CHAPTER 5

SEEDLING GROWTH WITH INCREASING CONCENTRATIONS OF MINE WATERS

In this chapter seedling growth with increasing concentrations of Ca, Mg and SO_4, and of increasing amounts of gypsum crystals in the growth medium is explored.

Firstly, the influence of increasing concentrations of three types of SO_4-dominated waters on the seedling growth in sand culture, is discussed. The three types of gradients were: where $CaSO_4$ was soluble; where $CaSO_4$ crystals were increasingly present; and where increasing SO_4 concentrations were gained with Na_2SO_4 in a simulated mine water saturated with $CaSO_4$. A gradient of simulated NaCl mine water was included for comparative purposes.

Secondly, the seedling growth on sand is compared to the growth on two acid soils with the same $CaSO_4$-dominated waters as in the above treatments.

The chapter is concluded with a general discussion of the results and a comprehensive conclusion.

5.1 INTRODUCTION

The piecewise linear response function of Maas & Hoffman (1977) for crop growth with increasing salinity has generally served as the guideline for salt tolerance of crops. The composition of the salinity has, however, mostly consisted of highly soluble salts such as NaCl, Na_2SO_4 and $MgSO_4$.

In a saline water with predominantly $CaSO_4$, the precipitation of $CaSO_4$ with increasing concentrations could affect growth responses differently from those instances when salinity is increased with highly soluble salts. It remains to be seen whether the above linear response function is applicable to this type of water. Some differences between these two saline compositions are the following :

- the precipitation of $CaSO_4$ can increase the osmotic potential
- the higher equivalents of SO_4 needed to gain a similar osmotic potential to that of NaCl could possibly bring nutrient imbalances into operation differing from those of NaCl
- Ca, Mg and SO_4 ions form strong ion pairs that are not reflected in the measurement of the electrical conductivity (EC), which may result in underestimating the effects of such waters on growth and yield (Papadopoulos, 1986).

"Effective osmotic potential"

Meiri (1994) stresses the need for salinity parameters that incorporate, inter alia, the temporal changes in root zone salinity during the growth of a crop. The replenishment of water on a daily basis - and sometimes twice daily - in these experiments, did not succeed in keeping the soil solution at a steady-state field capacity. The result was that the solutions in the vessels daily concentrated up to as much as 60 % of the original volumes of solutions used. The concentrations could thus generally be higher than those of the nutrient solutions and the osmotic potentials could be lower. The average osmotic potential in situ over the whole growth period is therefore referred to as the 'effective osmotic potential' (see 3.4). This could be lower or higher than that in the original treatment solutions, depending on the daily withdrawal of water by evapotranspiration and the precipitation of $CaSO_4$ respectively.

This chapter reports on sand culture experiments conducted in a growth chamber which investigated the seedling growth responses to increasing salt concentrations of three types of simulated $CaSO_4$ mine waters (Table 3.2). A $Na/Cl/SO_4$ simulated NaCl-dominated mine water was also included for comparative purposes (Table 3.3).

As the precipitation of $CaSO_4$, and hence also the osmotic potential of a soil solution, may be influenced by soil crystallizing nuclei (Papadopoulos, 1986), an additional experiment was conducted to compare the seedling growth of one crop - maize cv. SNK 2340 - on quartz sand with the seedling growth on two acid soils using the same method and treatments as for the above sand culture experiments.

5.2 SAND CULTURE EXPERIMENTS

Seedling growth response to increasing concentrations of simulated mine waters was investigated in a sand culture experiment in growth chambers with controlled environmental conditions. The annual crops included seven subtropical and six temperate species; lucerne was the only perennial evaluated in this investigation. Seeds were planted in washed quartz sand in 250 ml polystyrene vessels, allowing free drainage of treatment solutions. The method is discussed in Chapter 3 (3.2.2.2A).

The crop cultivars selected for this investigation were:

Annual subtropical	maize hybrids SNK 2340 and CRN 4403, sorghum hybrid PAN 888, pearl millet cv. SA Standard sunflower cv. PAN 43 soybean cv. Ibis cowpea cv. Dr Saunders dry bean cv's PAN 122 and 127
Annual temperate	wheat cv. Inia rye cv. SSR 1 triticale cv.'s Rex and Cloc 1 oats cv. Overberg barley cv. Stirling

annual ryegrass cv.'s Dargle and Midmar

Perennial temperate lucerne cv. PAN 4860.

The simulated mine waters investigated were:

1. Simulated Ca/Mg/SO_4 mine water (Kleinkopje, mine C 3/95) at
    a. soluble concentrations (treatments 2 to 5 or 6) (Table 3.2), and
    b. with increasing undissolved $CaSO_4$ crystals in suspension (treatments 6 or 7 to 10) (Table 3.2);

2. Increasing SO_4 concentrations gained with Na_2SO_4 in a simulated mine water (mine C 3/95) saturated with $CaSO_4$ (treatments 11 to 14) (Table 3.2);

3. Simulated NaCl-dominated mine water (New Denmark, mine B 3/95) (Table 3.3).

5.2.1 RESULTS AND DISCUSSIONS

The relative seedling growth on gradients of these four groups of simulated mine waters was plotted against the sum of anions as a parameter representing the osmotic potential (Papadopoulos, 1986) (3.4). The results are presented in tabulated form in APPENDIX C. Although responses were not always significant and differed in intensity, the seedling growth curves of the different crops generally followed similar patterns with each of the above mentioned types of water.

5.2.1.1 Simulated $CaSO_4$-dominated mine water (Kleinkopje, mine C 3/95)

With increasing $CaSO_4$ gradients the seedling growth of most of the crops followed a similar, irregular three-piece or four-piece growth curve to a greater or lesser extent. There was an initial gradual decrease, increase or no effect from the control to *ca* 2000 mg L^{-1} SO_4, followed by a sharper decrease to 2300 or 2500 mg L^{-1} SO_4 (more or less where saturation with $CaSO_4$ was expected). Then an unexpected tendency to *increased* growth followed where gypsum crystals were increasingly present, from 3000 to 5000 'mg L^{-1}' SO_4 (treatments 7 to 9) ('mg L^{-1} ' includes the undissolved gypsum - see 3.4), and a decrease at 5000 or 6000 'mg L^{-1}' SO_4 (treatment 9 or 10) where the ratio of Mg to Ca in solution was >1 (Table 3.2) (Figures 5.1 to 5.4).

A. **Soluble $CaSO_4$ gradients** (1500 to 2300 or 2500 mg L^{-1} SO_4)(Treatments 2 to 5 or 6, Table 3.2)

Where $CaSO_4$ was totally soluble in the treatment solutions, the seedling growth generally decreased in a linear manner with increasing concentrations, above a threshold value. Linear regression for decreases below 100 % in this part of the curve was significant for maize SNK 2340, sorghum, pearl millet, dry bean, wheat, rye, triticale cv. Cloc1, barley, oats and lucerne.

Up to *ca* 2000 mg L^{-1} SO_4 the effects were very gradual and generally not significantly different from the control. At 1500 mgl L^{-1} SO_4 maize SNK 2340, sorghum, pearl millet and lucerne already showed decreases in seedling growth, while wheat, triticale and oats were not affected and the seedling growth of maize CRN 4403, dry bean, cowpea, rye, barley, ryegrass Dargle and sunflower was increased at this SO_4 concentration (Figures 5.1 to 5.4). These groupings may be an early indication of the tolerance of these crops.

From 2150 to *ca* 2500 mg L^{-1} SO_4 (EC 300 to 400 mS m^{-1}) there were sharper decreases, with the seedling growth generally reaching a minimum in this concentration range. These decreases were significantly different from the controls for maize SNK 2340, sorghum, pearl millet, lucerne and oats, but not for soybean, cowpea and dry bean, or for the annual temperates, wheat, rye, triticale and barley (Figures 5.1 to 5.3). In contrast to the above mentioned crops the seedling growth of both ryegrass cultivars *increased* significantly in this part of the growth curve (Figure 5.4).

