paling of the leaves (Hewitt, 1963; Anderson, 1978), and the chlorosis observed was probably largely due to this. In addition the sulphur deficient plants showed a reduced leaf size as well as a reduced growth generally (figs. 3.1a and 3.1b). According to Hewitt (1963) this is typical of sulphur deficiency.

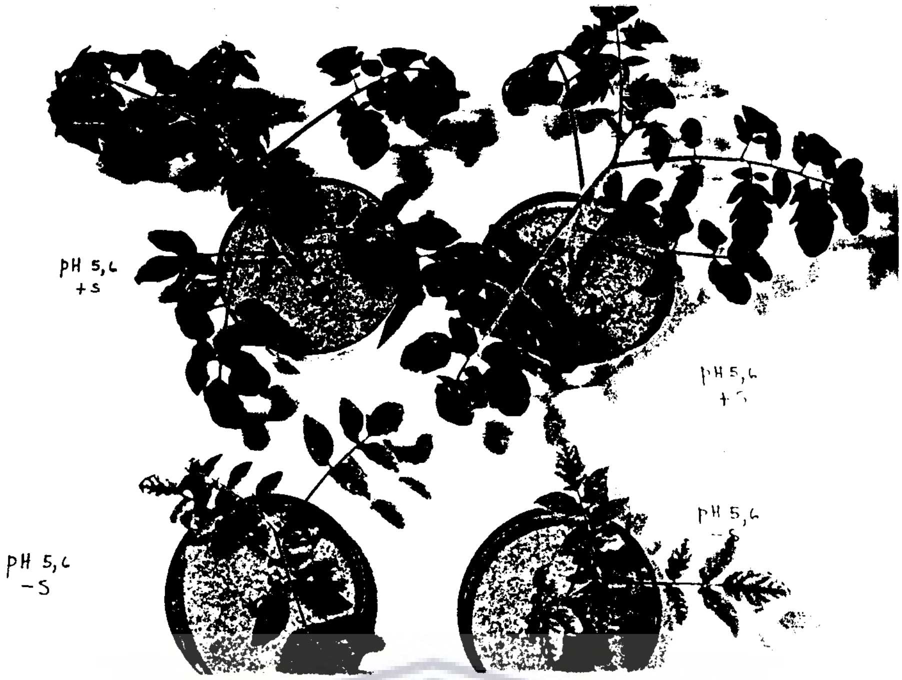

Fig. 3.1 (a) Tomato plants treated with sulphur deficient Hoagland nutrient solution(-S) and complete Hoagland nutrient solution (+S). Necrosis occurred in -S plants.

Fig. 3.1 (b) Sulphur deficient plants (-S) and adequate sulphur (+S) treated plants showing reduced and enhanced growth respectively at pH level 5,6.

Fig. 3.1 (c) Sulphur deficient (-S) and adequate sulphur (+S) treated plants, showing severe necrosis at pH level 2,0 after the first simulated acid rain treatment.

After the first treatment with simulated acid rain, both sulphur deficient (-S) and complete Hoagland (+ S) treated plants showed severe necrosis at pH 2,0 (fig. 3.1c). Necrotic spots occured randomly, particularly near the midrib and veins of leaves at pH 2,0, with lesions sometimes causing holes in the leaves. Similar results were obtained by (Keever and Jacobson, 1983; Rathier and Frink, 1984; Evans and Curry, 1979; Ferenbaugh, 1976; Hindawi et al. 1980 and Norby and Luxmoore, 1983). Continued simulated acid rain treatment at pH 2,0 resulted in curling under of leaflets. This is the result of lesions concentrated marginally (Keever and Jacobson, 1983; Rathier and Frink, 1984). Repeated application resulted in complete disintegration of leaf tissue. This is similar to the situation in Nicotiana (Rathier and Frink, 1984).

A few necrotic spots were initially also observed at pH level 3,2, not causing any major damage to the plants. Continued treatment at this level caused a decrease in plant damage which is the result of growth outstripping damage (Rathier and Frink, 1984). The sulphur deficient plants showed rapid increase in growth at pH 3,2, suggesting that the acid rain applied, supplied the necessary sulphur at this level. The same occurred at pH 4,4 and 5,6 for sulphur deficient plants after a few treatments. In this case acid rain appears to have the beneficial effect of supplying the sulphur required (Maugh, 1979). Plants showed an increase in growth at pH 3,2 in comparison with the other levels of treatment. However, other researchers have found widespread necrosis at pH 3,4 and lower (Evans & Curry, 1979; Ferenbach, 1976;

Hindawi et al.1980 and Norby & Luxmoore, 1983). No necrosis was observed at pH levels 4,4 and 5,6. Necrosis rarely occurs at pH 4 (Evans et al.1982).

3.3.2 The effects of Simulated Acid Rain on various Growth Parameters.

Table 3.1 The effect of simulated acid rain on various growth parameters in plants of Lycopersicon esculentum var. Red Kaki.

Parameter	pH of simulated acid rain				LSD	
	2,0	3,2	4,4	5,6	0,05	0,01
Heigh of shoots (cm)	12,15#	46,10*	35,48	38,25	4,39	5,92
No. of leaves on shoots	8,0*	13,7*	11,3	11,8	0,81	1,10
Fresh mass of shoots (g)	1,25#	29,61*	13,02	14,68	5,14	12,20
Dry mass of shoots (g)	0,23#	3,20*	1,39	1,61	0,57	0,77
Dry mass of roots (g)	0,039	0,54	0,24	0,25	0,116	0,156

* = Significant ; # = Highly significant

According to the results shown in Table 3.1, plants treated with simulated acid rain of pH level 2,0 showed highly significant reductions in the growth parameters studied. This stems from a reduction in vegetative growth at this pH level (Lee et al.1981; Evans, et al.1982; Raynal et al.1982 and Johnston et al.1982). The results further show a significant increase in all growth parameters at pH level 3,2 which is due to enhanced growth at this pH level (Wood & Bormann, 1977; Evans & Lewin, 1981; Lee et al.1981; Raynal et al.1982 and Troiano et al.1982). The results suggest a stimulation of plant growth under slightly acidic simulated rain (pH 3,2) conditions. This may be due to the sulphur present in the rain, being just the right concentration for growth promotion. No significant difference in growth can be observed between the plants exposed to simulated acid rain of pH 4,4 and the control (5,6-Table 3.1).

This pattern of decreased growth, increased growth or no change in growth rates at various acid levels is consistent with other studies (Evans and Lewin, 1981; Lee et al.1981 and Keever and Jacobson, 1983). Other researchers, however, reported decreased growth at all levels of acidic simulated rain relative to the growth at pH 5,6 (Hindawi et al.1980). Lee et al. (1981) suggested that the net effects of acidic simulated rain was the result of competing stimulatory and inhibitory effects. However, the affore-mentioned researchers did not make use of S-deficiency treatments. The net effects would undoubtedly be species-dependant and probably would vary with cultural and experimental procedures (Keever and Jacobson, 1983).

According to the results (Table 3.1) there is a significant reduction in the number of leaves formed at pH level 2,0 relative to the other pH levels, viz, 3,2; 4,4 and the control. The significant reduction in the number of leaves formed at pH 2,0 is obviously due to a reduction in growth at this pH.

The growth pattern for dry mass of roots, fresh mass of shoots and dry mass of shoots (Table 3.1) resembles that of height. These results clearly indicate growth reduction at pH 2,0, growth promotion at pH 3,2 and no real effect at pH 4,4 where compared with the control (pH 5,6).

3.3.3 The effects of Sulphur Nutrition on various Growth Parameters.

In a biological context, plants are the greatest consumers of sulphur from the physical environment and the most important producers of sulphur amino acids (methionine and cysteine). A deficiency in sulphur could result in a deficiency in these sulphur containing amino acids. (Anderson, 1978).

There are several reasons for suspecting that the supply of sulphate in rain may be important for plant growth. The latter is incorporated into metabolic processes and is essential for growth (Jacobson et al.1980). Sulphate is taken up through leaves as well as from soil (Tukey, 1970). Atmospheric supply of sulphate support plant growth in populations that do not receive soil applications of fertilizers containing this anion. An increase in the supply of nitrates and sulphates from the atmosphere allows plant populations to flourish and an exclusion of these nutrients can diminish growth (Jacobson et al.1980).

Table 3.2 The effect of Sulphur Nutrition on various growth parameters of tomato plants.

Parameters	Sulphur treatment		LSD	
	-S	+S	0,05	0,01
No. of leaves on shoots	10,4	12,0	0,57	0,78
Height of shoots (cm)	29,4	36,85	3,10	4,19
Fresh mass of shoots (g)	12,43	16,85	3,63	4,90
Dry mass of shoots (g)	6,54	9,53	0,40	0,55
Dry mass of roots (g)	1,28	1,47	0,08	0,11

The results (Table 3.2) show that sulphur deficiency resulted in a decrease in plant growth.

3.3.4 The effects of Simulated Acid Rain and Sulphur Nutrition on various Growth Parameters.

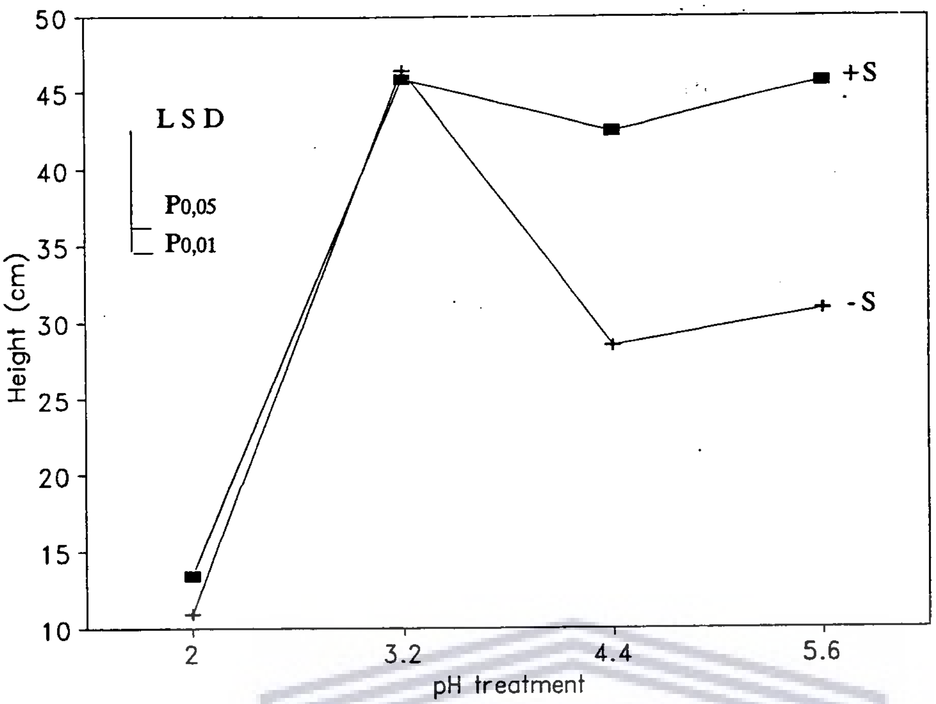

Fig. 3.2 (a) *The effect of simulated acid rain and sulphur nutrition on the height of tomato shoots.*

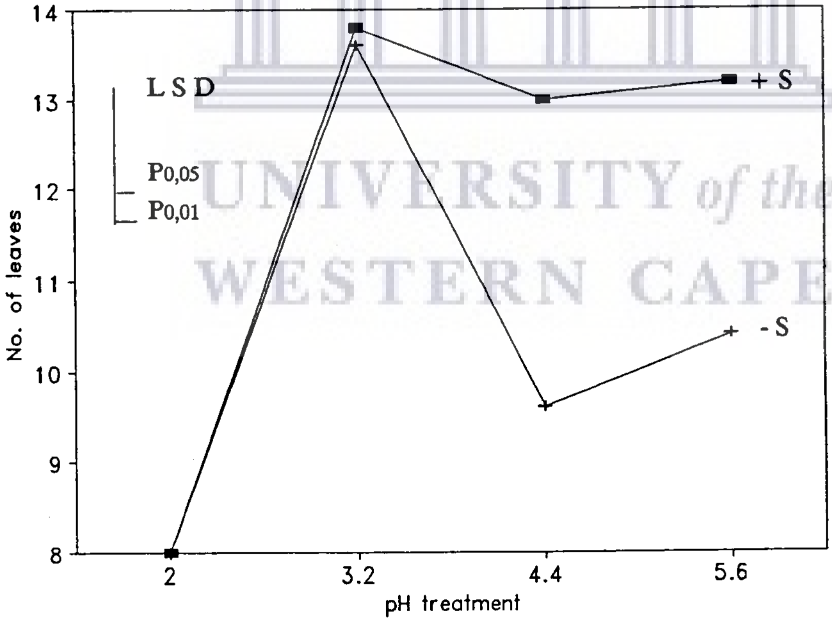

Fig. 3.2 (b) *The effect of simulated acid rain and sulphur nutrition on the number of leaves on tomato shoots.*

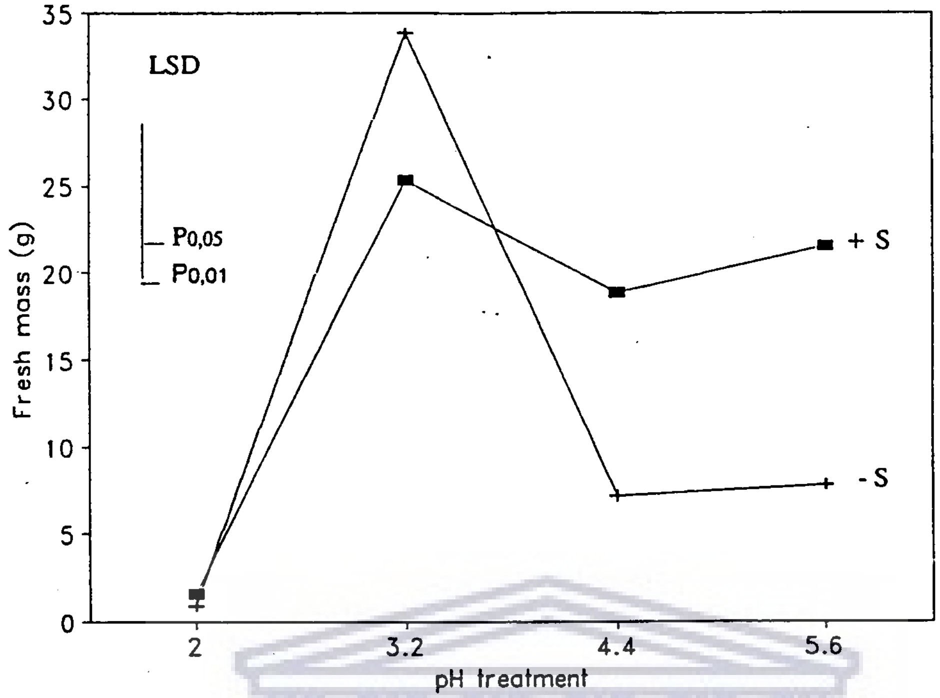

Fig. 3.2 (c) *The effect of simulated acid rain and suphur nutrition on the fresh mass of tomato shoots.*

