CHAPTER 6

TOLERANCE TO GYPSIFEROUS MINE WATERS AT THE GERMINATION, SEEDLING AND VEGETATIVE GROWTH STAGES

In this chapter the influence of actual $CaSO_4$-dominated mine waters on germination, seedling and vegetative growth of selected agronomic and forage crops are considered.

Firstly, the germination percentages on a Kleinkopje $CaSO_4$-dominated mine water are reported. This is followed by investigations into the influence of a lime-treated acid mine drainage water on the vegetative growth of, firstly, maize, sorghum, pearl millet, soybean, cowpea and sunflower in sand culture; and, secondly, of wheat, rye, oats, triticale, annual ryegrass and lucerne in water culture.

The tolerances of the crops in the seedling and vegetative growth stages are subsequently compared and discussed.

Finally the chapter is completed with a conclusion on the tolerance of these crops in the germination, seedling and vegetative growth stages, to $CaSO_4$-dominated mine water.

6.1 INTRODUCTION

It is well known that the sensitivity of crops to the traditional NaCl-dominated salinity can vary during the different ontological growth stages (Bernstein, 1964). Tolerance and sensitivity are, however, also intimately related to the chemical composition of the saline medium (Francois & Maas, 1994; Shannon, 1997). Research with $CaSO_4$-dominated water has been limited and has mainly been conducted on the yield components with no reference to differences in tolerance of the growth stages (Papadopoulos, 1986; MacAdam et al., 1997; Jovanovic et al., 1998).

It is important for irrigation management to determine whether and to what extent the various growth stages were influenced by $CaSO_4$-dominated water. The tolerance of the germination and generally vulnerable vegetative growth stages was thus investigated and compared with the seedling stage.

The purpose of the trials reported on in this chapter was to investigate

- the influence of actual $CaSO_4$ Kleinkopje mine waters on the *germination percentage* of selected agronomic and forage crop cultivars;

- the *vegetative growth* response and *nutrient uptake* with an actual lime-treated acid mine drainage water from the Kromdraai mine complemented with nutrients; a NaCl-dominated type of salinity from the New Denmark mine was included for comparative purposes; and

- possible differences in the tolerance in the *seedling* and *vegetative growth stages*.

6.2 GERMINATION

Germination can be influenced by salinity through a decreased entry of water due to lower osmotic potential, and/or the intake of ions to toxic levels. The percentage of germination is generally not decreased by salinity, but the rate of germination and emergence has been delayed by NaCl-type of waters (Francois & Maas, 1994).

6.2.1 METHOD AND MATERIALS

The germination percentages of the respective crops and cultivars with two types of actual mine waters, compared to deionized water, were determined in paper rolls; the method is described in Chapter 3 (3.2.1). A lime-treated AMD mine-water was initially used for the maize hybrids (Mine A 7/94), but maize SNK 2340 and all the other crops were evaluated with mine water from the Kleinkopje mine with higher Ca and SO_4 concentrations (Mine C) (3.1.2).

Several cultivars of the following crops were screened for their tolerance during the germination growth stage: annual subtropical - maize, sorghum, pearl millet, sunflower, soybean, cowpea, and dry bean; temperate - wheat, rye, triticale, oats, barley, annual ryegrass, and lucerne.

The mine waters used were:

1. a $CaSO_4$-dominated mine water from Kleinkopje, Mine C 10/94, for the subtropical crops, and Mine C 3/95 for the temperate crops (Table 3.1).

2. NaCl-dominated mine water from New Denmark, mine B 11/94, for the subtropical, and Mine B 3/95, for the temperate crops (Table 3.1).

6.2.2 RESULTS AND DISCUSSION

Generally the germination percentages of most of the cultivars of the above crops were not influenced by either the $CaSO_4$- or the NaCl-dominated waters. The results of the crops where germination was not influenced, are not given, but can be found in a previous report (Barnard et al., 1998).

The germination percentages of the 18 recommended **maize** hybrids were not significantly influenced by either the lime-treated acid mine drainage water or the sodic-saline mine water (Barnard et al., 1998). One high forage producing **sorghum** cv. SENTOP tended ($P< 0.1$) to be sensitive during very early seedling growth with the sulphate water, but the seedlings where the radicles had died when less than two centimetres long, are included (Table 6.1). With **pearl millet** the sulphate water significantly reduced the germination percentage of the high forage cultivar PAN 911, by eleven percent (Table 6.1).