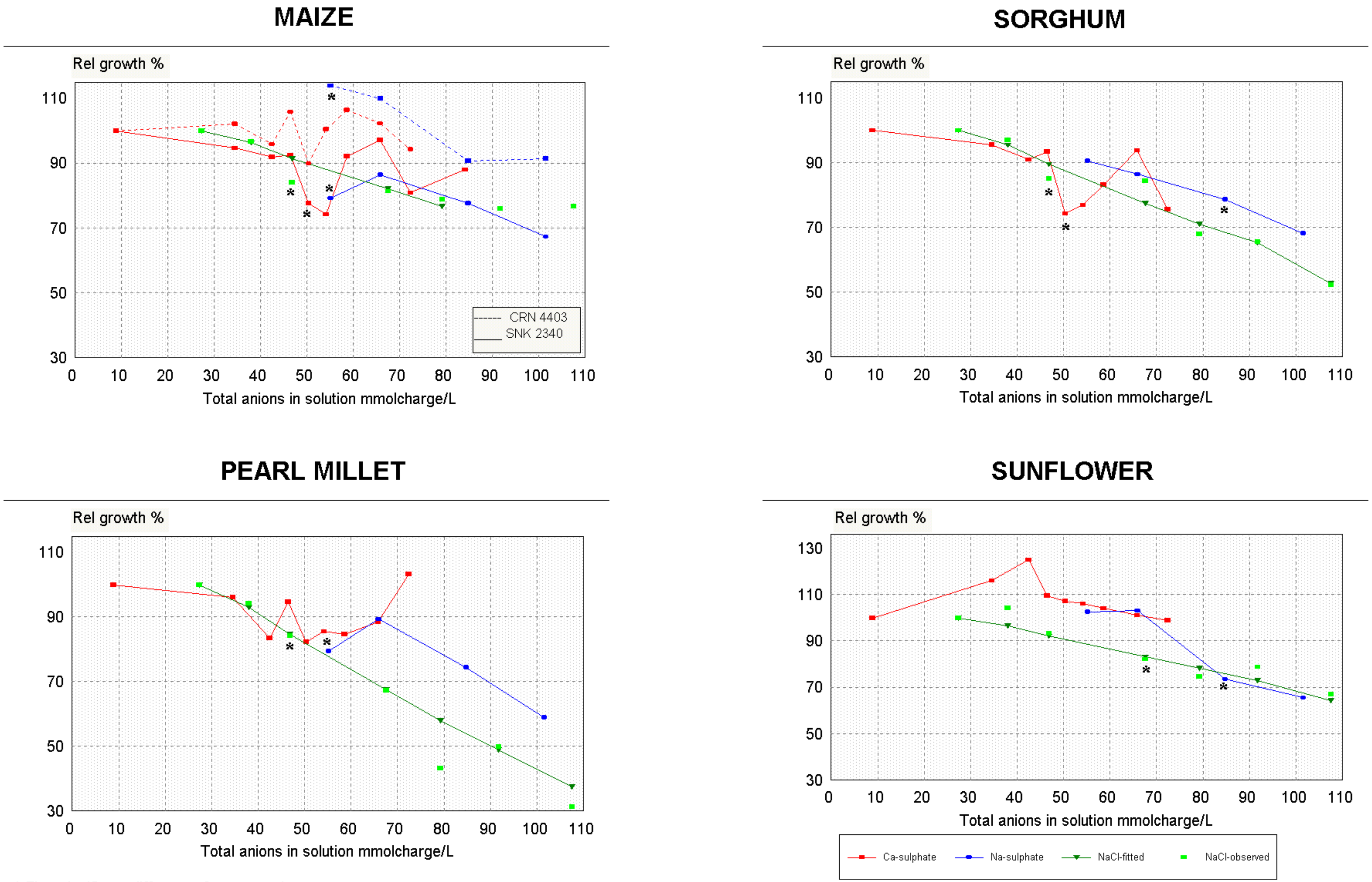
Maize, sorghum, **pearl millet** and **lucerne** responded in a similar way, the decreases becoming significant at *ca* 2300 mg L^{-1} SO_4 with the exception of pearl millet. Maize cv. SNK 2340 responded with a lower absolute and relative seedling growth than that of cv. CRN 4403, and was therefore more sensitive to increasing $CaSO_4$ concentrations (Figures 5.1 and 5.2) (Tables 5.1, maize; 5.3, sorghum; 5.5, pearl millet and 5.27 for lucerne).

The seedling growth of the subtropical legumes **soybean**, **cowpea** and **dry bean** followed a similar pattern to the subtropical cereals, but the growth was influenced to a lesser extent. The minimum growth was again in the vicinity of 2150 to 2500 mg L^{-1} SO_4 (treatments 4 to 6) (EC 349 to 386 mS m^{-1}), but was not significantly less than the seedling growth of the control (Figure 5.2) (Tables 5.7, soybean; 5.9, cowpea and 5.11 for dry bean).

The seedling growth of the annual temperate cereals **wheat**, **rye**, **triticale**, **barley** and **oats** also decreased with increasing concentrations but not as sharply as that of the subtropical annuals (Figures 5.3 and 5.4). These decreases were not significant with the exception of **oats** at 2500 mg L^{-1} SO_4 (EC 349 mS m^{-1}) (Tables 5.15, wheat; 5.17, rye; 5.19, triticale; 5.21, barley and 5.23 for oats)[1] .

In contrast to the above crops, both **ryegrass** cultivars showed an almost inverse response to the $CaSO_4$ gradient compared to the other temperate annuals. There was a dramatic and significant increase of 69 % in seedling growth at 3000 'mg L^{-1}' SO_4 for Dargle and 31 % at 4000 'mg L^{-1}' SO_4 for Midmar (Figure 5.4)(Table 5.25)[1].

[1] A higher ratio of NO_3 to NH_4 (4:1) was used for the temperate crops; if a 2:1 ratio had been used as in the case of the subtropical crops, the absolute tolerance would possibly have been greater (see wheat in the discussion).



MAIZE

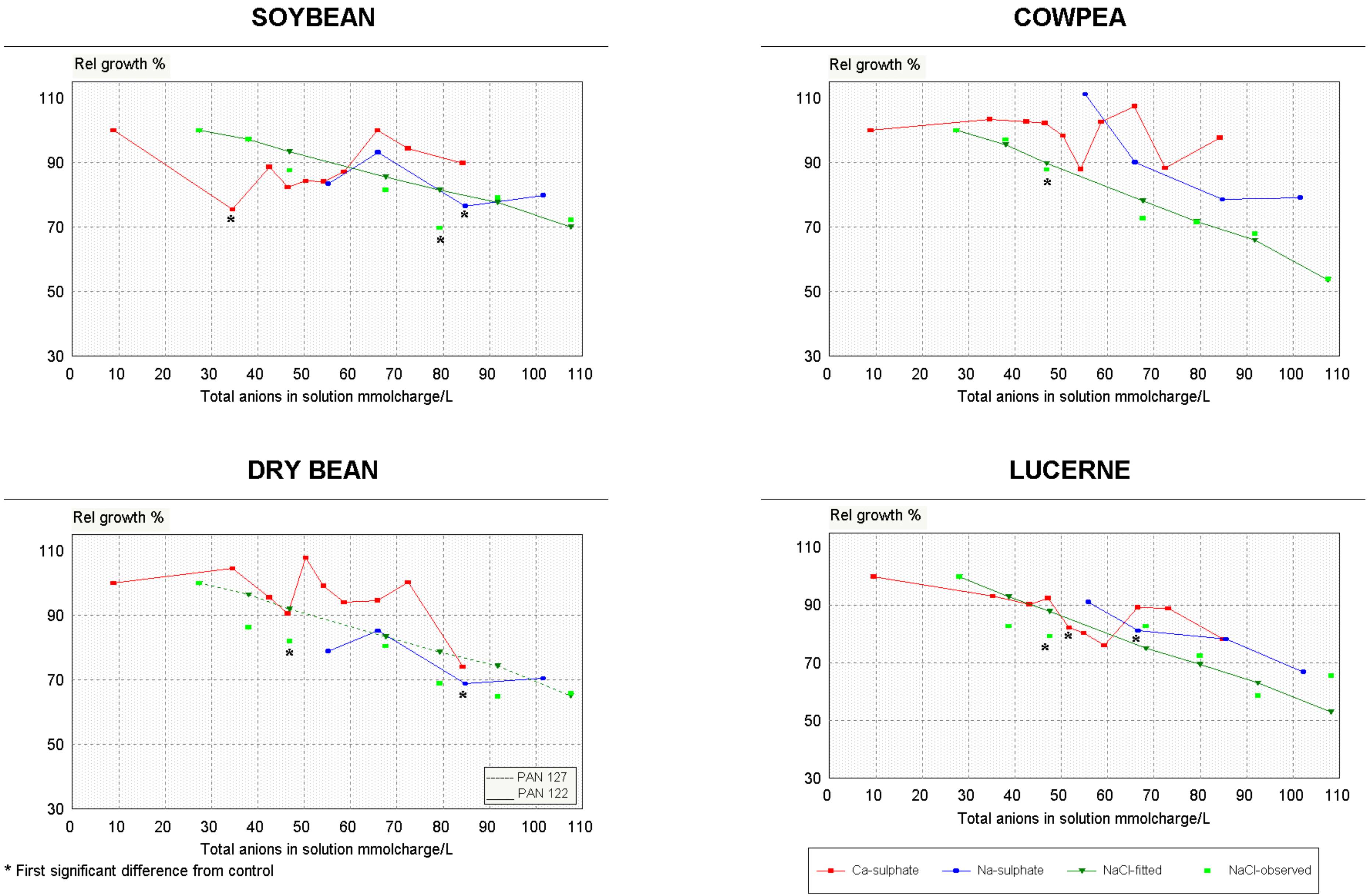
SORGHUM

PEARL MILLET

SUNFLOWER

* First significant difference from control

FIGURE 5.1 The influence of gradients of simulated mine waters on the seedling growth of maize SNK 2340 and CRN 4403, sorghum PAN 888, pearl millet SA Standard and sunflower SNK 43.