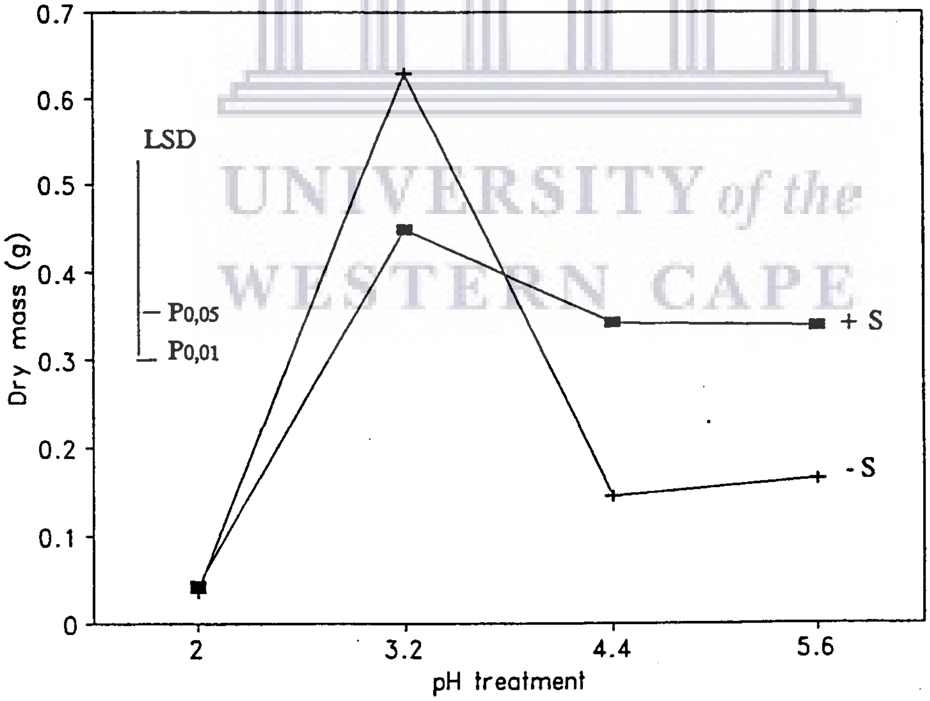

Fig. 3.2 (d) *The effect of simulated acid rain and suphur nutrition on the dry mass of tomato roots.*

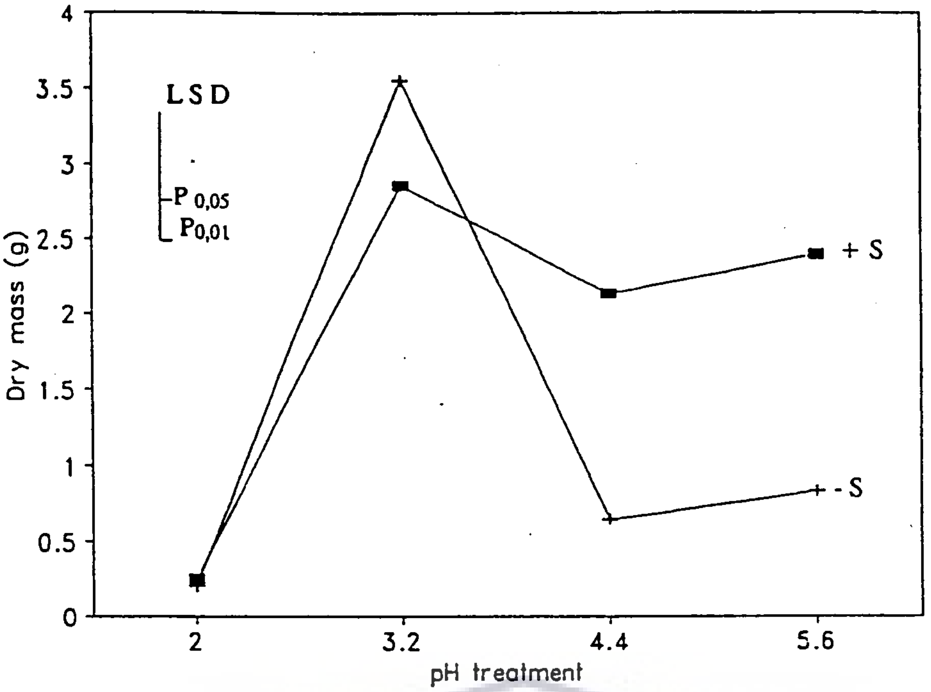

Fig.3.2 (e) *The effect of simulated acid rain and sulphur nutrition on the dry mass of tomato shoots.*

In the Figs.3.2(a-e) the effect of both sulphur treatment and simulated acid rain on plant height, number of leaves on shoots, shoot dry- and fresh mass, and root dry mass is shown.

The pattern of growth in this case is similar to the previous studies for both sulphur deficient and control plants. Significant reductions were observed in these parameters at pH levels 4,4 and the control (pH 5,6) for sulphur deficient plants (Figs. 3.2[a-e]), suggesting that the simulated acid rain had no effect on plant growth at these levels (Lee et al.1981; Evans et al.1981) Phillips et al. (1985) found similar results for root dry masses at pH level 6,5. Acid rain appeared to improve shoot and root growth in sulphur deficient plants much more than in the control plants at pH level 3,2 (Figs. 3.2 c,e) suggesting that the acid rain makes up for the sulphur deficiency (Maugh, 1979). Reductions in growth at pH level 2,0 were the same for both sulphur deficient- and the control plants (Figs. 3.2 [a-e]) .

3.3.5 Effect of Simulated Acid Rain on Nutrient Cations and Sulphate.

Acid precipitation contains relatively large amounts of nitrogen and sulphur in plant-available form, which gives a fertilizer effect in areas deficient in these nutrients. Many farm operators have to supply sulphate as a nutrient and acid deposition in many cases initially lessens the need for this nutrient input (Cole and Stewart, 1983).

According to Fairfax and Lepp (1975); Hindawi et al. (1980), and Wood and Bormann (1975), accellerated leaching of substances from foliage is one of the potential effects suggested by studies under simulated conditions. Foliar leaching may involve cation exchange in which the hydrogen ions in rain water replace the nutrient cations held on binding sites in the leaf (Wood and Bormann, 1975).

Table 3.3 The effect of simulated acid rain on nutrient cations and sulphate.

Nutrient conc. (g.kg^{-1})	pH of simulated acid rain				LSD	
	2,0	3,2	4,4	5,6	0,05	0,01
Root Na	19,69	5,53	6,46	5,62	7,25	9,79
Shoot Na	1,16	0,61	0,91	0,66	0,39	0,52
Root K	16,37	27,00	31,25	26,99	6,93	9,35
Shoot K	35,14	34,10	35,46	32,60	3,72	5,02
Root Ca	18,20	9,74	10,38	9,75	6,10	8,23
Shoot Ca	4,03	7 ,47	6,26	7,15	1,02	1,37
Root Mg	107,26	13,28	14,31	10,71	51,84	69,95
Shoot Mg	2,76	2,04	4,37	4,07	1,38	1,86
Root SO4^{-2}	711,53	107,39	97,28	81,97	400,98	540,97
Shoot SO4^{-2}	67,40	46,51	55,21	51,40	17,08	23,04

The effects of simulated acid rain on nutrient cations and sulphate in the roots and shoots of Lycopersicon esculentum var. Red Kaki is shown in Table 3.3 Nutrient concentrations in roots and shoots varied significantly with acid rain treatment (Table 3.3). Root nutrient concentrations were significantly higher at pH level 2,0 than for all other pH levels, except for K, which was significantly lower (Table 3.3). This is a direct result of acid rain damage to plants at this pH level. No significant difference in root nutrient concentrations between pH levels 3,2 , 4,4 and the control pH could be observed. The results thus suggest that nutrients accumulated in roots of Lycopersicon esculentum var. Red Kaki at pH level 2,0. Shoot Na- and SO_4^{-2}-concentrations were significantly higher and shoot Ca- and Mg-concentrations were significantly lower at pH level 2,0 than at the other pH levels, while no significant difference in shoot nutrients were observed among the other pH levels (Table 3.3).

3.3.6 The effect of Sulphur Nutrition on Nutrient Cations and Sulphate

Table 3.4 The effect of sulphur nutrition on nutrient cations and sulphate.

Nutrients conc. (g.kg^{-1})	Sulphur treatment		LSD	
	+ S	- S	0,05	0,01
Root Mg	35,61	37,16	36,66	49,46
Shoot Mg	3,12	3,49	0,98	1,32
Root Ca	9,10	14,89	4,31	5,82
Shoot Ca	6,44	6,01	0,72	0,97
Root K	21,79	29,02	4,90	6,61
Shoot K	33,8	34,84	2,63	3,55
Root Na	9,59	9,06	5,13	6,92
Shoot Na	0,79	0,87	0,27	0,37
Root SO_4^{-2}	242,89	256,18	283,54	382,52
Shoot SO_4^{-2}	53,5	56,75	12,07	16,29

The effect of sulphur nutrition on nutrient cations and sulphate is illustrated in Table 3.4. Sulphur deficiency did not affect root- and shoot-cations and sulphate concentrations, showing no significant differences in nutrient cations and sulphate, except for root-calcium- and potassium concentrations, being significantly higher in the sulphur deficient plants (Table 3.4). The results further suggest a relocation of potassium from roots to shoots in both sulphur deficient and the control plants. The potassium concentration of the shoots was significantly higher and that of the roots significantly lower in both the sulphur deficient plants and plants with adequate sulphur. Phillips et al. (1985) found similar results with magnesium concentrations in Bromus diandrus Roth. for sulphur deficient plants. The root potassium concentration was lower where sulphur supply was adequate (Table 3.4) showing the same trend as in the simulated acid rain treatment where- plants receiving more sulphur (pH 2,0) had less potassium. Phillips et al. (1985) found similar results with Bromus diandrus Roth.

3.3.7 The effects of Simulated Acid Rain and Sulphur nutrition on nutrient Cations and Sulphate

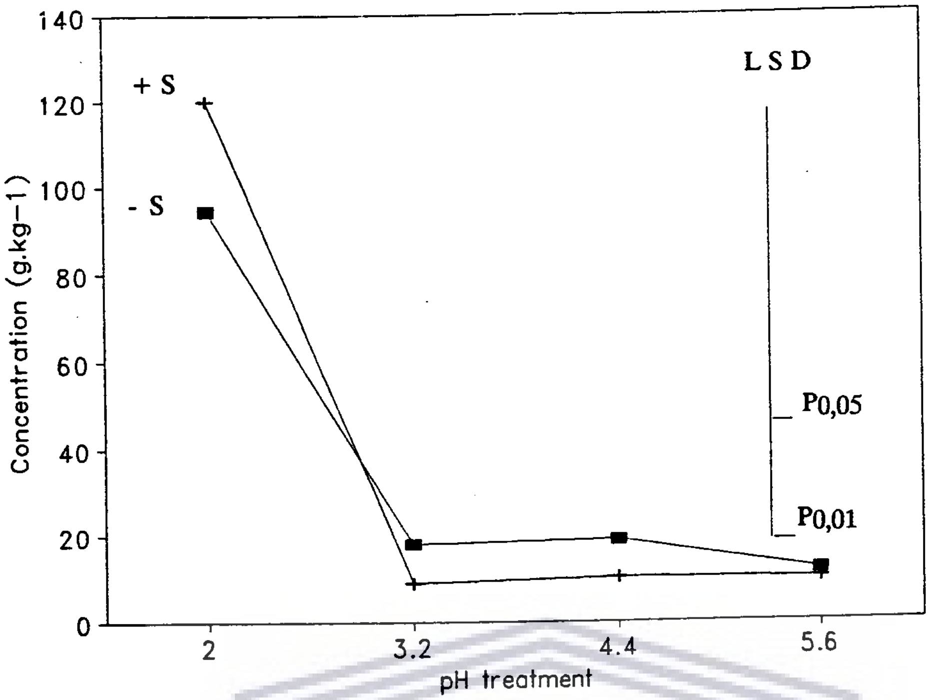

Fig. 3.3 (a) *The effect of simulated acid rain and sulphur nutrition on magnesium concentration of tomato roots.*

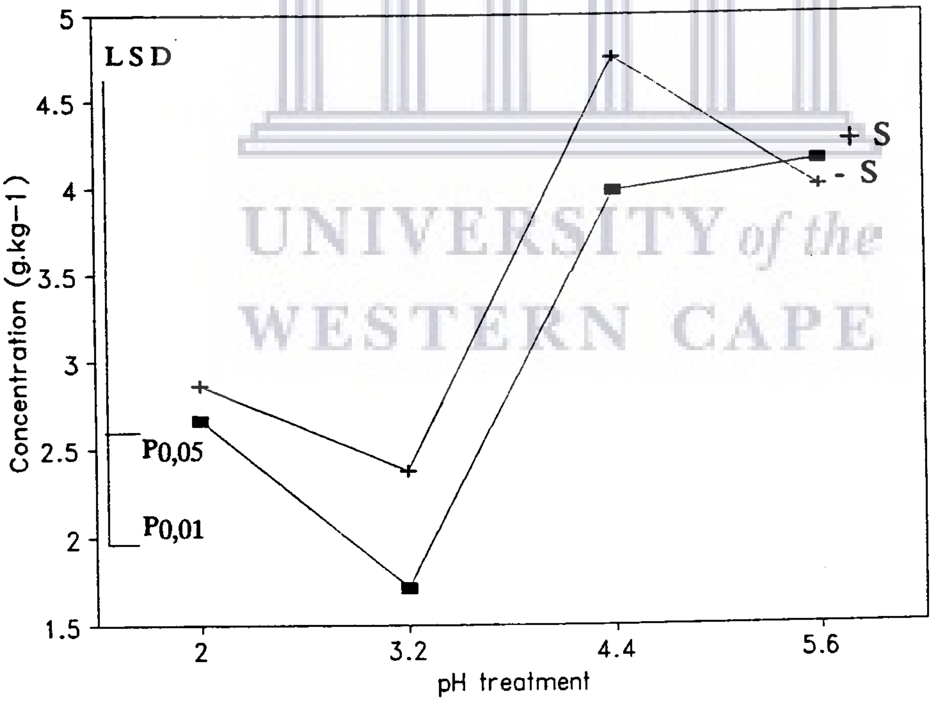

Fig. 3.3 (b) *The effect of simulated acid rain and sulphur nutrition on magnesium concentration of tomato shoots.*