SOYBEAN

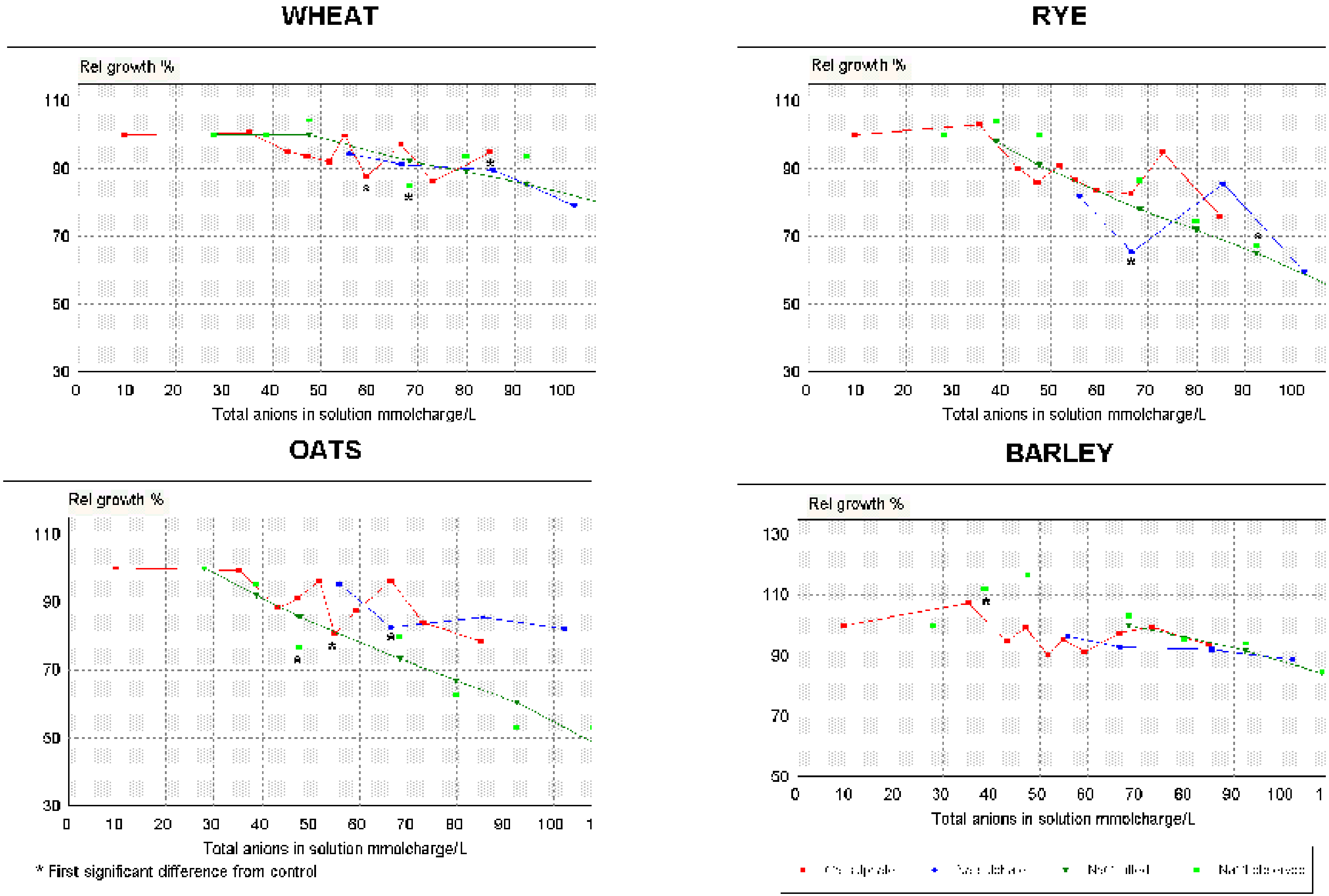
COWPEA

DRY BEAN

LUCERNE

* First significant difference from control

FIGURE 5.2 **The influence of gradients of simulated mine waters on the seedling growth of soybean Ibis, cowpea Dr. Saunders, dry bean PAN 122 and 127 and lucerne PAN 4860.**



WHEAT

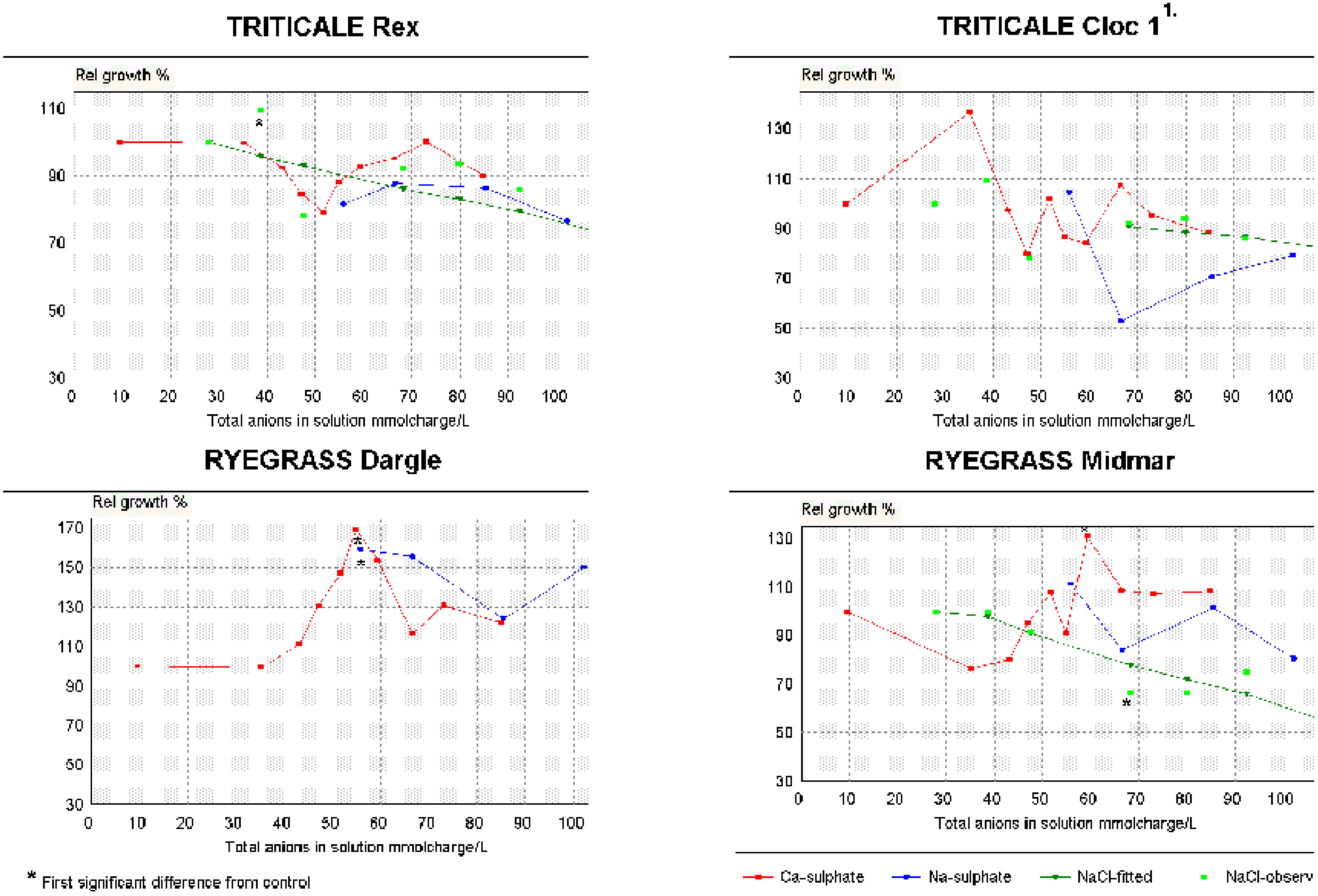
RYE

OATS

BARLEY

* First significant difference from control

FIGURE 5.3 **The influence of gradients of simulated mine waters on the seedling growth of wheat Inia, rye SSR1, oats Overberg and barley Stirling**



* First significant difference from control

1 c.v. was high 36,8%

FIGURE 5.4 The influence of gradients of simulated mine waters on the seedling growth of triticale Rex and Cloc 1 and annual ryegrass Dargle and Midmar

Sunflower, a dryland crop, responded with increased seedling growth to all these $CaSO_4$ treatments, which could be due to its high tolerance to osmotic potential decreases (Chimenti & Hall, 1993, 1994) and a possible nutrient effect by increased Ca, Mg and S in comparison to the one third strength Hoagland in the control (Figure 5.1) (Table 5.13).

Cultivar differences were evident in the growth curves of the crops where two cultivars were evaluated, that is between the two maize (Figure 5.1), triticale and ryegrass cultivars (Figure 5.4)[1].

Discussion

Where $CaSO_4$ was soluble, with increasing concentrations of Ca, Mg and SO_4, seedling growth generally followed the expected linear decrease above a threshold value as expounded by Maas and Hoffman (1977).

Although the solutions in the vessels were regularly replenished in an effort to maintain field capacity and concentrations, this was not successful. Daily mass decreases of 17 to 40 % were recorded. The actual salinities in the root growth media over the two weeks growth period were therefore probably higher than those of the treatment solutions applied.