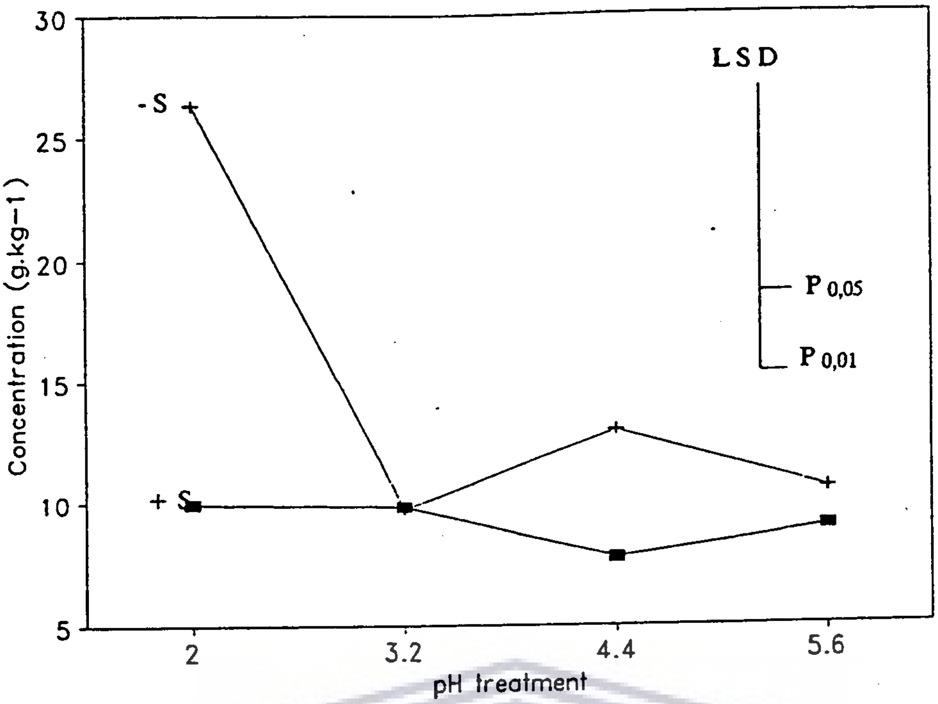

Fig. 3.3 (c) *The effect of simulated acid rain and sulphur nutrition on calcium concentration of tomato roots.*

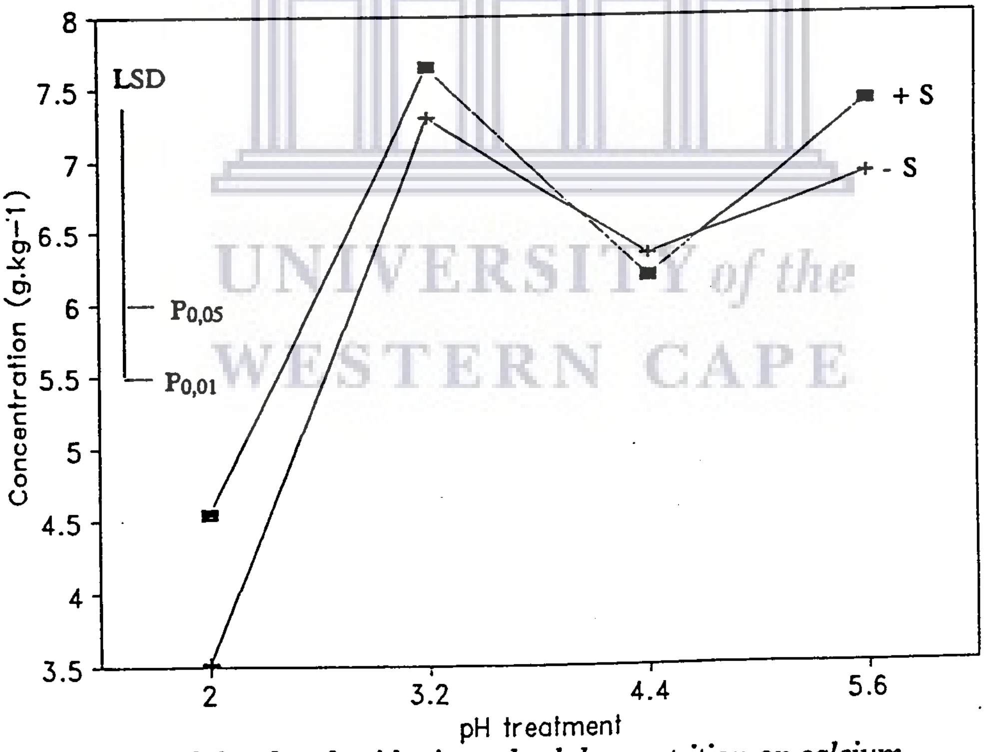

Fig. 3.3 (d) *The effect of simulated acid rain and sulphur nutrition on calcium concentration of tomato shoots.*

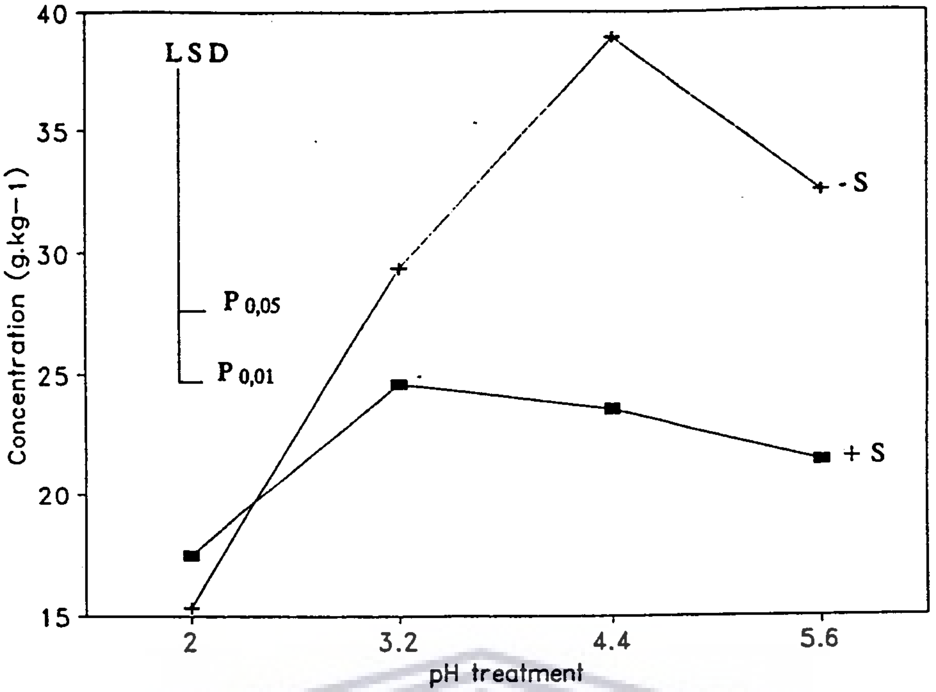

Fig. 3.3 (e) *The effect of simulated acid rain and sulphur nutrition on potassium concentration of tomato roots.*

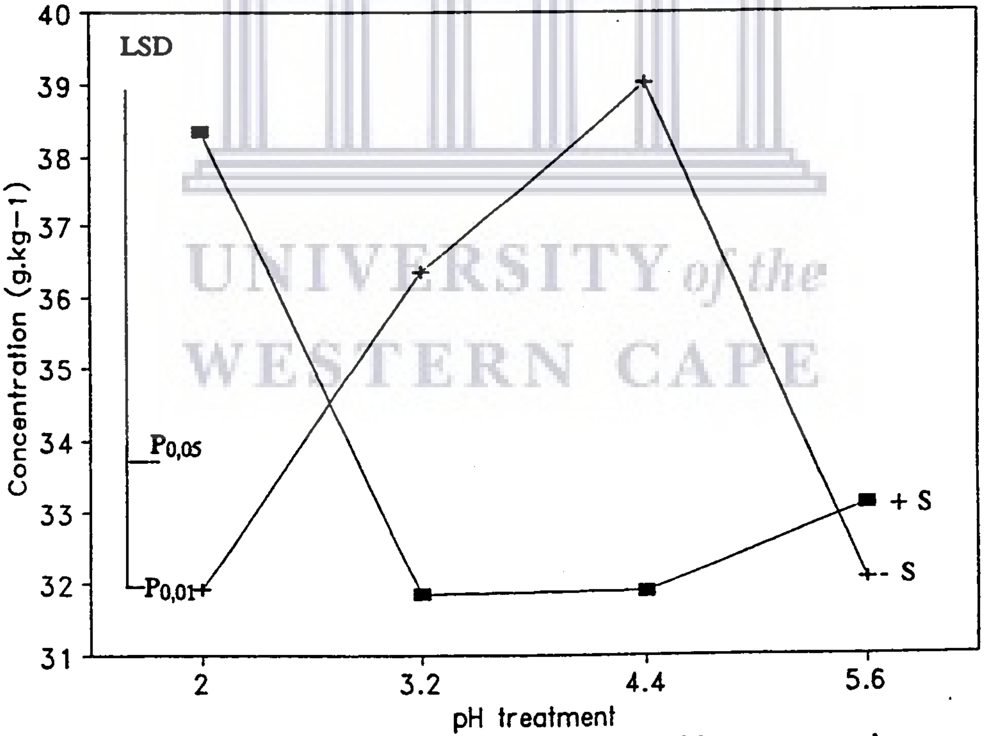

Fig. 3.3 (f) *The effect of simulated acid rain and sulphur nutrition on potassium concentration of tomato shoots.*

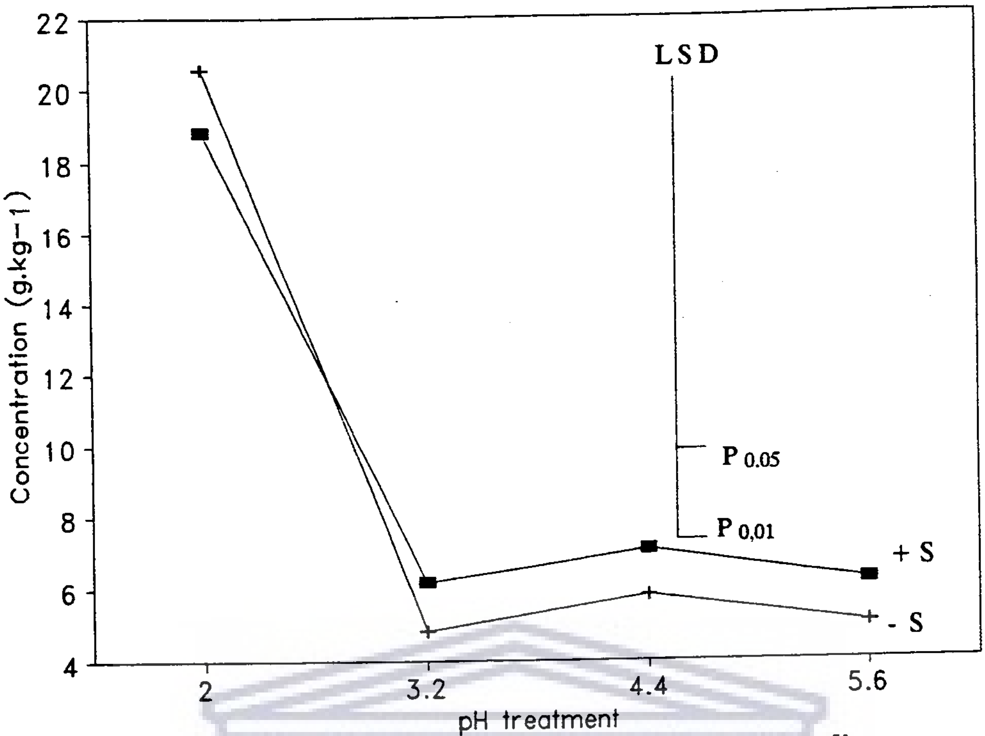

Fig. 3.3 (g) *The effect of simulated acid rain and sulphur nutrition on sodium concentration of tomato roots.*

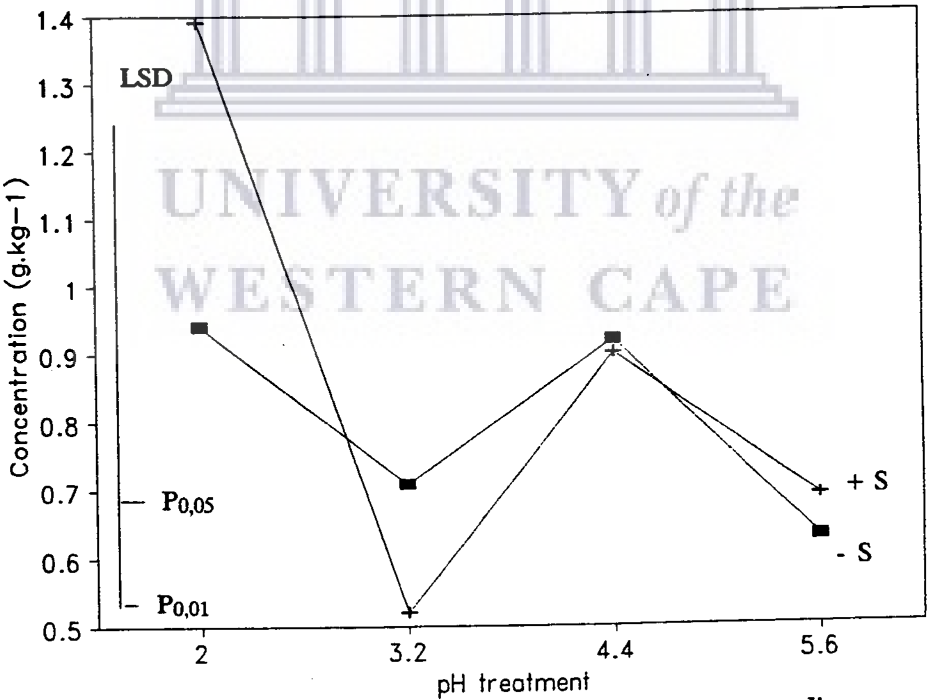

Fig. 3.3 (h) *The effect of simulated acid rain and sulphur nutrition on sodium concentration of tomato shoots.*