It was expected that when the growth medium reached the saturation point of $CaSO_4$, the increase of salinity would be slower (and thus decreases of seedling growth less) in comparison to the stage before saturation. Generally, however, such a second stage was not clearly evident in these curves. This could probably be explained by a too slow rate of precipitation of $CaSO_4$ which could probably be due to the short time intervals and the absence of crystallizing nuclei in the washed quartz sand.

It is suggested that the responses of the different crops were probably connected to the major mechanisms by which NaCl salinity affects seedling or general growth of a specific crop, and to the sensitivity of the particular cultivar used. In **maize** (Cramer, 1994), **sorghum** (Shannon, 1997)

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[1] Statistical comparison was not possible with maize as the two cultivars were not evaluated in the same experiment; and it was not viable with the other two crops as in each case one of the cultivars showed high variation.

and **pearl millet** (Ashraf & Idrees, 1995) it is mainly the decreased osmotic potential that suppresses growth generally, and seedling growth in the case of **lucerne** (Ashraf & O'Leary, 1994). With **soybean** (Abel & McKenzie, 1964; Parker, Gascho & Gaines, 1983), **cowpea** (Keating, 1986), **wheat** (Gorham et al., 1986; Maas & Poss, 1989), **rye** (Francois et al., 1989) and **triticale** (Francois et al., 1988) an ionic effect of Cl is the main adverse mechanism, with decreased osmotic potential exerting a lesser influence (Shannon, 1997) (see Chapter 4).

The sensitivities of **oats** (Maas & Grieve, unpublished data, 1984 in: Grattan & Grieve, 1994) and **barley** (Shannon, 1997) are mainly connected to the presence of Na and/or Cl, and to the degree in which adaptative mechanisms such as osmoregulation are present in a cultivar (see Chapter 4 p.78).

These respective mechanisms together with the low concentration of Na and Cl explain the greater effect of these treatments on the seedling growth of maize, sorghum, pearl millet and lucerne in contrast to the crops where the suppression of growth is by Cl and other ionic effects.

The main mechanism for the salt tolerance of **annual ryegrass** has been found to be an ability for osmoregulation, which is indirectly enhanced by an increase of the cation content of the growth medium (Sagi et al,1997) (see Chapter 4 p.76). The increased seedling growth could thus be explained by the increased Ca and Mg contents of these treatments. Furthermore, as these two cultivars were probably bred for a good yield on acid soils, which usually has a fairly low cation content due to leaching, it may grow even better in the presence of increased cations. In **dry bean** and **sunflower** positive nutrient effects were also possibly operative as the seedling growth increased with some of these Ca, Mg and SO_4 increases compared to the control.

With Na and Cl being absent in these treatments it is suggested that the degree in which seedling growth decreased with increasing concentrations of $CaSO_4$ is probably an indication of its sensitivity to decreasing osmotic potential. This is undergirded by the observation that the crops most sensitive to these simulated waters were those where osmotic potential was the main mechanism by which salinity suppresses growth.

Negative nutrient interactions such as competition of SO_4 with MoO_4 or other anions, and of Ca with other cations, may have been an additional factor in suppressing growth in this part of the growth curve (*cf.* Ströhmenger et al., 1999). Chemical analyses of the seedling top growth of maize cv. SNK 2340 on the SO_4-dominated water, did not, however support possible competition effects: the dry matter contents of N, P, K, Mg and most of the micro-nutrients were higher than those of the control (Table 5.29) (5.2.1.4). The only exception was a decrease of Mn-uptake which may, however, be beneficial with mine waters where the Mn-uptake was increased as in the case of the vegetative growth trials with Kromdraai lime-treated acid mine drainage water (Mine A 2/94) (Table 6.14).

Conclusion

In the first part of the growth curve, where $CaSO_4$ was soluble, it is suggested that the tolerance of seedling growth was mainly connected to

- the mechanism by which salinity generally suppresses growth of specific crops and the absence of Na and especially Cl from the $CaSO_4$ water,

- the sensitivity of a crop or cultivar to decreasing osmotic potential, and

- the presence and nature of adaptive mechanisms of specific crops and cultivars.

B. Simulated $CaSO_4$ mine water (Kleinkopje, mine C 3/95) **with increasing $CaSO_4$ crystals in suspension** (Treatments 6 or 7 to 10) (Table 3.2)

From treatments of *ca* 3000 to 5000 'mg L^{-1}' SO_4, where undissolved gypsum crystals were increasingly present, there was a general tendency of unexpected increases of seedling growth, despite an increasing EC of the treatment solutions applied (Figures 5.1 to 5.4).

Seedling growth increased significantly from 2500 to 4000 'mg L^{-1}' SO_4 for **maize** cv. SNK 2340 and **sorghum**, and without statistical significance for **pearl millet** and **maize** cv. CRN 4403 (Figure 5.1) (Tables 5.1, maize; 5.3, sorghum and 5.6 for pearl millet).With **lucerne** the seedling growth increased at 4000 and 5000 ‘mgL^{-1}’ SO_4 ($P< 0.10$) (Figure 5.2) (Table 5.27). Similar increases of **soybean**, **cowpea** and **dry bean** were not significant. These tendencies were more pronounced with soybean than cowpea, with only slight increases with dry bean which was probably overshadowed with positive nutrient effects (Figure 5.2) (Table 5.7, soybean; 5.9, cowpea and 5.11 for dry bean cv. Pan 122).

There was no apparent trend for **wheat** and **rye**, while **triticale**, **barley** and **oats** tended to increase from 2300 or 2500 to 5000 ‘$mg\ L^{-1}$’ SO_4, triticale cv. Rex and oats being the most prominent (Figure 5.3) (Table 5.15, wheat; 5.17, rye; 5.19, triticale; 5.21, barley; and 5.23 for oats).

Both **ryegrass** cultivars showed an almost inverse response to the $CaSO_4$ gradient compared to the other temperate annuals: In contrast to the increased growth of the above crops there was a significant *decrease* above 2500 up to 4000 ‘$mg\ L^{-1}$’ SO_4 for Dargle (and a tendency for Midmar, $P = 0.09$); the seedling growth levelled off to 120 % for Dargle and 110 % for Midmar at 4000, 5000 and 6000 ‘$mg\ L^{-1}$’ SO_4 (Figure 5.4) (Table 5.25).

The seedling growth of **sunflower** decreased very gradually with these treatments but was still higher than that of the control (Figure 5.1) (Table 5.13).

With increasing gypsum crystal content the increased seedling growth was significant for maize, sorghum and lucerne ($P<0.05$ or $P<0.10$), while for pearl millet, soybean, cowpea, triticale, oats and barley it was evident but not significant. Still another group (wheat and rye) showed no such increases, while the seedling growth of ryegrass and sunflower was decreased with increasing crystal content, but was still greater than the control.

For most of the crops evaluated there was a second growth decrease at 5000 and/or 6000 ‘$mg\ L^{-1}$’ SO_4 (treatments 9 and/or 10). This was probably due to an unfavourable Mg to Ca ratio in solution of these treatments because of the lower solubility of $CaSO_4$ (Table 3.2); maize (both cultivars), pearl millet, soybean, cowpea and triticale Rex were the least affected (seedling growth *ca* 90 %) (Figures 5.1 to 5.4) (Tables 5.1, maize; 5.6, pearl millet; 5.7, soybean; 5.9, cowpea; and 5.19, triticale). Sorghum, dry bean cv. PAN 122, lucerne, rye and oats were decreased to a greater extent (72 to 79 %) (Figures 5.1 to 5.4) (Tables 5.3, sorghum; 5.11, dry bean ; 5.27, lucerne; 5.17, rye and 5.23 for oats). No further suppression of ryegrass was perceptible (Figures 5.4) (Table 5.25).These decreases at 5000 and/or 6000 'mg L^{-1}' SO_4 might have been aggravated by a pore clogging effect caused by the repeated replacement of the treatment suspensions.

Discussion

It is suggested that the increased seedling growth with the suspension treatments was due to an *increase* of the effective osmotic potential; this was probably caused by rapid daily precipitation of gypsum, which was accelerated by the presence of the undissolved gypsum crystal nuclei, during the daily withdrawal of water from the root growth medium. The increasing crystal contents from treatment 7 to 9 (thus an increase of crystal surface) may also have increased the rate of precipitation, and thus the effective osmotic potential. This could account for increased growth with increasing crystal content.

It is furthermore suggested that the degree in which seedling growth increased is coupled to the sensitivity of specific crops to changes in osmotic potential in the seedling growth stage. This is indicated by the observation that the crops where this response was most perceptible, were once again those where osmotic potential has been found to be the major suppressing mechanism of salinity. This data confirms those of the soluble $CaSO_4$ treatments (5.2.1.1 A).

Conclusion

It is concluded that the responses of seedling growth to these treatments are linked firstly to the influence of the undissolved $CaSO_4$ crystals on the effective osmotic potential via accelerated precipitation of $CaSO_4$, and secondly to the major salt tolerance or sensitivity mechanisms of particular crops and cultivars. It is suggested that the degree of the response is probably an indication of the particular crop and cultivars' sensitivity to changes in the effective osmotic potential.

5.2.1.2 A simulated mine water (Kleinkopje 3/95) **saturated with $CaSO_4$ with increasing**

concentrations of Na_2SO_4 (Treatments 11 to14) (Table 3.2)

Where increasing SO_4 concentrations were obtained with Na_2SO_4 in simulated mine water solutions saturated with $CaSO_4$, seedling growth generally decreased in a linear manner. This linear regression was significant for maize cv.'s SNK 2340 and CRN 4403, sorghum, pearl millet, cowpea, lucerne and wheat, but not for soybean, dry bean PAN 122 and the other temperate cereals. The seedling growth of the last mentioned crops was therefore not significantly suppressed by osmotic potential and/or Na ionic effects.

Comparison of the seedling growth on $CaSO_4$, Na_2SO_4 and NaCl at similar osmotic potentials may give an indication of possible ionic effects of Na and/or Cl. This comparison of the growth curves on the different types of simulated mine waters was, however, complicated by the influence of evapotranspiration and precipitation of gypsum (especially by the effect of the speed of crystallization) on the effective osmotic potential. As these factors could affect the in situ osmotic potentials in the root zone, a comparison of the growth curves with $CaSO_4$, Na_2SO_4 and NaCl at the osmotic potentials of the applied treatment solutions would therefore not be valid for the actual in situ situation.

However, when comparing these growth curves there are indications that the presence of Na and Cl may have had ionic effects on the seedling growth of some of the crops (Figures 5.1 to 5.4). This may be in contrast to the findings of some authors that the adverse mechanism of salinity on seedling growth is mainly due to osmotic potential effects (Munns et al., 1995; Neumann, 1997). It is suggested that these growth curves may indicate that ionic effects in the seedling growth stage need further investigation.

There is a strong indication of a Na and/or Cl ionic effect in **dry bean** cv. PAN 122 (Figure 5.2). This is similar to findings that Na ionic effects suppressed growth more than decreasing osmotic potential in snapbean cv. Contender (Awada et al., 1995). Tolerance in soybean and dry bean has also been associated with Na accumulation in the roots (Cordovilla , Ocaña, Ligero & Lluch, 1995), which could be a protective mechanism against the effect of Na in the shoots. The fact that the regression with increasing Na_2SO_4 was not significant for soybean and dry bean may indicate the presence of such a mechanism.

A negative Na effect was also indicated in maize cv. SNK 2340 by the chemical analyses of the top growth, where the uptake of Na was accompanied by a decrease of nutrient cations (Table 5.29). In contrast a positive effect of Na, possibly by inorganic osmotic adaptation, is strongly apparent with the seedling growth of the maize cv. CRN 4403 (Figure 5.1).

The absence of high Na concentrations from a $CaSO_4$ water can thus be advantageous to the seedling growth of some crop cultivars. This once again emphasizes the importance of the nature of the suppressing mechanism and the composition of specific waters in the tolerance to a $CaSO_4$-dominated water.

5.2.1.3 NaCl gradients (Mine B 3/95)(Table 3.3)

With increasing Na/Cl/SO_4 concentrations, simulating a NaCl-dominated mine water, seedling growth generally decreased in a linear fashion according to the Maas & Hoffman (1977) theory. The threshold and slope values for these growth curves were computed with the SALT programme (Van Genuchten, 1983) (3.3.2), and are given in Barnard et al. (1998).

5.2.1.4 Chemical analyses

The top growth of maize SNK 2340 with selected treatments of the three SO_4 waters was analysed to investigate whether the growth differences with soluble $CaSO_4$, suspensions and Na_2SO_4 were possibly the result of nutrient effects. No apparent nutrient interactions were evident for either of the $CaSO_4$ treatments. The dry matter contents of the shoots were: N in the optimum to high range; P, K and Mg very high; Ca high and the micronutrients in the optimum range for maize (Loué, 1987)(Table 5.29). These high values were probably due to the plants being in the seedling stage. The total amounts of N, P and K taken up for each treatment were in proportion to the growth. The Ca and Mg uptake was not markedly different from that on the control. The SO_4 uptake was increased on both SO_4 waters and the Mn uptake was decreased (Table 5.29).

With increasing Na_2SO_4 treatments the relative growth was decreased, with a concurrent increase of dry matter Na and a decrease of K, Ca, Mg, Fe, Mn and Cu (Table 5.29). Maize cv. SNK 2340 is therefore not an excluder of Na which seems to have caused some nutrient imbalances that affected the growth.

From these analyses it is concluded that seedling growth decreases and increases in maize cv. SNK 2340 with increasing Ca, Mg and SO_4 were probably not the result of nutrient imbalances caused by the high SO_4 or Ca. It does seem, however, that an increase of Na led to increased uptake that suppressed seedling growth via interactions with K, Ca, Mg, Fe, Mn and Cu. In contrast the seedling growth of the maize cv. CRN 4403 with Na_2SO_4 treatments saturated with $CaSO_4$, was generally higher than that of the $CaSO_4$ treatments at similar osmotic potentials of the treatment solutions (Figure 5.1). In this case Na was either excluded or compartmentalized, or the Na may have contributed to inorganic osmotic adaptation.

TABLE 5.29 Concentration of nutrient elements in the seedling top growth of maize SNK 2340 with a gradient of simulated $CaSO_4$ and Na_2SO_4 mine water (Figure 5.1)

Treatment	SO_4 in solution	Ca in solution	Mg in solution	N	P	K	Ca	Mg	Na	Sulphate	Fe	Mn	Cu	Zn	Total mass	Relative growth
	mg L^{-1}	mg L^{-1}	mg L^{-1}	%							mg kg^{-1}				g/10 plants	%
$CaSO_4$:																
Control 1	255	121	114	3.3	0.5	2.9	0.6	0.4	0	2.11	146	165	9	23	2.05	100
2	1485	345	209	3.45	0.6	3	0.6	0.7	0	3.43	138	77	14	30	1.94	95
6	2428	603	411	3.72	0.6	3.4	0.7	0.7	0	3.88	182	69	14	29	1.59	78
8	2985	589	551	3.57	0.6	3.1	0.6	0.8	0	4.03	155	65	12	29	1.99	97
9	3300	597	678	4.94	0.7	3.8	0.6	0.7	0	3.76	189	63	12	38	1.48	72
Na_2SO_4 :																
12	2989	526	313	3.7	0.7	3.9	0.7	0.6	0.3	3.94	198	62	14	27	1.77	86
14	4703	526	308	3.5	0.7	2.8	0.5	0.4	1.4	3.4	171	50	9	27	1.38	

5.2.2 CONCLUSION FOR SAND CULTURE EXPERIMENTS

It is suggested that the seedling growth responses with the simulated $CaSO_4$ mine waters were mainly related to the effective osmotic potentials of the solutions in the vessels, which was in turn dependent on the rapidity of the precipitation of gypsum during evapotranspiration.

In the treatments where $CaSO_4$ was soluble, seedling growth decreased in a linear manner above a threshold value with increasing concentrations of Ca, Mg and SO_4, which was similar to the growth response function expounded by Maas and Hoffman (1977). Precipitation of gypsum in these treatments was probably retarded by the absence of nuclei for crystallization in the washed quartz sand, and by the short time intervals between applications, which probably resulted in decreases of the effective osmotic potential. The presence of undissolved gypsum crystals, however, probably caused an *increase* of the effective osmotic potential in the vessels by acting as crystallizing nuclei and therefore accelerating precipitation during the withdrawal of water from the root growth medium by evapotranspiration.

At high concentrations of the $CaSO_4$ - dominated water the relative seedling growth decreased. This was probably because the Mg to Ca ratio in solution reached values detrimental to growth, caused by the withdrawal of Ca from solution by precipitation.

A comparison of the seedling growth curves with $CaSO_4$ waters of varying compositions, and Na and Cl contents, indicates that - in addition to osmotic potential - other mechanisms, such as Na and/or Cl ionic effects, could also determine the response of seedling growth of some crops and cultivars to these waters. Although the trends seen in these growth curves generally agree with the findings of Munns et al. (1995) and Neumann (1997) that the effect of salinity on *seedling* growth was mainly due to the decreased osmotic potential of salinity, the above ionic effects may need further consideration.

Generally the sand culture experiments indicate that the tolerance of seedling growth to $CaSO_4$ dominated waters was mainly related to

- the sensitivity of a crop or cultivar to decreasing osmotic potential,

- the mechanism by which salinity generally suppresses growth of specific crops and the absence of Na and especially Cl from the $CaSO_4$ water, and

- the presence and nature of adaptive mechanisms of specific crops and cultivars and the influence of $CaSO_4$- dominated water on these mechanisms.

5.3 SOIL versus SAND EXPERIMENT

Soil contains abundant nuclei which could accelerate the crystallization of $CaSO_4$; this in turn would increase the effective osmotic potential of the soil solution during evapotranspiration and probably also the seedling growth. An experiment similar to the above sand cultures was thus conducted with maize SNK 2340, to compare the seedling growth on quartz sand with that on two acid soils.

The method is given in Chapter 3 (3.2.2.2 B).

The acid soils were chosen because the soils in the vicinity of the coal mines, where this water can be utilised for irrigation, are generally acidic. Seedling growth in quartz sand was compared to that in two acid soils with a gradient of simulated $CaSO_4$ - dominated mine water.