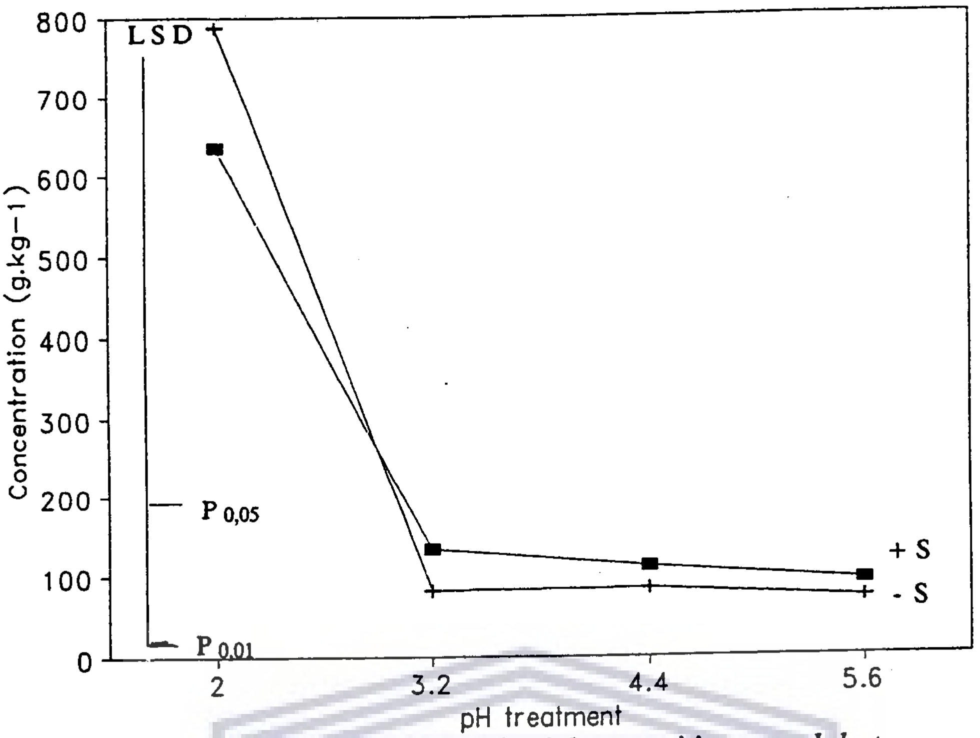

Fig. 3.3 (i) *The effect of simulated acid rain and sulphur nutrition on sulphate concentration of tomato roots.*

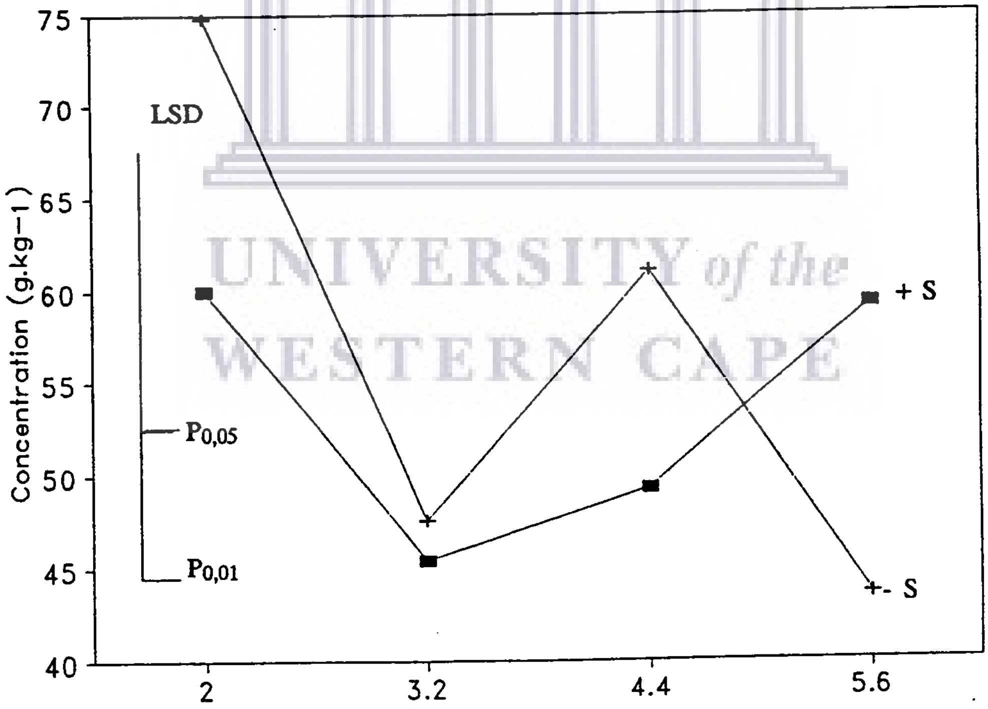

Fig. 3.3 (j) *The effect of simulated acid rain and sulphur nutrition on sulphate concentration of tomato shoots.*

The pattern of root- and shoot nutrient concentrations in (Figs. 3.3 a - j) both sulphur deficient and the control plants resembles that in 3.3.5., with only slight variations. Root potassium concentrations were significantly higher at pH levels 4,4 and the control pH for sulphur deficient plants and significantly lower in the control plants at these pH levels (Fig. 3.3 e). Root calsium- and sulphate concentrations varied significantly between sulphur deficient- and the control plants, respectively (Figs. 3.3 c,j). Significant differences between sulphur deficient and the control plants can be observed for shoot sodium- and sulphate concentrations respectively (Figs. 3.3 h,j).

3.4 CONCLUSION

This study was undertaken to investigate the effect of simulated acid rain and sulphur nutrition on the growth, sulphate and cation content of tomato plants. The results have indicated that acid treated, sulphur deficient plants, showed normal growth when compared to that of the control plants. This finding thus favour our hypothesis stating, "Sulphur deficient plants subjected to the correct levels of simulated acid rain will show normal growth." Our null hypothesis stating that growth of sulphur deficient plants would be worse than that of the control, then does not hold. The results have further indicated that the control plants showed reduced growth for fresh- and dry mass of shoots at pH 3,2, compared to that of the sulphur deficient plants [Figs. 3.2 (c), (d)]. These results thus again favour our hypothesis, stating that plants with adequate sulphur will be damaged by acid rain. The null hypothesis then stating that control plants would show no difference from sulphur deficient plants to similar acid rain treatments does not hold.

Tomato plants treated with sulphur deficient Hoagland solution showed chlorosis and reduced leaf size. This is typical of sulphur deficiency (Hewitt, 1963; Anderson, 1978).

After the first treatment with simulated acid rain, both sulphur deficient and control plants showed severe necrosis at pH level 2,0. Repeated application of simulated acid rain at this level resulted in complete disintegration of leaf tissue. Plants treated with simulated acid rain of pH level 3,2 initially showed necrotic spots, but with continued treatment, they disappeared. Rathier and Frink (1984) obtained similar results with Nicotiana which they attributed to growth outstripping damage at this level. The sulphur deficient plants showed rapid increase in growth at pH level 3,2, suggesting that the acid rain applied, supplied the necessary sulphur for growth promotion. Overall, plants showed an increase in growth at pH level 3,2 in comparison with the other levels of treatment.

Simulated acid rain decreased growth parameters such as plant height, shoot fresh-and-dry mass and root dry mass in both sulphur deficient and control plants at pH level 2,0, increasing them at pH level 3,2 and no change at pH levels 4,4 and 5,6. This is consistent with other studies (Evans and Lewin, 1981; Lee et al. 1981; Keever and Jacobson, 1983(a)). The sulphur deficient plants in comparison with the control plants, showed a significant decrease in the average plant growth for all the above-mentioned parameters.

Sulphur deficient plants also showed significant reductions and significant promotion in plant height, number of leaves and shoots, shoot dry-and-fresh mass and root dry mass at pH levels 4,4 and 5,6 and at pH level 3,2, respectively. This suggests that simulated acid rain had no effect on plant growth in sulphur deficient plants at pH levels 4,4 and 5,6, and promoted growth in sulphur deficient plants at pH level 3,2 significantly.

Sodium, potassium, calcium, magnesium and sulphate contrations in roots and shoots varied significantly with acid rain treatment. Shoot sulphur concentrations were significantly higher than all other minerals at all pH levels. Root sodium-, -calcium-, -magnesium- and -sulphate concentrations were significantly and highly significantly higher at pH level 2,0 than at all other pH levels.

Calcium and potassium movements from roots to shoots were retarded in sulphur deficient plants. The results suggest a relocation of potassium from roots to shoots in both sulphur deficient- and adequate sulphur treated plants - similar results were obtained by Phillips et al. (1985) with magnesium concentrations in Bromus diandrus Roth. in sulphur deficient plants. Plants receiving more sulphur had less potassium (Phillips et al.1985 found similar results with Bromus diandrus Roth.)

The rate of magnesium leaching in both sulphur deficient and control plants were relatively higher at pH level 2,0 than at all other pH levels, and higher in adequate sulphur treated plants than sulphur deficient plants at pH levels 3,2 and 4,4.

Relocation of potassium from the roots to the shoots occured at all pH levels for adequate sulphur plants and at pH levels 2,0 and 3,2 for sulphur deficient plants. Results suggest rapid leaching of sodium at pH level 2,0 for both sulphur deficient and adequate sulphur treated plants.

Shoot sulphate concentration was significantly higher for sulphur deficient plants and significantly lower for adequate sulphur plants at pH levels 2,0 and 4,4. The opposite occurred at pH level 5,6. Root sulphate concentrations were significantly lower for sulphur deficient plants and significantly higher for adequate sulphur plants at pH levels 3,2; 4,4 and 5,6. The opposite occurred at pH level 2,0.

Finally the effect of simulated acid rain on the growth of Lycopersicon esculentum var. Red Kaki showed reduced growth at pH level 2,0 (in sulphur deficient- and adequate sulphur plants); enhanced growth at pH level 3,2 (with sulphur deficient plants more enhanced than adequate sulphur plants) and no effect at pH levels 4,4 and 5,6 (with sulphur deficient plants showing reduced growth in comparison with adequate sulphur plants).

3.7 REFERENCES

ABRAHAMSEN, G., BJOR, K., HORNTVEDT, R. &TVEIT, B. 1976. Effects of acid precipitation on forest and freshwater ecosystems in Norway. -SNSF-project, Norway, FR 6/76 : 36 - 63.

ALMER, B., DICKSON, W., EKSTROM, C., HORNSTROM, E.& MULLER, U. 1974. Effects of acidification on Swedish lakes. Ambio 3 : 30 - 36.

ANDERSON, J.W. 1978. Sulphur in biology. Edward Arnold, London.

ANON. 1984. How to neutralize acid rain. Nature. 310 : 611 - 612.

BEYERS, C.P. DEL. 1977. Evaluation of the sulphur content of selected soils in the winter rainfall region. Elsenburg J. 1 : 18 - 21.

BJOR, K. & TEIGEN, O. 1980. Effects of acid precipitation on soil and forest. 6. Lysimeter experiment in greenhouse. - In : Drablos, D. & Tollan, A.(eds.). Proc. Int. Conf. Ecol. Impact acid precip. - SNSF - project : 200 - 201. Norway

BOHM, M. 1983. Acid rain : towards automated monitoring. Symposium on Atmospheric Sciences in South Africa. CSIR, Pretoria.

BOULD, C. & HEWITT, E.J. 1963. Mineral nutrition of plants in soils. In F.C. Steward(ed.). Plant physiology, a treatise. Vol. 3, Inorganic nutrition of plants. Academic Press, New York.

COLE, C.V. & STEWART, J.W.B. 1983. Impact of Acid Deposition on P - Cycling. Env. & Exp. Bot. 23 : 235 - 241.

COWLING, E.B. & LINTHURST, R.A. 1981. The Acid Precipitation

Phenomenon and Its Ecological Consequences. Bio Science 31 : 649 - 654.

EVANS, L.S. & CURRY, T.M. 1979. Differential response of plant foliage to simulated acid rain. Am. J. Bot. 66 : 953 - 962.

EVANS, L.S. & LEWIN, K.F. 1981. Effects of simulated acid rain on growth and yield of soybeans and pinto beans. In : Atmospheric Sulphur Deposition (Ed. by Shriner, D.S., Richmond, C.R. & Lindberg, S.E.), Ann. Arbor Science. Ann Arbor. : 299 - 308.

EVANS, L.S., LEWIN, K.F., CONWAY, C.A., PATTI, M.J. 1981 Seed yields (quantity and quality) of field-grown soybeans exposed to simulated acidic rain. New Phytol. 89 : 459 - 470.

FAIRFAX, J.A.W. & LEPP, N.W. 1975. Effect of simulated acid rain on cation loss from leaves. Nature 255 : 324 - 325.

FARNELL, E.P., NILSON, I., TAMM, C.O. & WIKLANDER, G. 1980. Effects of artificial acidification with sulphuric acid on soil chemistry in a Scots pine forest. - In : Drablos, D. & Tollan, A. (eds.). Proc., Int. Conf. Ecol. Impact acid precip. - SNSF - project, : 186 -187. Norway.

FERENBAUGH, R.L. 1976. Effects of simulated acid rain on Phaseolus vulgaris L. (Fabaceae). Am. J. Bot. 63 : 283 - 288.

HAINES, B., JORDAN, C., CLARK, H. & CLARK, K. 1982. Acid Rain in an Amazon Rainforest. - Tellus.

HEWITT, E.J. 1966. Sand and water culture methods used in the study of plant nutrition, revised 2nd ed. Commonwealth Bureau of Horticulture and Plantation Crops, East Malling Tech. Communication No. 22..

HEWITT, E.J. 1963. The essential nutrient elements : requirements and interactions in plants. In F.C. Steward(ed.). Plant physiology, a treatise Vol. 3, Inorganic nutrition of plants. Academic Press, New York.

HINDAWI, I.J., REA, J.A. & GRIFFIS, W.C. 1980. Response of bushbean exposed to acid mist. Am. J. Bot. 67 : 168 -172.

HODGKIN, S.E. & BRIGGS, D. 1981. The effect of simulated acid rain on two populations of Senecio vulgaris L. New Phytologist 89 : 687 - 691.

IRVING, P.M., MALEY, J.A. & GRADERT, C.M. 1981. Rainfall acidity interlaboratory study - RAINS. In: Radiological and Environmental Research Division Annual Report, January - December, 1980. ANL-80-115 : 1 - 4, Argonne National Laboratory, Argonne, Illinois.

JACKSON, M.L. 1962. Soil Chemical Analysis. Constable, London.

JACOBSON, J.S., TROIANO, J., COLAVITO, L.J., HELLER, L.I. & McCUNE, D.C. 1980. Polluted rain and plant growth. 291 - 306. In 12th Rochester Int. Conf. Environmental Toxicology, University of Rochester, N.Y. Plenum Press, New York.

JOHNSON, J.W., SHRINER, D.S., KLANER, C.I. and LODGE, D.M. 1982. Effect of rain pH on senescence, growth, and yield of bush bean. Environ. Exp. Bot. 22:329 - 337.

KEEVER, G.J. 1982. Plant response to simulated acid rain with special reference to foliar injury, foliar leaching, trichome status and plant nutrition. Ph.D Thesis, Cornell University, Ithaca, N.Y.

KEEVER, G.J. and JACOBSON, J.S. 1983. Response of Glycine max (L.) Merrill to simulated acid rain, II. Localization of foliar injury and growth response. Field Crops Research, 6: 251 - 259.

LEE, E.H., HEGGESTAD, H.E. and BENNET, J.H. 1982. Effects of sulphur dioxide fumigation in open-top field chambers on soil acidification and exchangeable aluminium. J. Environ. Qual. 11 : 99 - 102.

LEE,J.J., NEELY, G.E., PERRIGAN, S.C. and GROTHAUS, L.S. 1981. Effects of simulated acid rain on yield, growth and foliar injury of several crops. Environ. Exp. Bot. 21 :171-185.

LIKENS, G.E. 1976. Acid Precipitation. Chem. Eng. News, 54 : 29 - 44.

LIKENS, G.E. and BORMANN, F.H. 1974. Acid rain: a serious regional environmental problem. Science 184 : 1176 - 1179.

LIKENS, G.E., BORMANN, F.H. and JOHNSON, N.M. 1972. Acid rain. Environment 14 : 33 - 44.

MAUGH, T.H., II. 1979. SO_2 pollution may be good for plants. Science 205 (4404) : 383.

MELLANBY, K. 1980. The Biology of pollution, 2nd edn., Edward Arnold, London.

MIDDLETON, J.T., KENDRICH, J.B., Jr. and SCHWALM, H.W. 1950. Injury to herbaceous plants by smog or air pollution. Plant Disease Reptr. 34 : 245 - 252.

NORBY, R.J. and LUXMOORE, R.J., 1983. Growth analysis of soybean exposed to simulated acid rain and gaseous air pollutants. New Phytol. 95 : 277 - 287.

ODEN, S., 1968. The acidification of air and precipitation and its consequences on the natural environment. Bulletin No. 1 Swedish Natural Science Research Council, Stockholm.

OTTAR, B., 1972. Norwegian report on acid rain to the organization for Economic Cooperation and Development. OECD Air Management Sector Group Report.

PHILLIPS, G.M., RAITT, L.M. and AALBERS, J., 1985. Effect of simulated acid rain and sulphur nutrition on the growth, sulphate and cation content of Bromus diandrus Roth. S.Afr. J. Plant Soil, 2 : 98 - 100 University of the Western Cape, Bellville.

RATHIER, T.M. and FRINK, C.R., 1984. Simulated Acid Rain: Effects on leaf quality and yield of broadleaf tobacco. Water, Air and Soil Pollution 22 : 389 - 394.

RAYNAL, D.J., ROMAN, J.R. & EICHENLAUB, W.M. 1982. Response of tree seedlings to acid precipitation. II. Effect of simulated acidified canopy throughfall on sugar maple. Environ. Exp. Bot. 22 : 385 - 392

SINGH, B.R., ABRAHAMSEN, G. and STUANES, A., 1980. Effects of simulated acid rain on sulphate movement in acid forest soils. - Soil Sci. Soc. Am. J. 44 : 75 - 80.

STUANES, A.O., 1983. Possible indirect long-term effects of acid precipitation on forest growth. Aquilo Ser. Bot. 19 : 50 - 63.

SWEDISH PREPARATORY COMMITTEE. 1971. Air pollution across national boundaries: the impact on the environment of sulphur in air and precipitation. Report for the United Nations Conference on the Human Environment. P.A. Norstedt and Sons. Stockholm.

TAMM, C.O. and COWLING, E.B., 1977. Acidic precipitation and forest vegetation. Water Soil Air Pollut. 7 : 503 - 512.

TAMM, C.O., WIKLANDER, G. and POPOVIC, B., 1977. Effects of application of sulphuric acid to poor pine forests - Water, Air, and Soil Pollution 8 : 75 - 87.

THOMAS, M.D., HENDRICKS, R.H. and HILL, G.R., 1952. Some impurities in the air and their effects on plants. In: Air Pollution : 41 - 47, McGraw - Hill Book Co., Inc., New York, NY.

TROIANO, J., HELLER, L. and JACOBSON, J.S., 1982. Effect of added water and acidity of simulated rain on growth of field grown radish. Environmental Pollution (Series A), 29 : 1 -11.

TRUSWELL, J.F., 1970. An introduction to the historical geology of South Africa. Purnell, Cape Town.

TUKEY, H.B., 1970. The leaching of substances from plants. A. Rev. Pl. Physiol 21 : 305 - 324.

TYSON, P.D., KRUGER, F.J., & LOUW, C.W. 1988. Atmospheric pollution and its implications in the Eastern Transvaal Highveld. South African National Scientific programmes report, 150 : Foundation for Research development, CSIR. Pretoria.

VAN WYK, D.B.1985. The influence of catchment management on erosion and subsequent sediment and nutrient in South African mountain streams, Jonkershoek Forestry Research Centre Report J13/85, South African Forestry Research Institute, Stellenbosch.

WITTWER and BUKOVAC., 1969. The uptake of nutrients through leaf surfaces. in K. Scharrer and H. Linser , eds. Handbuch der Pflanzenernahrung und Dungung. : 235 - 261. Springer- Verlag, New York.

WOOD, T. and BORMANN, F.H., 1975. Increases in foliar leaching caused by acidification of an artificial mist. Ambio 4 : 169 - 171.

WOOD, T. and BORMANN, F.H., 1977. Short-term effects of a simulated acid rain upon the growth and nutrient relations of Pinus strobus L. Water, Air and Soil Pollution 7 : 479 -488.

CHAPTER 4

EFFECT OF SIMULATED ACID RAIN AND SOIL ACIDITY ON THE GROWTH, SULPHATE, CATION AND HEAVY METAL CONTENT OF Lycopersicon esculentum var. Red Kaki

ABSTRACT

Tomato seedlings (Lycopersicon esculentum var. Red Kaki) were grown in two soil types viz base rich soil containing lime from the Cape Flats Nature Reserve, and acidic soil from the margin of the Cape Flats, Eerste River. They were exposed to simulated acid rain for ten minutes a day twice weekly for four weeks at pH levels 2,0 ; 3,2 ; 4,4 and 5,6 (control). Seedlings were treated with half strength Hoagland nutrient solution once a week throughout the experiment, and supplied with distilled water once a week to prevent drying out. Simulated acid rain treatments started at the age of six weeks (from seed to plant stage).

Plants grown in both soil types showed severe leaf necrosis at pH 2,0 , generally resulting in reduced growth, with the base rich plants being less adversely affected than the acidic plants at this pH. Shoot fresh and dry mass, as well as root dry mass were significantly higher for the base rich soil, and significantly lower for the acidic soil. Root and shoot K- and SO_4^{-2} concentration were much higher than root and shoot Na- , Ca- , Mg- , Fe- , and Al concentrations for all pH levels studied. Shoot K- , Ca- and SO_4^{-2} concentrations were significantly higher than root K- , Ca- and SO_4^{-2} concentrations, respectively at pH 2,0 and 3,2. Acidic plants contained greater quantities of root and shoot Na , Mg , Fe and Al and lower quantities of Ca and SO_4^{-2}, compared to that of the base rich plants. These results suggest the accumulation of Fe and Al in- and the leaching of SO_4^{-2} from the acidic soil.

4.1 INTRODUCTION

Although acid rain, in many cases, may have no direct influence on the aboveground portion of a plant, acid solutions may alter properties of the soil that result in harm to the plant system (Chang and Alexander, 1983). Acid rain can affect vegetation indirectly by leaching of nutrients from the soil (Rathier and Frink, 1983). It not only acidifies the soil by depleting nutrients, but also causes the mobilization of Al and other metals which are toxic to the plants (Krug and Charles, 1983). Not all soils are equally capable of resisting acidification (Lau and Mainwaring, 1985). Wiklander(1979) suggested that soils with pH values under 5 and low in Ca content are more sensitive to acid precipitation than soils with pH values above 6 and higher Ca content. McFee(1980) recommended using cation exchange capacity as a criterion to assess soil sensitivity to acid deposition.

The type and amount of clay and humus determine the cation exchange capacity of a soil, which is a measure of its buffering capacity against changes in pH, and thus, the effects of acid precipitation. The first effects of acid additions are on the balance of cations on the cation exchange capacity unless the soil contains excess base such as calcium carbonate (McFee,1980). Soils with little clay and little humus have low cation exchange capacity, and thus little resistance to pH changes. When the soil contains moderate or high cation exchange capacity, the effects of acid inputs will be slow or even negligible (McFee,1980). Wiklander(1979) has pointed out that the efficiency of hydrogen ions in replacing metal cations is strongly dependent on soil properties, such as soil pH, and also dependent upon the accompanying ions in the acid precipitation.

The aim of this experiment was to investigate how tomato plants, grown in soils of different buffering capacity, would be affected by simulated acid rain treatment. Thus our hypothesis is that plants growing on acidic soils are much more susceptible to acid rain than those on a well buffered soil. The null hypothesis then is that there are no differences between the plants on the two soils exposed to similar simulated acid rain treatments.

4.2 MATERIALS AND METHOD

Lycopersicon esculentum var. Red Kaki seedlings were grown in two soil types viz base rich soil containing free lime from the Cape Flats Nature Reserve and acid soil from the margin of the Cape Flats, Eerste River. The seedlings were planted in 15cm pots and grown at a density of one plant per pot as used by Evans et al.(1981). Twenty plants per soil type were used. The plants were subjected to a two-facter randomized block experiment, under controlled conditions in a Fisons Growth Chamber, as used by Phillips et al.(1985), with temperature (20° C night and 27° C day), relative humidity (60% day and 70% night), light intensity (app 90 umol.$m^{-2}.s^{-1}$) and a photoperiod of sixteen hours (Evans et al.1981; Norby and Luxmoore, 1983).

The seedlings were treated with half strength Hoagland nutrient solution (Hewitt, 1966) throughout the experiment, once weekly to try to eliminate

4.3 RESULTS AND DISCUSSION

4.3.1 The effects of simulated acid rain on various growth parameters in *Lycopersicon esculentum* var. Red Kaki

Table 4.1 The effect of simulated acid rain on various growth parameters in *Lycopersicon esculentum* var. Red Kaki

Parameters	pH of simulated acid rain				L S D	
	2,0	3,2	4,4	5,6	0,05	0,01
Height of plant(cm)	32,0	40,3	41,7	42,5	3,34	4,51
No. of leaves	11,1	13,2	12,8	13,4	0,793	1,07
Fresh mass of shoots (g)	18,08	43,95	43,75	42,44	3,32	4,48
Dry mass of shoots (g)	1,43	3,33	3,07	3,12	0,37	0,51
Dry mass of roots (g)	0,042	0,276	0,196	0,201	0,156	0,21

According to the results in Table 4.1, plants treated with simulated acid rain of pH 2.0 showed significant reductions in the growth parameters studied. Similar reductions were also obtained by Lee *et al.*(1981), Evans *et al.*(1981), Raynal *et al.*(1982). The results further show no significant differences at pH levels 3,2; 4,4 and the control(5,6). This is contrary to the previous experiment with tomato plants and sulphur nutrition (Ch. 3), where a significant increase in all growth parameters at pH level 3,2 was observed.

However, these results are consistent with studies undertaken by Evans and Lewin (1981), Lee et al.(1981) and Keever and Jacobson (1983).

4.3.2 The effect of soil acidity on various growth parameters in Lycopersicon esculentum var. Red Kaki

Parameters	Soil type		LSD	
	Base rich soil	Acidic soil	0,05	0,01
No. of leaves	12,60	12,65	0,56	0,76
Height of plants (cm)	39,45	38,80	2,36	3,19
Fresh mass of shoots (g)	38,60	35,52	2,35	3,17
Dry mass of shoots (g)	2,94	2,53	0,27	0,36
Dry mass of roots (g)	0,489	0,357	0,11	0,15

The results in Table 4.2 show that parameters such as shoots fresh- and dry mass, as well as root dry mass were significantly higher for tomato plants grown in the base-rich soil than in the acidic soil. This increased growth of tomato plnats in the base rich soil, compared to that of the acidic soil could be the result of the presence of a high calcium content in the afore mentioned soil type.