5.3.1 RESULTS AND DISCUSSION

The growth curves found with these soils were similar to the responses of most of the crops in the previous sand culture experiments. With increasing concentrations of Ca, Mg and SO_4 the seedling growth with both the soils and the sand followed the now familiar three-piece or four-piece irregular growth curve found in the above sand culture experiments (Figure 5.5).The growth curves on the soils as well as the sand were however ‘flatter’, with less significance between treatments than in the previous sand culture trial (Figures 5.5 vs. 5.1).

The *relative* salt tolerance was less on the soils than on the sand (Figure 5.6) (Table 5.30). This is, however, a typical example of an “apparent salt tolerance” (2.4.1), which is probably caused here by the differences of fertility of the soils and sand. The growth of the three controls differ significantly, which clearly indicates fertility differences. It was thus considered more correct to evaluate the tolerance with the absolute growth curves (Figure 5.5).

There was a gradual decreasing tendency up to 2000 mg L^{-1} SO_4, followed by a sharper decline from 2150 to 2300 or 2500 mg L^{-1} SO_4 (EC 350 to 400 mS m^{-1}) (Figure 5.5). These decreases were highly significant for the reddish-brown soil (pH 4.7), but not for the greyish-brown mine soil and the sand.

With the presence of undissolved $CaSO_4$ crystals the growth again *increased* at 3000 'mg L^{-1}' SO_4 (treatment 7), though not significantly. With a further increase of concentration and gypsum crystal content at 4000 'mg L^{-1}'SO_4 (treatment 8), the seedling growth on the soils tended to decrease, in contrast to growth on the sand (Figure 5.5); these trends at treatments 7 and 8 were, however, not significant. This indicates that added undissolved $CaSO_4$ crystals could have had a greater effect on osmotic potential and growth in sand than in the acid soils. As soil nuclei were present in all the treatments of the soils, it is understandable that additional nuclei in the form of $CaSO_4$ crystals would have a less marked effect on growth than in the acid-washed sand where no other nuclei were present.

In these acid soils crystallization of gypsum may have been inhibited by adsorptive coatings of aluminium phosphates or humic substances on the soil crystal nuclei faces (as quoted in Van Den Ende, 1991); the consequence would be a slower precipitation of $CaSO_4$ that would not increase the effective osmotic potential as much as in sand where these inhibiting soil properties were absent.

The absolute seedling growth on the reddish-brown soil (pH 4.7) was > mine soil (pH 4.3) > sand; differences between the first mentioned soil and sand were highly significant for all treatments, but seedling growth on the mine soil was not significantly greater than that on the sand. The seedling growth on the two soils did not differ significantly. These growth differences could be due to the greater fertility of the two soils compared to the sand, as indicated by better growth on the control treatments.

The weaker growth at 6000 'mg L^{-1} ' (treatment 10) for sand and the mine soil, though not significant, is again probably due to the unfavourable ratio of Mg to Ca in solution (Table 3.2). This was not evident with the reddish-brown soil, probably because of the fertility and higher cation exchange (CEC) properties of this particular soil.

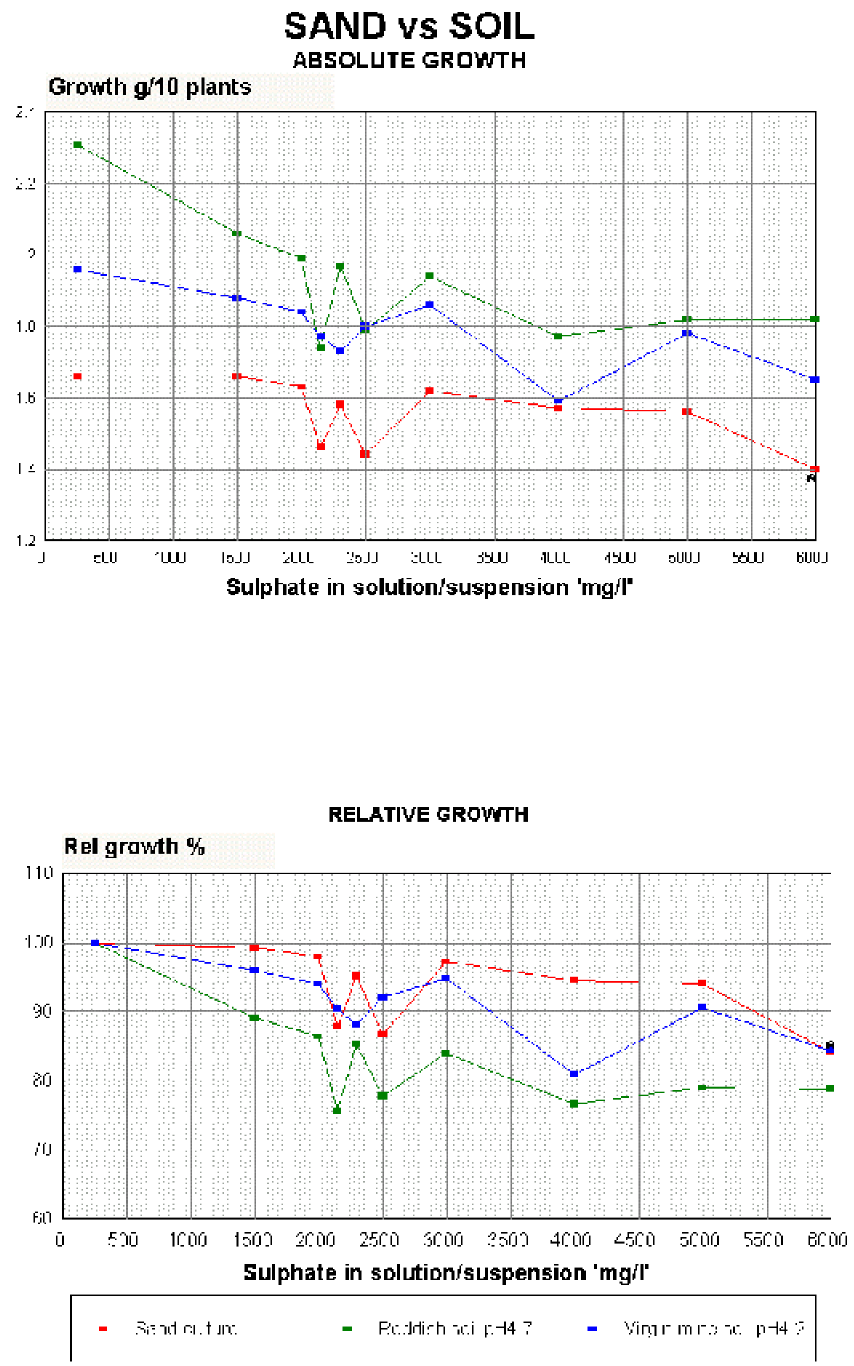

FIGURE 5.5 The influence of a gradient of simulated CaSO$_4$ mine water on the absolute and relative seedling growth of maize SNK 2340, comparing the response on sand with that on two acid soils.

TABLE 5.30 The influence of a gradient of a simulated $CaSO_4$ mine water on the seedling top growth of maize SNK 2340 with quartz sand compared to that with two acid soils (Figure 5.5)

Treatment	SO_4	EC	Sand		Reddish-brown soil (pH 4.7)		Virgin mine soil (pH 4.2)	
	(mg $^{L-1}$)	mS m^{-1}	g/10 plants	Rel. growth %	g/10 plants	Rel. growth %	g/10 plants	Rel. growth %
1	255	97	1,66	100	2,31**	100	1,96**	100
2	1500	280	1,66	100	2,06 **	89**	1,88	96
3	2000	327	1,63	98	1,99 **	86**	1,84	94
4	2150	349	1,46	88	1,74 **	76**	1,77	90
5	2300	368	1,58	95	1,97 **	85**	1,73	88
6	2500	386	1,44	87	1,79 **	78**	1,80	92
7	3000	403	1,62	97	1,94 **	84**	1,86	95
8	4000	453	1,57	95	1,77	77	1,59	81
9	5000	492	1,56	94	1,82 **	79 *	1,78	91
10	6000	525	1,40	84	1,82 **	79**	1,65 *	84

* Tendency of soils to differ from sand ($P < 0,1$)

** Significant difference of soils to sand ($P < 0,05$)

5.3.2 DISCUSSION FOR SOIL EXPERIMENT

The decrease of osmotic potential by salinity has generally been found to be the major growth suppressing mechanism for seedling growth (Neuman, 1997) and for the general growth of maize (Cramer, 1994). The effective osmotic potential is determined firstly by the degree of daily concentration of the root growth medium, and secondly by the precipitation of gypsum.

Withdrawal of water from the root zone is mainly related to the rate of growth and evapotranspiration. As the root growth medium concentrates, crystallization of $CaSO_4$ may take place. The rate of crystallization may be stimulated by many types of nuclei in soils, or inhibited by various adsorptive coatings such as aluminium phosphates in acid soils, $CaCO_3$ and humic substances (as quoted by Van den Ende, 1997).

Soluble $CaSO_4$ gradients (Treatments 2 to 5 or 6) (1500 to 2300 or 2500 mg L^{-1} SO_4) (Table 3.2)

It was expected that the abundant nuclei in soil would accelerate precipitation of gypsum with the soluble treatments in the same way as the undissolved crystals in the suspension treatment. The seedling growth, however, still decreased with these treatments. It is possible that the presence of aluminium phosphates in these acid soils and - to a lesser extent - humic substances in the virgin mine soil may have contributed to a possible diminished precipitation of gypsum which could result in the effective osmotic potential and seedling growth being decreased.

The time interval between replenishing is another important factor in precipitation, especially in situations with no nuclei present. In this trial the time interval was about twice that of the time interval in the previous experiments with maize, where water was replenished twice daily in the second week to prevent wilting. As the growth curves on both the soils, as well as the sand, are ‘flatter’, with less significance between treatments than in the previous sand culture trial, it is probably the longer time interval and not the presence of soil nuclei that ameliorated the seedling growth in this trial, compared to the previous trial (Figure 5.1 vs. Figure 5.5).

It is interesting to compare the relative growth percentages of maize SNK 2340 on the sand in this evaluation (where the time interval was about twice that of the previous experiment) to those of the first sand culture trials (Table 5.30 vs. Table 5.1): with the longer interval the minimum relative growth on sand was 87 % at 2500 mg L^{-1} SO_4 compared to the 78 % with the previous trial with shorter time intervals. It is possible that with the longer interval more gypsum precipitated with a simultaneous greater increase of the effective osmotic potential.

The decreases of seedling growth with the soluble $CaSO_4$ solutions (treatments 2 to 6) were not only due to diminishing osmotic potentials (increasing concentrations) of the treatments but also to additional increases in concentration by evapotranspiration, even possibly to short periods of super-saturation (see Van den Ende, 1991). Greater concentration effects can be expected in these treatments, due to a slower precipitation of gypsum; precipitation would probably be slower due to the absence of added gypsum crystals, together with a possible inhibiting influence of aluminium phosphate and humic substance adsorption on the soil nuclei surfaces.

Simulated $CaSO_4$ mine water (Kleinkopje, mine C 3/95) **with increasing crystals in suspension** (Treatments 6 or 7 to10) (Table 3.2)

The increases of growth in treatments with added $CaSO_4$ crystals, can again be attributed to accelerated precipitation in the soil solutions between replenishments; this was probably caused by the presence of the added undissolved crystals (possibly strengthened by the soil nuclei) in the treatments. These increases were not significant in this trial in contrast to significance in the previous trial where the time intervals between replenishments were shorter (Figure5.1) (5.2.2). With shorter intervals the effect of the added gypsum crystals would be expected to be more manifest compared to precipitating crystals in the soluble treatments. With increased time intervals precipitation would take place more readily in both these solutions and there should be a smaller difference between them.

Generally the results may also be related to the *hydraulic conductances* of the growth media which decreased in the following order: sand > virgin mine soil > reddish brown soil. When nutrient solutions were added to the red soil, there was a greater draining time lag which could lead to greater salinisation of the soil, and thus a greater growth suppression, compared to the control (Figure 5.5).

Another contributing factor could be that owing to better growth on the soils, the average *water loss* by evapotranspiration was generally higher on the soils than with the sand: mine soil > red soil>sand (*ca* 33>31>22 ml/vessel/day).Concentration of the soil solutions would thus be more on the soils than on the sand. This could subsequently lead to a greater decrease of the osmotic potential in the root zone with the soils, which may however be counteracted by a speedier precipitation of gypsum in a non-acidic soil. It did not seem to have an effect in the acid soils.

To summarise, the *final seedling growth response* would thus depend on the *effective osmotic potential* which in turn would be determined by:

- The balance between the inhibition and stimulation of the precipitation of $CaSO_4$, together with

- the daily concentration by evapotranspiration; and

- the time interval between replenishing.

5.3.3 CONCLUSION FOR SOIL EXPERIMENT

The expected ameliorating influence by soil crystal nuclei on the effective osmotic potential - and thus on seedling growth - was not evident with these acid soils. This is probably due to the inhibiting effect of aluminium phosphates - present in the acid soils - on the rapidity of precipitation, and the concomitant influence on the effective osmotic potential which, in turn, could affect the seedling growth. The seedling growth on the acid soils followed similar growth decreases and increases to that on the quartz sand. It is suggested that the similarity of the growth curves is mostly due to the absence, or presence, of the added undissolved gypsum crystals in the respective treatments.

The *absolute* seedling growth was generally higher with the soils, which was probably due to the higher fertility of the soils compared to that of the one third strength Hoagland nutrition. The *relative* growth decreases on the soils were, however, greater on these acid soils than on the sand. This probably was mainly due to the superior growth of the respective controls. The greater decreases in relative growth on the soils may be a warning that this water can be relatively more harmful to seedling growth on acid soils, than to seedling growth as was found on the sand. This would depend on the chemical and physical properties of individual soils which are illustrated by the different growth responses on the two soils.

5.4 DISCUSSION

Gypsum precipitation and 'effective osmotic potential'

The precipitation of gypsum from the root growth solution results in a decrease of the electrolytical conductivity, thereby increasing the osmotic potential and probably also the 'effective osmotic potential' (3.4).

It is well known that the presence of crystals accelerates crystallization; Van den Ende (1991) also found that the addition of gypsum crystals to soil press extracts decreased the Ca and SO_4 contents as well as the electrolytical conductivity values much *sooner* than in an identical extract where no gypsum crystals had been added . The washed quartz sand used in the current experiments was virtually free of amorphous material and was probably depleted of possible nuclei which could stimulate the crystallization of gypsum. It could therefore be expected that the *rate* of precipitation and the simultaneous increase of osmotic potential would be much slower in treatment solutions devoid of crystallization nuclei (treatments 1 to 5 or 6) than in those where undissolved gypsum crystals were present (treatments 7 to 10). Precipitation with increasing concentration by evapotranspiration would thus be slower, and more dependent on time, in treatment solutions 1 to 5 or 6, whereas in the treatments with undissolved gypsum, crystallisation would take place almost immediately when saturation point was reached. The resultant effective osmotic potential would thus be increased.

The *time interval between replenishing* is another important factor in precipitation. Given enough time, gypsum will eventually precipitate but without crystallizing nuclei it may be retarded. It is probable that - with longer intervals - more gypsum would precipitate, leading to a greater increase of the effective osmotic potential and a higher relative seedling growth. This was illustrated in the case of maize seedling growth on sand with different time intervals in the first sand culture experiments compared to sand in the 'soil experiment'; with the longer interval the minimum relative growth was 87 % (Table 5.30) compared to 74 % (Table 5.1) in the previous trial with shorter time intervals.

Precipitation of gypsum could also possibly have affected the osmotic potential in the Na_2SO_4 solutions. Although the Na salt is soluble, these solutions were saturated with $CaSO_4$ that could have precipitated when water was withdrawn by evapotranspiration. In the current trials such an effect was, however, improbable as the rate of such precipitation would be slow, due to the absence of nuclei in the washed quartz sand and the short time intervals between replenishing.

The expected response with a gradient of $CaSO_4$-dominated water is that below the solubility product of Ca and SO_4 growth will decrease with increasing salinity. When gypsum starts precipitating, it is expected that salinity - and thus growth - would either not decrease any further, or at a much slower rate. The trend, however, was that although the electrolytical conductivity of the treatment solutions still *increased* (due to increasing $MgSO_4$), instead of a further decrease, the seedling growth of most of the crops in these trials now tended to *increase*. This could be explained by the presence of undissolved gypsum crystals in the suspensions applied. These crystals probably increased the rapidity of crystallization as evapotranspiration daily depleted the water in the vessels, resulting in a higher effective osmotic potential. The increasing tendency of seedling growth with the suspensions (treatments 7 to 8 or 9) corresponds with an increasing content of undissolved gypsum crystals.

The decrease of seedling growth up to 2500 ‘mg L^{-1} ’ SO_4 was probably more severe in the washed quartz sand than it would be in soil in field conditions where abundant nuclei are usually present. The salinity in the sand culture was probably much higher than that of the initial treatment solutions, even possibly to the point of super-saturation for short periods (see Van den Ende, 1991). In contrast the increase of salinity in soil may be ameliorated by accelerated precipitation of gypsum by soil nuclei. It can thus be expected that in a field situation the seedling growth would be higher than in this sand culture.

However, when extrapolating these results to a soil environment, the rapidity of the gypsum precipitation - and thus the effective osmotic potential - may be influenced not only by the abundance of the soil nuclei but also by the mineral and organic composition of the soils involved.

The formation of gypsum crystals in situ in soil can be affected by a number of soil factors. Van den Ende (1991) refers to the findings of various researchers who observed that organic anionic poly-electrolytes can inhibit the formation of gypsum crystals and that humic substances in the soil solution occur as such electrolytes. Adsorption of these substances on crystal and other nuclei surfaces was considered the cause of this inhibition. He also draws on research that other substances, such as polyphosphates (especially in the presence of abundant orthophosphates), and various mineral coatings such as $CaCO_3$ in calcareous, and aluminium phosphates in acid soils, could contribute to inhibiting the precipitation of gypsum. In the current soil experiment this seems to be confirmed for the two acid soils evaluated.