4.3.3 The effect of simulated acid rain and soil acidity on the various growth parametrers in Lycopersicon esculentum var. Red Kaki

Table 4.3 The effect of simulated acid rain and soil types on various growth parameters in Lycopersicon esculentum var. Red Kaki

Parameters	Soil types	pH of simulated acid rain				LSD	
		2,0	3,2	4,4	5,6	0,05	0,01
No. of leaves	BRS	11,8	13,0	12,4	13,2	1,12	1,5
	AS	10,4	13,4	13,2	13,6		
Height of plants (cm)	BRS	37,6	39,0	39,8	41,4	4,7	6,4
	AS	26,4	41,6	43,6	43,6		
Fresh mass of shoots (g)	BRS	26,64	42,72	41,6	43,42	4,7	6,34
	AS	9,52	45,18	45,9	41,46		
Dry mass of shoots (g)	BRS	1,99	3,33	3,08	3,36	0,54	0,72
	AS	0,86	3,34	3,06	2,87		
Dry mass of roots (g)	BRS	0,32	0,65	0,5	0,49	0,22	0,30
	AS	0,08	0,55	0,4	0,40		

BRS = Base rich soil ; AS = Acidic soil.

The results (Table 4.3) show that at pH level 3,2 and 4,4 had no significant effect on the growth parameters studied, when compared to that of the control pH for both the tomato plants grown in the base-rich soil (in future these will be referred to as Base-rich Soil Plants- abbreviated to BSP) and the tomato plants grown in the acidic soil (in future these will be referred to as Acidic Soil Plants- abbreviated to ASP). These results suggest that the simulated acid rain treatments of pH levels 3,2; 4,4 and the control (pH 5,6) had little or no effect on the soil status (van Loon, 1984) and in turn plant growth (Lee et al.1981) per se. However, reduced growth can be observed at pH level 2,0 (Lee et al.1981; Evans et al.1981; Raynal et al.1982), compared with the other pH levels (Table 4.3), for all parameters studied in both soil types.

Furthermore the results clearly indicate significant higher values for the tomato plants grown in the base rich soil (BSP) and significantly lower values for the plants grown in the acidic soil (ASP) at pH level 2,0 for all parameters studied (Table 4.3). These results could be ascribed to the fact that the base rich soil, containing free lime ($CaCO_3$) is less sensitive to acid precipitation (Wiklander,1979), thus serving as a suitable buffer against acid rain treatment (van Loon,1984), allowing for nutrients to be taken up by the plant at this low level (2,0), whereas the acidic soil acted in the opposite manner (Wiklander,1979). The results further show no significant difference between the BSP and the ASP for simulated acid rain treatments of pH 3,2 and above for all parameters studied.

4.3.4 The effect of simulated acid rain on nutrient cations, heavy metals and sulphate in Lycopersicon esculentum var. Red Kaki

Foliar leaching is a well-documented phenomenon (Tukey et al.1958). Many substances including organic and inorganic minerals can be leached by water from foliage of many species (Morgan and Tukey, 1964). Wood and Borman (1975) suggested that the increasing acidity of natural precipitation may accelerate foliar leaching of nutrient cations of exposed plants. Foliar leaching of substances gives rise to reduced yield quality and nutritive value of economic plants (Tukey et al.1958). Foliar leaching may also lead to nutrient deficiency symptoms and require the addition of fertilizer. Mitterhuber et al.(1989) concluded that in relation to the total amount of mineral nutrients in trees, leaching is considered to be to small to be the primary cause of damage to trees stressed by acid rain, as has been suggested in the literature.

Table 4.4 The effect of simulated acid rain on nutrient cations, heavy metals and sulphate (g.kg^{-1}) in Lycopersicon esculentum var. Red Kaki

Conc.	pH of simulated acid rain				LSD	
	2,0	3,2	4,4	5,6	0,05	0,01
Root [Na]	5,07	5,43	5,84	3,45	1,84	2,48
Shoot [Na]	0,80	0,84	0,60	0,30	0,41	0,56
Root [K]	46,3	51,1	57,2	58,5	10,2	13,7
Shoot [K]	69,5	60,89	59,90	61,45	8,48	11,44
Root [Ca]	5,17	3,64	3,40	4,11	1,94	2,62
Shoot [Ca]	5,32	6.36	5,22	6,06	0,84	1,13
Root [Mg]	5,12	6,28	6,23	5,65	1,93	2,60
Shoot [Mg]	3,07	3,79	3,72	3,29	0,47	0,63
Root [Fe]	2,48	2,40	2,33	2,32	0,33	0,45
Shoot [Fe]	0,59	0,48	0,50	0,57	0,13	0,18
Root [Al]	5,30	5,07	5,85	5,29	0,97	1,30
Shoot [Al]	0,71	0,49	0,55	0,60	0,12	0,16
Root [SO_4^{-2}]	25,79	23,19	43,01	32,68	16,87	22,76
Shoot [SO_4^{-2}]	36,74	29,65	32,27	31,54	8,03	10,84

According to the results in Table 4.4, nutrient concentrations in roots and shoots varied significantly with simulated acid rain treatment. In general monovalent cations are more readily leached from plant material than divalent cations (Tukey,1970). The relatively high root and shoot K concentrations for all pH levels (Table 4.4), compared with the other nutrient cations may be due to the fact that K is one of the primary nutrients needed by crops (Mortvedt, 1983) and is therefore present in much higher concentrations. The relatively higher root- and shoot SO_4^{-2} concentrations for all pH levels can be ascribed to the supply of sulphur by the simulated acid rain (Maugh, 1979). The significantly lower root SO_4^{-2} concentrations at pH levels 2,0 and 3,2 could be due to increased leaching of sulphate from the soil when acidity increases (Abrahamsen et al.1976; Bjor and Teigen, 1980; Farrell et al.1980; Singh et al.1980; Stuanes, 1983).

The results (Table 4.4) also show that root Na-, Mg-, Fe- and Al concentrations are significantly higher than shoot Na-, Mg-, Fe- and Al concentrations, respectively for all pH levels, suggesting that these nutrients accumulated in the roots. Significantly higher concentrations of shoot K-, -Al- and -SO_4^{-2} were also observed in the roots, suggesting a relocation of these nutrients to the shoots.

Simulated acid rain of pH 2,0 and 3,2 caused a significant increase in root and shoot Na, compared to that of the control (pH 5,6). Shoot K and Mg were also significantly increased at pH 2,0 and pH 3,2 respectively, while root K showed significantly reduced values at pH 2,0 and 3,2 compared to the control. Shoot Al was significantly higher at pH 2,0 compared to pH levels 3,2; 4,4; and the control, while root Al showed no significant differences among the pH's tested. Root SO_4^{-2} was slightly higher at pH 2,0 compared to the control, while shoot SO_4^{-2} was slightly lower at pH 2,0 than that of the control, suggesting that relocation of sulphate to the shoots was rapid at pH

2,0, while movement of sulphate in the control plants was relatively slow. The rest of the cations, heavy metals and sulphate concentrations did not differ significantly among pH levels.

4.3.5 The effect of soil acidity on nutrient cations, heavy metals and sulphate in Lycopersicon esculentum var. Red Kaki.

It is now well documented that soil acidification is associated with the leaching of base cations such as Ca, Mg, K and Mn (Brown, 1985; Overrein et al.1980; Stuanes, 1983; Rorison, 1986; Foster, 1990) and the accumulation of potentialy toxic metal ions (Al and Fe), especially Al (Cronan, 1980; Mollitor and Raynal, 1982; Stuanes, 1983; van Loon, 1984; Lau and Mainwaring, 1985; Rorison, 1986; Ohno et al.1988). Simulated acid rain additions to soil cause increased sulphate concetrations which will lead to the leaching of this anion, taking with it cations to maintain electrical neutrality (Abrahamsen et al.1976; Tamm and Cowling, 1977; Bjor and Teigen, 1980; Farrell et al.1980; Sing et al.1980).

Table 4.5 The effect of soil acidity on nutrient cations, heavy metals and sulphate (g.kg^{-1}) in Lycopersicon esculentum var. Red Kaki

Conc.	Soil type		LSD	
	Base rich	Acidic	0,05	0,01
Root [Na]	3,02	6,87	1,30	1,75
Shoot [Na]	0,46	0,81	0,29	0,39
Root [K]	56,10	50,40	7,20	9,71
Shoot [K]	62,49	63,38	5,99	8,09
Root [Ca]	5,45	2,72	1,37	1,85
Shoot [Ca]	7,73	3,75	0,59	0,80
Root [Mg]	4,66	6,98	1,36	1,84
Shoot [Mg]	3,05	3,89	0,33	0,45
Root [Fe]	1,29	3,47	0,24	0,32
Shoot [Fe]	0,26	0,81	0,09	0,13
Root [Al]	3,37	7,39	0,68	0,92
Shoot [Al]	0,31	0,86	0,082	0,11
Root [SO4^{-2}]	39,38	22,95	11,93	16,09
Shoot [SO4$^{-2]}$	38,21	26,89	5,68	7,66

The results (Table 4.5) show that root and shoot Na-, Mg-, Al- and Fe concentrations were significantly higher in the ASP than in the BSP, while root and shoot Ca and SO4^{-2} concentrations were significantly higher in the BSP and significantly lower in the ASP. Root and shoot K concentrations did not differ much between ASP and BSP (Table 4.5).

These results suggest that leaching of cations such as Na, K and Mg was not significant, but accumulation of heavy metals such as Al and Fe was significant in the acidic soil. The latter findings were consistent with other studies (Cronan, 1980; Stuanes, 1983; van Loon,1984; Rorison, 1986; Ohno et al.1988).

The significantly higher shoot and root Ca concentrations in the base rich soil is a direct result of the soil being rich in free lime ($CaCO_3$). The uptake of Ca by the plant system, depends on the availability of Ca in the soil. Soils low in Ca have evolved lower requirements for, and lower tolerances of this element, compared with species from calcareous soils (Rorison, 1986).

The relatively higher SO_4^{-2} concentrations in the ASP, compared with that of the BSP, may be due to leaching of SO_4^{-2} with increased acidity (Stuanes, 1983). If this is true, it means that the base rich soil served as a suitable buffer.

4.3.6 The effect of simulated acid rain and soil acidity on nutrient cations, heavy metals and sulphate in Lycopersicon esculentum var. Red Kaki.

Table 4.6 The effect of simulated acid rain and soil acidity on nutrient cations, heavy metals and sulphate (g.kg^{-1}) in Lycopersicon esculentum var. Red Kaki

		pH of Simulated Acid Rain				LSD	
Conc	Soil type	2,0	3,2	4,4	5,6	0,05	0,01
Root [Na]	BRS	2,25	3,61	3,57	2,67	2,60	3,50
	AS	7,89	7,25	8,13	4,22		
Shoot [Na]	BRS	0,56	0,79	0,29	0,21	0,58	0,79
	AS	1,04	0,89	0,91	0,39		
Root [K]	BRS	57,7	52,2	59,3	55,3	14,4	19,4
	AS	34,9	50,0	55,0	61,8		
Shoot [K]	BRS	70,15	61,0	57,95	60,84	11,99	16,18
	AS	68,84	60,77	61,84	62,06		
Root [Ca]	BRS	6,11	4,88	4,87	5,91	2,75	3,71
	AS	4,23	2,40	1,93	2,31		
Shoot [Ca]	BRS	7,23	8,70	7,03	7,97	1,19	1,60
	AS	3,41	4,02	3,42	4,14		
Root [Mg]	BRS	3,51	3,92	5,97	5,25	2,73	3,68
	AS	6,72	8,63	6,50	6,06		
Shoot [Mg]	BRS	2,98	3,03	3,10	3,08	0,66	0,89
	AS	3,16	4,55	4,34	3,49		
Root [Fe]	BRS	1,37	1,31	1,21	1,26	0,47	0,63
	AS	3,58	3,48	3,45	3,38		
Shoot [Fe]	BRS	0,23	0,18	0,29	0,34	0,19	0,25
	AS	0,96	0,79	0,72	0,79		
Root [Al]	BRS	3,24	3,00	3,63	3,60	1,37	1,84
	AS	7,36	7,13	8,08	6,98		
Shoot [Al]	BRS	0,30	0,26	0,32	0,36	0,16	0,22
	AS	1,11	0,73	0,77	0,84		
Root [SO_4^{-2}]	BRS	30,46	26,64	57,49	42,95	23,86	32,19
	AS	21,13	19,73	28,53	22,42		
Shoot [SO_4^{-2}]	BRS	42,16	32,90	39,87	37,90	11,36	15,32
	AS	31,32	26,4	24,66	25,19		

BRS = Base rich soil ; AS = Acidic soil.

The results in Table 4.6 show the effect of both simulated acid rain and soil acidity on the nutrient status in tomato plants grown in a base rich and an acidic soil. In the case of the tomato plants grown in a base rich soil, shoot and root Na-, -K-, -Ca-, -Mg-, -Fe- and Al concentrations did not differ significantly for all pH levels studied. These findings suggest that the simulated acid rain treatments had little or no effect on the uptake of the afore-mentioned nutrients in a base-rich soil with free lime, indicating that the latter soil served as a very good buffer (Wiklander,1979; van Loon, 1984). Root and shoot sulphate concentrations varied with simulated acid rain treatments. In the case of the base-rich soil (Table 4.6), with significantly higher root sulphate concentrations at pH level 4,4 and significantly lower shoot sulphate cocentrations at pH level 3,2.

As for acidic soil, results varied significantly with simulated acid rain treatment (Table 4.6). Root and shoot Na concentrations were significantly higher at pH 2,0, compared with the control, suggesting that Na was more readily available for plant uptake with increased soil acidity, rather than it being leached. Shoot K-, root Ca-, shoot Fe-, shoot Al- and shoot SO_4^{-2} concentrations were also marginally higher at pH level 2,0, compared with the control. On the other hand root K was the only nutrient showing significant reductions at pH level 2,0, compared with the control. This result may be attributed to a relocation of K from the roots to the shoots, rather than it being leached, as the K concentration of the shoots was significantly higher and that of the roots significantly lower in the acidic sand (Table 4.6).