Salt sensitivity/tolerance mechanisms of crops and tolerance to $CaSO_4$-dominated water

The degree in which a specific crop or cultivar showed the above tendencies seemed to be connected to the mechanism by which NaCl-dominated salinity generally influences the growth of a particular crop or cultivar. In both parts of the growth curve it was mostly those crops where osmotic potential effects have been found to be the major adverse mechanism that showed the most evident response to these waters e.g., maize (Cramer, 1994), and sorghum (Shannon,1997). Where Na and/or Cl ionic effects have been found to be the main property of salinity that suppresses growth - as with for example soybean (Abel & McKenzie, 1964; Parker, Gascho & Gaines, 1983), cowpea (Keating, 1986) and wheat (Shannon, 1997) - the seedling growth was suppressed to a lesser extent by increasing concentrations of the $CaSO_4$-dominated waters. This was probably due to the very low Na and Cl content of these waters and/or to the genetic osmotic adaptation properties of the chosen cultivars.

The above observations, together with the very low Na and Cl concentrations in these treatments, suggest that the degree to which a specific crop or cultivar responded to the increasing $CaSO_4$ concentrations in these growth curves may be an indication of its sensitivity to osmotic potential changes; it could also be an indication of how this type of water influences the metabolic processes of osmoregulation as is probably the case with ryegrass (Sagi et al., 1997) (4.2.2.1); and of possibly being nutritionally beneficial to the growth of crops that have a high Ca and S requirement such as legumes.

No conclusions on possible suppression of growth by the high Ca and SO_4 concentrations could be obtained from these experiments, except that nutrient analyses of the top growth of maize did not indicate any such negative interactions. Possible Ca and S interactions are discussed in greater detail in Chapter 6 (6.4.1 and 6.4.2).

5.5 SUMMARY AND CONCLUSIONS

1. *The seedling growth of most of the crops followed a similar irregular three-piece or four-piece growth curve with increasing Ca, Mg and* SO_4 *concentrations in the simulated* $CaSO_4$-*dominated mine waters*. This growth curve included treatments where $CaSO_4$ was soluble, as well as suspensions where gypsum crystals were increasingly present.

Initially there was a gradual decrease, increase or no effect; this was followed by a sharper decrease up to concentrations of Ca and SO_4 where the solubility product was more or less reached in the treatment solutions, then a tendency to *increased* growth where undissolved $CaSO_4$ crystals were increasingly present. Where the Mg to Ca ratio in solution was >1 seedling growth of most of the crops finally decreased again.

In the first and second parts of the growth curve where $CaSO_4$ was soluble, the seedling growth generally followed the expected linear decrease above a threshold value as expounded by Maas and Hoffman (1977). The significance of the decreases differed and may be seen as an indication of the sensitivity or tolerance of specific crops and cultivars. The actual concentrations in the root zones were considerably increased by daily evapotranspiration , but the continued linear decreases up to saturation concentrations of the applied treatment solutions, were an indication that salinity was not noticeably limited by precipitation of gypsum during evapotranspiration in this part of the curve.

The increases of seedling growth in the third part of the growth curve, despite decreasing osmotic potential in these treatment solutions, were unexpected. It was anticipated that beyond saturation concentrations salinity would be limited by the precipitation of gypsum. Only small decreases in the osmotic potential and seedling growth were expected.

It is suggested that the differences in seedling growth response between the second and third part of the curve could probably be attributed to the rate of precipitation of gypsum when saturation concentrations were reached through the withdrawal of water by evapotranspiration. In the first and second part of the curve crystallization is probably retarded by the absence of any nuclei in the washed quartz sand (it is possible that supersaturation occurred for a part of the day in some of the treatments where the salts were soluble - seeVan den Ende, 1991), whereas the presence of undissolved gypsum crystals in the suspension treatments used in the third part of the growth curve, probably accelerated precipitation. The result would be a decrease in the effective osmotic potential in the first two parts of the curve and an increase in the third part, with corresponding decreases or increases of the seedling growth respectively.

The *minimum seedling growth* generally occurred with the treatments where concentrations were in the vicinity of saturation but where undissolved crystals were still apparently absent. In a soil environment where nuclei are usually abundantly present, it can therefore be expected that precipitation would be much quicker than in the sand and that the resulting effective osmotic potential and seedling growth would be higher than indicated by the results on the sand culture. Drying of the soil in field conditions should thus not lead to the same rate of concentration and a concomitant lower osmotic potential, than in the sand culture. Seedling growth in soil would probably be similar to that in the treatments where the seedling growth was increased by the presence of gypsum crystals stimulating the precipitation rate.

The precipitation of gypsum could, however, also be retarded by several soil factors. The acceleration of crystallization by soil nuclei can be reduced by coatings of - for example - aluminium phosphates, $CaCO_3$ and humic substances (as quoted by Van den Ende, 1991). If the soil water is kept at field capacity by frequent irrigation, precipitation can also be slower than with longer time intervals and subsequent drying of the soil (Van den Ende, 1991).

Overall the seedling growth of the crops and cultivars evaluated did not, however, decrease beyond 70 %. Although it should be sufficient growth to bridge the sensitive seedling stage to the more tolerant vegetative growth stage (see Chapter 6), primordial spikelet development of especially cereal crops may be impaired, which may eventually affect the yield (Francois & Maas, 1994) (2.6.1).

The differences in seedling growth curves between the two ryegrass, maize and triticale cultivars with these treatments also confirm the conclusion of Chapter 4, that *cultivars could differ* in their response to a $CaSO_4$-dominated water.

2. It is suggested that *the main property of the $CaSO_4$-dominated mine water that caused suppression of seedling growth was the decreased osmotic potential*. It was observed that the above mentioned trends were most evident with crops where the major adverse mechanism is related to osmotic potential effects. It is therefore suggested that the extent to which a crop or cultivar manifested decreases (and increases) of seedling growth with increasing concentrations of simulated $CaSO_4$-dominated mine waters, may therefore be an indication of its sensitivity to osmotic potential changes of the external solution.

The most sensitive crops were maize cv. SNK 2340, sorghum cv. PAN 888, pearl millet cv. SA Standard and lucerne cv. PAN 4860. Although following the same trend, the subtropical legumes soybean cv. Ibis and cowpea cv. Dr Saunders were less sensitive, indicating either a lesser influence of osmotic potential, a greater inbred tolerance to osmotic potential decreases or positive nutritional effects. However, salt tolerance of these last mentioned crops is mainly related to the absence of Cl which has been found to be the main growth inhibiting effect of saline water for these legumes. Generally the annual temperate crops were less sensitive to osmotic potential than the subtropical annuals.

When selecting crops and cultivars for use with this type of water, a knowledge of the adverse and adaptation mechanisms may be a useful indicator of tolerance to a $CaSO_4$-dominated water.

Crops where an ionic effect is the main growth suppressing mechanism with NaCl-dominated salinity may be relatively tolerant to this type of water, depending on the degree to which osmotic potential plays a part in the growth suppression of such a crop.

It is therefore concluded that *the seedling growth of crops that are mainly sensitive to osmotic potential effects would be more sensitive to $CaSO_4$-dominated mine water than those where the adverse mechanisms are mainly related to ionic effects of Na and Cl.*

3. This water may also be *nutritionally beneficial* to crops. It could benefit crops such as legumes and the Cruciferae family that have a high S requirement. The exceptionally good growth of dry bean with this water illustrates the possibility of such an effect. In ryegrass the increased Ca and Mg content probably stimulated the metabolic process of osmoregulation and thus the seedling growth. In leached acid and irrigated soils, the high Ca and Mg could also be valuable to replenish the depleted Ca and Mg content of these soil types.

4. The *chemical composition of a specific $CaSO_4$-dominated water must be carefully considered* as the presence of ions such as Mg, Na, Cl and certain trace elements could have distinctive effects on plant growth and animal or human health.

Where Mg is present in appreciable amounts, the precipitation of gypsum over long periods without leaching by rain or a good quality water, could lead to a growth suppressing ratio of Mg to Ca. The general trend of suppressed seedling growth with the highest Ca/Mg/SO_4 treatment is a *warning against prolonged irrigation with such a gypsiferous water during periods of drought.*

The presence and concentration of Na and/or Cl in a $CaSO_4$-dominated water can affect tolerance, depending on the adverse and adaptation mechanisms of specific crops and cultivars. In a saturated $CaSO_4$ water *with increasing Na_2SO_4 concentrations,* seedling growth generally decreased in a linear manner above 20 mmol L^{-1} Na; and in a NaCl-dominated mine water the seedling growth of most crops also decreased in a linear manner with significance mostly reached at 20 or 40 mmol L^{-1} Na and 16 or 29mmol L^{-1} Cl respectively.

5. It is suggested that when using this type of water for irrigation, soil can be expected to have an ameliorating effect as the presence of crystallizing nuclei may positively affect the osmotic potential by accelerating the precipitation of gypsum. This would, however, depend on the chemical properties of individual soils which, together with the physical properties of individual soils, could affect the overall response of seedling growth to a $CaSO_4$-dominated irrigation water.

The data suggest that the tolerance to a $CaSO_4$-dominated water in the seedling growth stage depends mainly on the sensitivity of a crop or cultivar to external osmotic potential changes and on the chemical composition of specific irrigation waters. The severity of suppression would furthermore depend on the influence of the rapidity of gypsum precipitation on the effective osmotic potential, which in turn can be influenced by the rate of growth, evapotranspiration, soil properties and time.