Shoot and root Na were significantly higher in the ASP than in the BSP for all pH levels studied. Root K was significantly higher in the BSP than in the ASP at pH 2,0, while no significant differences could be observed for the other pH levels. Shoot K showed no significant difference between tomato plants grown in the two soil types at all pH levels studied. Root Ca was significantly higher (at pH 4,4 and 5,6) and higher (at pH 2,0 and 3,2) in the BSP than in ASP. Shoot Ca was significantly higher in the BSP than in the ASP for all pH levels studied. Root Mg was significantly higher in the ASP than in the BSP at pH levels 2,0 and 3,2, while shoot Mg was significantly higher in the ASP than in the BSP at pH 3,2, and did not differ significantly for the other pH levels studied (Table 4.6). Root and shoot Fe were significantly higher in the ASP than in the BSP for all pH levels of simulated acid rain. The pattern of results for root and shoot Fe was similar for root and shoot Al, suggesting that both Fe and Al were more readily absorbed by plants grown in an acidic soil than by plants grown in a base-rich soil. Root SO4-2 was higher at pH levels 2,0; 3,2 and 5,6 and significantly higher at pH 4,4 in the BSP than in the ASP, while shoot sulphate was higher at pH levels 2,0 and 3,2, and significantly higher at pH levels 4,4 and 5,6 in the BSP than in the ASP, suggesting that sulphate was more readily absorbed by the plants grown in the base-rich soil than by the plants grown in the acidic soil.

CONCLUSION

Lycopersicon esculentum var. Red Kaki, like other dicotyledenous plants such as Glycine max (Evans and Curry, 1979), Zinnia elegans Jacq. (Keever and Jacobsen, 1983), Phaseolus vulgaris L. cv. Contender (Hindawi et al.1980), and Pisum sativum L. (Ashenden and Bell, 1989) was adversely affected by simulated acid rain of pH as low as 2,0, while monocotyledenous plants, such as Triticum aestivum L. cv. (Arthur71, Abe and Oasis) (Johnston and Shriner, 1985), Zea mays L. cv. (B73, times) (Banwart et al.1990), Avena sativa L. cv. Ogle (Pell and Puente, 1987) and Bromus diandrus Roth. (Phillips et al.1985) were scarcely affected by levels of acidity of pH as low as 2,5, while others exhibited enhanced growth at pH levels as low as 2,3. L. esculentum was unaffected by pH levels 3,2 and above.

The tomato plants grown in the base-rich soil were less adversely affected by simulated acid rain treatments of pH 2,0 than those grown in the acidic soil. This "increased" growth response of tomato plants at pH level 2,0 in the base rich soil may be due to the presence of the free lime (Shortle and Smith, 1988) or the base-rich soil acting as a suitable buffer against acidity (van Loon, 1984). On the whole, plant yield of tomato plants grown in the base-rich soil, did not differ significantly from those grown in the acidic soil. The results also indicated no significant differences between the BSP and ASP at pH levels 3,2 and above, suggesting that the null hypothesis, stating that there are no differences between the plants on the two soils exposed to similar simulated acid rain treatments is favoured. Our hypothesis then, stating that plants growing on acidic soils are much more susceptible to acid rain than those on a well buffered soil, does not hold.

The results have shown that nutrient cations such as Na, to a lesser degree Mg and heavy metals such as Fe and Al accumulated in the roots of tomato plants. Furthermore the root and shoot concentrations of these elements were significantly higher for the tomato plants grown in acidic soil, compared with those grown in the base-rich soil. This higher Fe and Al concentrations in the plants grown in the acidic soil may be another reason for reduced yield of these plants (Stuanes, 1983; van Loon, 1984; Rorison, 1986; Ohno et al.1988). However it is clear from the growth results that Fe and Al concentrations did not reach toxic levels. Al also did not impair the uptake of Ca as in the case of Clarkson and Sanderson(1971), Johnson and Jackson(1964), as the significant reduction in Ca levels in the acidic soil may be the result of the absence of free lime, compared to free lime being present in abundance in the base-rich soil (Table 4.5).

Ca in the form of $CaCO_3$ in the base-rich soil appears to suppress deleterious effects of Al because of its abundance. Calcium, available as free lime along with the input of sulphate from the simulated acid rain treatments may enhance productivity (van Loon, 1984) at pH levels above 3,2. This phenomenon was evident for tomato plants grown in the base-rich soil, compared to tomato plants grown in acidic soil with a much lower Ca content.

From these results it is now clear that tomato plants grown in a base-rich soil are less sensitive to simulated acid rain at pH level 2,0, compared with tomato plants grown in acid soil at the latter pH level. The growth pattern showed little difference between the tomatoes grown in the two soils with simulated acid rain treatment of pH 3,2 and above. The nutrient status in the roots and shoots of the tomato plants grown in the base-rich soil (BSP) and that of the tomato plants grown in the acidic soil (ASP), show that the base-rich soil acted as a suitable buffer against simulated acid rain treatment.

REFERENCES

ABRAHAMSEN, G., BJOR, K., HORNTVEDT, R. & TVEIT, B.1976. Effects of acid precipitation on forest and freshwater ecosystems in Norway- SNSF- project, Norway, FR 6/76: 36-63.

ASHENDEN, T.W. & BELL, S.A.1989. Growth response of three legume species exposed to simulated acid rain. Environ. Pollut. 62(1): 21-30.

BANWART, W.L., ZIEGLER, E.L. & PORTER, P.M.1990. Field corn response to acid rain-drought stress interaction. J. Environ. Qual. 19(2): 321-324.

BJOR, K. & TEIGEN, O.1980. Effects of acid precipitation on soil and forest. (6). Lysimeter experiment in green house. Proc. Int. Conf. Ecol. Impact acid precip.- SNSF project: 200-201.

BROWN, K.A.1985. Acid deposition: Effects of Sulphuric acid at pH 3 on chemical and biochemical properties of bracken litter. Soil Biol. Biochem. 17(1): 31-38.

CHANG, F.H. & ALEXANDER, M.1983. Effects of simulated acid precipitation on growth and nodulation of leguminous plants. Bull. Environ. Contam. Toxicol. 30: 379-387.

CRONAN, C.S.1980. Solution chemistry of a New Hampshire subalpine ecosystem: a biogeochemical analysis. Oikos. 34: 272-281.

CLARKSON, D.T. & SANDERSON, J.1971. Inhibition of uptake and long distance transport of calcium and aluminum and other polyvalent cations. J. Exp. Bot. 22: 837-851.

EVANS, L.S. & CURRY, T.M.1979. Differential responses of plant foliage to simulated acid rain. Am. J. Bot. 66: 953-962.

EVANS, L.S. & LEWIN, K.F.1981. Effects of Simulated acid rain on growth and yield of soybeans and pinto beans. Ann. Arbor Science, Ann. Arbor.: 299-308.

EVANS, L.S., LEWIN, K.F., CONWAY, C.A. & PATTI, M.J.1981. Seed yields (quantity and quality) of field-grown soybeans exposed to simulated acid rain. New Phytol. 96: 207-213.

EVANS, L.S., CURRY, T.M. & LEWIN, K.F.1982. Response of leaves of Phaseolus vulgaris L. to simulated acid rain. New Phytol. 88: 403-420.

FARREL,E.P., NILSSON, I., TAMM, C.O. AND WIKLANDER, G.1980. Effects of Artificial acidification with sulphuric acid on soil chemistry in a Scots pine forest. Proc. Int. Conf. Ecol. Impact acid precip.- SNSF- project: 186-187.

FOSTER, P.M.1990. The oxidation of sulphur dioxide in power plant plumes. Atmos. Environ.3(2): 157-175.

FERENBAUGH, R.W.1976. Effect of simulated acid rain on Phaseolus vulgaris L. Am. J. Bot. 63: 283-288.

HEWITT, E.J.1966. Sand and water culture methods used in the study of plant nutrition, revised second ed. Commonwealth Bureau of Horticulture and Plantation Crops, East Malling Tech. Communication No. 22.

HUETTE, D.O. & MENARY, R.C.1980. Effect of aluminum on growth and nutrient uptake of cabbage, lettuce, and kikuyu grass in nutrient solution. Aust. J. Agric. Res. 31: 749-761.

HINDAWI, I.J., REA, J.A. & GRIFFIS, W.C.1980. Response of bushbean exposed to acid mist. Am. J. Bot. 67: 168-172.

IRVING, P.M., MALEY, J.A. & GRADERT, C.M.1981. Rainfall acidity interlaboratory study- Rains. In: Radiological and Environmental Research Division Annual Report, January- December, 1980. ANL- 80- 115: 1-4, Argonne National Laboratory, Argonne, Illinois.

JACKSON, M.L.1962. Soil Chemical Analysis. Constable, London.

JOHNSTON, J.W., SHRINER, D.S., KLANER, C.I. & LODGE, D.M.1982. Effect of rain pH on senescence, growth, and yield of bushbean. Environ. Exp. Bot. 22: 329-337.

JOHNSTON, J.W. & SHRINER, D.S.1985. Response of three wheat Triticum aestivum cultivars to simulated acid rain. Environ. Exp. Bot. 25(4): 349-354.

JOHNSON, R.E. & jACKSON, W.A.1964. Calcium uptake and transport in wheat seedlings affected by aluminum. Soil Sci. Soc. Am. Proc. 28: 381-386.

KEEVER, G.J. & JACOBSON, J.S.1983. Simulated Acid Rain Effects on Zinnia as influenced by Available Nutrients. J. Amer. Soc. Hort. Sci. 108(1): 80-83.

KEEVER, G.J. & JACOBSON, J.S.1983. The response of Glycine max. (L.) Merrill to simulated acid rain. I. Environmental and morphological influences on the foliar leaching of ^{86}Rb. Field Crops Res. 6: 241-250.

KRUG, E.C. & FRINK, C.R.1983. Acid rain on acid soils: A new perspective.

Science 221: 520-525.

LANCE, J.C. & PEARSON, R.W.1969. Effect of low concentrations of aluminum on growth and water and nutrient uptake by cotton roots. Soil Sci. Soc. Am. Proc. 33: 95-98.

LAU, W.M. & MAINWARING, S.J.1985. The determination of soil sensitivity to acid deposition. Water, Air, and Soil Pollution 25: 451-464.

LEE, J.J., NEELY,G.E., PERRIGAN, S.C. & GROTHAUS, L.S.1981. Effects of simulated acid rain on yield, growth and foliar injury of several crops. Environ. Exp. Bot. 21: 171-185.

MAUGH, T.H.1979. SO_2 pollution may be good for plants. Science 205: 383.

McFEE, W.W.1980. Sensitivity of Soil Regions to Long Term Acid Precipitation. Ann. Arbor Sci.: 495-506.

MITTERHUBER, E., PFANZ, H. & KAISER, W.M.1989. Leaching of solutes by the action of acid rain. A comparison of efflux from twigs and single needles of Picea-abies L. Karst. Plant Cell Environ. 12(1): 93-100.

MOLLITOR, A.V. & RAYNAL, D.J.1982. Acid precipitation and ionic measurements in Adirondack forest soil. Soil Sci. Soc. Am. J. 46: 137-141.

MORTVEDT, J.J.1983. Impacts of acid deposition on micronutrients cycling in agro-ecosystems. Environ. Exp. Bot. 23(3): 243-249.

NORBY, R.J. and LUXMOORE, R.J.1983. Growth analysis of soybean exposed to simulated acid rain and gaseous air pollutants. New Phytol. 95: 277-287.

OHNO, T., SUCOFF, E.I., ERICH, M.S., BLOOM, P.R., BUSHENA, C.A. & DIXO, N.R.K.1988. Growth and nutrient content of Red spruce seedlings in soil amended with Aluminum. J. Environ. Qual. 17(4): 666-672.

OVERREIN, L.N., SEIP, H.M. & TOLLAN, A.1980. Acid precipitation-effects on forest and fish. Final report of the SNSF- project 1972-1980. SNSF-project.

PHILLIPS, G.M., RAITT, L.M. & AALBERS, J.1985. Effect of simulated acid rain and sulphur nutrition on growth, sulphate and cation content of Bromus diandrus Roth. S. Afr. J. Plant Soil 2(2): 98-100.

PELL, E.J. & PUENTE, M.1987. Impact of simulated acid rain on yield of a field-grown oat crop. Environ. Exp. Bot. 27(4): 403-408.

RORISON, I.H.1986. The response of plants to acid soils. Experentia 42: 357-361.

RAYNAL, D.J., ROMAN, J.R. & EICHENLAUB, W.M.1982. Response of tree seedlings to acid precipitation. ii. Effect of simulated acidified canopy throughfall on sugar maple seedling growth. Environ. Exp. Bot. 22: 385-392.

SINGH, B.R., ABRAHAMSEN, G. & STUANES, A.1980. Effects of simulated acid rain on sulphate movement in acid forest soils. Soil Sci. Soc. Am. J. 44: 75-80.

STUANES, A.O.1983. Possible indirect long-term effects of acid precipitation on forest growth. Aquilo Ser. Bot. 19: 50-63.

SHORTLE, W.C. & SMITH, K.T.1988. Aluminum- Induced Calcium

Deficiency Syndrome in Declining Red Spruce. Science 240: 1017-1018.

TAMM, C.O. & COWLING, E.B.1977. Acid precipitation and forest vegetation. Water Soil Air Pollut. 7: 503-512.

TUKEY, H.B., Jr., TUKEY, H.B. & WITTWER, S.H.1958. Loss of nutrients by foliar leaching as determined by radioisotopes. Proceedings of American Society of Horticultural Science, 71: 496-506.

VAN WYK, D.B.1985. The influence of catchment management on erosion and subsequent sediment and nutrient in South African mountain streams, Jonkershoek Forestry Research Centre Report J13/85, South African Forestry Research Institute, Stellenbosch.

VAN LOON, G.W.1984. Acid rain and soil. Can. J. Physiol. Pharmacol. 62: 991-997.

WILLIAMS, D.J. & MOSER, B.G.1976. Airborne sea salt sedimentation measurements and a method of reproducing its effect on vegetation. Atmos. Environ. 10: 531-534.

WIKLANDER, L.1979. Ecological Effects of Acid Precipitation, workshop Proc. EPRI, EA-76-7-LD, SOA 77-403, England, 1-24.

WOOD, T. & BORMANN, F.H.1975. Increases in foliar leaching caused by acidification of an artificial mist. Ambio 4: 169-171.

CHAPTER 5

SUMMARY

The experimente were performed to investigate:

(a) the response of seed germination of nineteen selected species to various levels of acid solutions (pH-levels 5,6 ; 4,4 ; 3,2 and 2,0).

(b) the effect of simulated acid rain (pH-levels 5,6) on tomato plants differing in sulphur nutrition and on tomato plants grown in two soil types viz an acidic and a base-rich soil.

In the case of seed germination of the nineteen selected species the germination of Dimorphotheca pluvialis (L.) Moench (disc florets), Acacia saligna (scarified) and Otholobium fruticans (L.) Stirton. was below 35%, while the germination of the other species was much higher. Germination of species such as Erucastrum strigosum, Acacia saligna (unscarified), Brassica oleracea var. Glory of Enkhuizen, Geissorrhiza sp., Bromus diandrus Roth., Otholobium fruticans (L.) Stirton, and Brassica rapa var. rapa were significantly inhibited by simulated acid rain treatment of pH level 2,0, compared with that of the control (pH level 5,6), as was the case with Douglas-fir at this pH level (McColl and Johnson, 1983), and yellow birch and red maple at pH 3,0 (Raynal et al.1982). Conicosia pugioniformis (L.) N.E.Br. was the only species that had germination promoted by simulated acid rain treatment. Similar results were obtained by Raynal et al.(1982) with white pine. Germination of the rest of the selected species was not affected by simulated acid rain treatment, as was the case with sugar maple and hemlock (Raynal et al.1982).

Simulated acid rain resulted in significant reductions in the growth of sulphur deficient and control tomato plants grown at pH level 2,0. These reductions were accompanied by necrosis as in the case of Keever and Jacobson (1983); Rathier and Frink (1984) and Norby and Luxemoore (1983), and curling under of leaflets (Keever and Jacobson, 1983; Rathier and Frink, 1984). In contrast to this, growth of both sulphur deficient- and control tomato plants was significantly promoted by simulated acid rain treatment of pH 3,2, with sulphur deficient plants showing significantly higher values. These results suggest that simulated acid rain acted as a fertilizer by supplying the sulphur in the case of the sulphur deficient plants.

Simulated acid rain treatments gave rise to the accumulation of Ca, Na, Mg, and sulphate in the roots of tomato plants at pH level 2,0. This phenomenon was probably due to plant damage at this pH level. Nutrient cation- and sulphate concentrations did not differ significantly between the sulphur deficient- and the control plants, except for root K- and Ca concentrations which were significantly higher in the sulphur deficient plants.

The effect of simulated acid rain on tomato plants grown in the base-rich and the acidic soils generally also resulted in reduced growth at pH level 2,0 as in the previous experiment. However, growth results at pH level 3,2 did not differ from that of the control, as previously experienced with sulphur deficiency where significant promotion in plant growth was observed at this particular pH level. Tomato plants grown in the base-rich soil (referred to as Base-rich Soil Plants- abbreviated to BSP) showed increased growth, while those tomato plants grown in the acid soil (referred to as Acid Soil Plants- abbreviated to ASP) showed reduced growth. This increased plant growth in the base-rich soil may be due to the presence of free lime in the latter soil type. The free lime may have had a fertilizer effect (Shortle and Smith, 1988) or a buffering effect on tomato plants. Although both BSP and ASP showed significant reductions in plant growth at pH level 2,0, growth results were significantly higher for BSP and significantly lower for ASP at this pH level, suggesting that tomato plants grown in the base-rich soil are less sensitive to acid rain treatment (Wiklander, 1979). Results have shown no significant difference in plant growth for both BSP and ASP at pH levels 3,2; 4,4; and the control.

Plant nutrient concentrations varied significantly with simulated acid rain treatments. However, root and shoot K concentrations were relatively higher than that of the other cations for all pH levels studied. This relatively higher K concentrations may be due to K being one of the primary nutrients required by crops (Mortvedt, 1983) and is thus absorbed in greater concentrations. The relatively high $SO4^{-2}$ concentrations at all pH levels, compared with the other nutrients, can be ascribed to the presence of sulphur in the simulated acid rain solution (Maugh, 1979). The significantly lower root $SO4^{-2}$ concentrations at pH levels 2,0, compared with that of the control, may be due to leaching of the latter anion with increased acidity (Abrahamsen et al.1976; Stuanes, 1983).

The nutrient status of the BSP, compared to that of the ASP has shown that root and shoot Na, Mg, Fe, and Al concentrations were significantly higher in the ASP and significantly lower in the BSP, suggesting that these nutrients were more available in an acidic soil, than in a base-rich soil. On the other hand root and shoot Ca and SO_4^{-2} concentrations were significantly higher in the plants grown in the base-rich soil (BSP). The higher Ca concentrations in the BSP are due to the presence of $CaCO_3$ in the soil (Rorison, 1986), while the higher SO_4^{-2} concentrations may be due to its neutralizing effect with the free lime (Mortvedt, 1983), whereby it is retained, rather than leached. Plant nutrient concentrations for the combined effect of simulated acid rain and soil acidity showed very little or no difference among the pH levels studied, while the root and shoot nutrient status in tomato plants for the two soils are the same as pointed out earlier (Chapter 4).

Finally these findings conclude the investigation on the effects of simulated acid rain on seed germination and on the growth and mineral nutrition of tomato plants, subjected to the conditions outlined in each experiment.

OPSOMMING

Die eksperimente was uitgevoer om:

(a) die invloed van verskillende suuroplossings (pH -vlakke 5,6 ; 4,4 ; 3,2 ; 2,0) op die ontkieming van negentien geselekteerde spesies te ondersoek.

(b) die effek van gesimuleerde suurreën (pH vlakke 5,6; 4,4; 3,2 en 2,0) op tamatieplante wat verskil in swawel voeding asook op tamatieplante wat in twee verskillende grondtipes (nl. suurgrond en basis-verrykte grond) gekweek is, te ondersoek.

In die geval van die saadontkieming van die negentien geselekteerde spesies het Dimorphotheca pluvialis (L.) Moench (lintblomme), Acacia saligna (geskuur) en Otholobobium fruticans (L.) Stirton, ontkieming van laer as 35% getoon, terwyl ontkieming van die ander spesies veel hoër was. Ontkieming van spesies soos Erucastrum strigosum, Acacia saligna (ongeskuur), Brassica oleracea var. Glory van Enkhuizen, Geissorrhiza sp, Bromus diandrus Roth, Otholobium fruticans (L.) Stirton en Brassica rapa var. rapa was merkbaar geïnhibeer deur suur behandling by pH-vlak 2,0 in vergelyking met die kontrole (pH-vlak 5,6) soos in die geval van "Douglas-fir" by hierdie pH-vlak. Conicosia pugioniformis (L.) N.E.Br. was die enigste spesie wat bevorder was deur die suurreën behandeling. Soortgelyke resultate was bevind deur Raynal et al. (1982) met "White pine". Ontkieming van die res van die geselekteerde spesies was nie geaffekteer deur gesimuleerde suurreën behandeling, soos in die geval van "sugar maple" en "hemlock" (Raynal et al. 1982)

Gesimuleerde suurreën het tot gevolg 'n beduidende afname in die groei van swawel tekort- en kontrole tamatieplante by 'n pH-vlak van 2,0. Hierdie afnames gaan gepaard met nekrose soos in die geval van Keever en Jacobson (1983); Rathier en Frink (1984) en Norby en Luxemoore(1983) asook omkrul van blare (Keever en Jacobson, 1983; Rathier en Frink, 1984). In kontras hiermee was die groei van beide swawel tekort en kontrole tamatieplante noemenswaardig verhoog deur gesimuleerde suurreën behandeling by 'n pH-vlak van 3,2 , met swawel tekort plante wat hoër waardes vertoon. Hierdie resultate impliseer dat gesimuleerde suurreën as bemesting opgetree het deur die swawel te verskaf in die geval van plante wat 'n tekort vertoon het.

Gesimuleerde suurreën behandeling gee aanleiding tot die akkumulasie van Ca, Na, Mg en sulfate in die wortels van tamatieplante op pH-vlak 2,0. Hierdie verskynsel kan toegeskryf word aan die skade wat plante op hierdie pH-vlak opdoen. Voedingstof katioon en sulfaat konsentrasies het nie betekenisvol verskil by die swawel tekort en die kontrole plante nie behalwe vir die wortel K en Ca konsentrasies wat hoer was in die swawel tekort plante.

Die effek van gesimuleerde suurreën op tamatieplante neem toe in die basis-verrykte en suur gronde en het tot gevolg 'n afname in groei by pH-vlak 2,0 soos in die vorige eksperiment. Die groei resultate op pH-vlak 3,2 het egter nie verskil van die kontrole soos voorheen ondervind by swawel tekort waar 'n beduidende toename in plantgroei waargeneem word by hierdie pH-vlak. Tamatieplante gekweek in die basis-verrykte grond (verwys na as "Base-rich Soil Plants" - afgekort BSP) het 'n toename in groeie getoon, terwyl die tamatieplante wat in die suurgrond (verwys na as "Acid Soil Plants" - afgekort ASP) gekweek was, verminderde groei getoon het.

Hierdie toename in die groei van plante in die basis-verrykte grond mag weens die teenwoordigheid van vrye kalk in laasgenoemde grondsoort wees. Die vrye kalk mag 'n bemestingseffek (Shortle en Smith, 1988) of 'n buffereffek op tamatieplante het. Alhoewel BSP en ASP 'n beduidende vermindering in die groei van plante by pH-vlak 2,0 getoon het, was groei resultate beduidend hoër vir BSP en beduidend laer vir ASP op hierdie pH-vlak. Dit wil dus voorkom asof tamatieplante wat gekweek word in basis-verrykte grond minder sensitief vir suurreën behandeling is (Werklander, 1979). Resultate het geen beduidende verskil in die groei van plante in beide BSP en ASP by pH-vlakke 3,2 ; 4,4 en die kontrole getoon nie.

Plantvoeding konsentrasies het beduidend gevarieer met gesimuleerde suurreën behandeling. Die K-konsentrasie in wortels en stingels was egter relatief hoër as in die ander katione vir alle pH-vlakke wat bestudeer is. Hierdie relatief hoër K-konsentrasie mag wees as gevolg van die feit dat K een van die hoofvoedingstowwe is wat benodig word deur gewasse (Mortvedt, 1983) en word dus in groter konsentrasies geabsorbeer. Die relatief ho- SO_4^{-2} konsentrasies by alle pH-vlakke, in vergelyking met die ander voedingstowwe, kan toegeskryf word aan die teenwoordigheid van swawel in die gesimuleerde suurreën oplossing (Maugh, 1979). Die beduidende laer konsentrasies van SO_4^{-2} in wortels by pH-vlak 2,0 in vergelyking met die van die kontrole, mag wees as gevolg van die loging van laasgenoemde anione met verhoogde suurgehalte.

Die voedingstatus van die BSP in vergelyking met ASP het getoon dat wortel en stingel Na, Mg, Fe en Al konsentrasies merkbaar hoër in die ASP en merkbaar laer in die BSP was. Dit dui aan dat hierdie voedingstowwe meer beskikbaar was in die suurgrond as in basis-verrykte grond. Aan die ander kant was wortel en stingel Ca en SO_4^{-2} konsentrasies merkbaar hoër in plante wat in die basisverrykte grond gekweek is. Die hoër Ca-konsentrasies in die BSP is te danke aan die teenwoordigheid van $CaCO_3$ in die grond (Rorison, 1986), terwyl die hoër SO_4^{-2} konsentrasies miskien toe te skryf aan die neutraliserende effek daarvan met die vrye kalk (Mortvedt, 1983), waarvolgens dit behou eerder as geloog word.

Plantvoeding konsentrasies vir die gesamentlike effek van gesimuleerde suurreën en grondsuur het weinig of geen verskil getoon tussen die pH-vlakke wat bestudeer is nie, terwyl die wortel- en stingel voedingstatus in tamatieplante vir die twee grondsoorte dieselfde is soos vroeër aangetoon (Hoofstuk 4).

Bostaande bevindinge sluit die ondersoek na die uitwerkings van gesimuleerde suurreën op saadontkieming en op die groei en minerale voeding van tamatieplante, onderhewig aan die toestande wat by elke eksperiment aangetoon is, af.

REFERENCES

ABRAHAMSEN, G., BJOR, K., HORNTVEDT, R. & TVEIT, B. 1976. Effects of acid precipitation on forest and freshwater ecosystems in Norway- SNSF- project, Norway, FR 6/76: 36-63.

KEEVER, G.J. & JACOBSON, J.S. 1983. Simulated Acid Rain Effects on Zinnia as influenced by Available Nutrients. J. Amer. Soc. Hort. Sci. 108(1): 80-83.

MAUGH, T.H. 1979. SO_2 pollution may be good for plants. Science 205: 383.

McCOLL, J.G. & JOHNSON, R. 1983. Effects of simulated acid rain on germination and early growth of Douglas-fir and ponderosa pine. Plant and Soil. 74: 125-129.

MORTVEDT, J.J. 1983. Impacts of acid deposition on micronutrients cycling in agro-ecosystems. Environ. Exp. Bot. 23(3): 243-249.

NORBY, R.J. & LUXMOORE, R.J. 1983. Growth analysis of soybean exposed to simulated acid rain and gaseous air pollutants. New Phytol. 95: 277-287.

RATHIER, T.M. & FRINK, C.R. 1984. Simulated Acid Rain: Effects on leaf quality and yield of broadleaf tobacco. Water, Air and Soil Pollution. 22: 389-394.

RAYNAL, D.J., ROMAN, J.R. & EICHENLAUB, W.M. 1982. Response of tree seedlings to acid precipitation. II. Effect of simulated acidified canopy throughfall on sugar maple seedling growth. Environ. Exp. Bot. 22: 385-392.

RORISON, I.H. 1986. The response of plants to acid soils. Experentia. 42: 357-361.

SHORTLE, W.C. & SMITH, K.T. 1988. Aluminum- Induced Calcium Deficiency Syndrome in Declining Red Spruce. Science. 240: 1017-1018.

STUANES, A.O. 1983. Possible indirect long-term effects of acid precipitation on forest growth. Aquilo Ser. Bot. 19: 50-63.

TURNER, G.D., LAU, R.R. & YOUNG, D.R. 1988. Effect of acidity on germination and seedling growth of Paulownia tomentosa. Journal of Applied Ecology 25: 561-567.

WIKLANDER, L. 1979. Ecological Effects of Acid Precipitation. Workshop Proc. EPRI, EA-76-7-LD, SOA 77-403, England: 1-24.