TABLE 6.1 The influence of two mine waters on the germination percentage[1] of sorghum

and pearl millet **cultivars**

Cultivars	Germination %			c.v. %	Relative germination %	
	Deionised water	Mine C	Mine B		Mine C	Mine B
SORGHUM						
1. SNK 3860	93	93	93	2.2	100	100
2. SNK 3939	97	97	94	2.1	100	97
3. SENFOR[1]	80	84	92**	5.8	105	115**
4. SENTOP[1]	97	91*	92	3.1	94*	95
5. SNK 3000	88	91	95	6.6	103	108
6. PAN 8494	88	85	83	4.4	97	94
7. PAN 8501	93	90	91	4.4	97	98
8. PAN 8522	89	91	88	3.5	102	99
9. PAN 8564	99	98	98	1.9	99	99
10. PAN 8591	98	98	98	1.9	100	100
11. NK 283	96	92	94	5.1	96	98
12. PAN 888	99	98	98	1.9	99	99
13. CRN 776W	95	98	92	2.3	103	97
14. CRN 7686[1]	82	80	74**	10.7	98	90**
PEARL MILLET						
PAN 911	95	85**	98	3.8	89**	103
SA Standard	91	92	92	4.6	101	101

c.v. 4.3%

* Tending to significant difference from control ($P < 0.1$).

** Significant difference from control ($P < 0.05$).

Mine C 10/94.

Mine B 11/94.

1. This includes seedlings that died after the radicle grew to 1-2 cm; more apparent with control for SENFOR and NaCl-dominated water for CRN 7686.

The **soybean** cultivars were not significantly influenced by the high sulphate water; the cultivar

A5409 showed a tendency to a germination decrease of six percent. The germination percentage of **cowpea** cv. Dr Saunders was increased significantly by five percent, while **dry bean** germination was not affected significantly (Table 6.2). On the NaCl-dominated water germination of four **soybean** cultivars was suppressed and that of **dry bean** and **cowpea** not affected (Table 6.2).

TABLE 6.2 The influence of two mine waters on the germination percentage of soybean, dry bean **and** cow pea **cultivars**

Cultivar	Germination %			c.v. %	Relative germination %	
	Deionized water	Mine C	Mine B		Mine C	Mine B
SOYBEAN						
1. Bakgat	82	79	75**	7.3	96 a	92 a
2. Ibis	88	90	92	5.6	104 a	106 a
3. PAN 494	100	98	99	1.7	98 a	99 a
4. PAN 577G	99	98	99	2.1	99 a	100 a
5. Prima	98	99	100	1.9	101 a	102 a
6. Hutcheson[1.]	(38)	(25)**	(28)**	25.8	(68) b	(74) b
7. A2233[1.]	(88)	(86)	(80)**	9.0	(98) a	(89) ab
8. A5409	95	89*	86**	2.1	94 a	90 ab
9. A7119	85	83	86	3.6	97 a	101 a
COWPEA						
1. Dr Saunders	95	100**	97	1.7	105 a	102 a
c.v. %	4.4				11.1	10.7

[1.] Brackets indicate that values were probably influenced by an infection.

DRY BEAN						
1. PAN 122	93	94	96	1.5	101 a	103 a
2. PAN 127	99	98	100	2.1	99 a	101 a
3. Mkusi	98	99	100	1.9	101 a	102 a
4. Nandi	98	99	95	2.4	101 a	97 a
c.v. %	4.4				11.1	10.7

* Tendency to differ from control ($P < 0.1$)
** Significant difference from control ($P < 0.05$)
Mine C 10/94 (soybean & cowpea); 3/95 (dry bean)
Mine B 11/94 (soybean & cowpea); 3/95 (dry bean)

The temperate annuals were generally more tolerant to both types of mine water than the subtropical annuals. Germination percentages were generally not influenced by either the sulphate or sodic-saline mine water. Exceptions were an **oats** cultivar, Overberg, with sulphate salinity where the germination was possibly affected by infection (Table 6.4), and **rye** SSR1 with the NaCl-dominated water (Table 6.5).

TABLE 6.3 The influence of two mine waters on the germination percentage of oats **cultivars**

Cultivars	Germination %			Relative germination %		c.v. for cultivars %
	Deionized water	Mine C	Mine B	Mine C	Mine B	
OATS						
1. SSH 421	99	99	99	100	100	1.5
2. SSH 423	98	99	98	101	100	2.2
3. Witteberg	100	100	100	100	100	0.0
4. Perdeberg	98	99	99	101	101	2.8
5. Echidna	100	99	100	99	100	0.8
6. Overberg[1]	93	86 **	88	92 **	95	2.7

c.v. 2.6%

1. All treatments had a black powdery infection.

TABLE 6.4 The influence of two mine waters on the germination percentage of rye **cultivars**

Cultivars	Germination %			Relative germination %		c.v. %
	Deionized water	Mine C	Mine B	Mine C	Mine B	
RYE						
1. SSR 727	88	93	92	106	105	6.4
2. SSR 729	95	98	95	103	100	2.7
3. SSR 1[1.]	63	60	53 **	95	84 **	16.6
4. Henoch	98	96	94	98	96	2.46

c.v. 6.06%

1. The low germination of SSR 1 could be possibly be due to the seed having aged.

* Tendency to differ from control (P < 0.1)
** Significant difference from control (P < 0.05)

The germination percentages of the **lucerne** cultivars were not significantly suppressed on the high sulphate mine water. Topaz, however, tended to decrease by eleven percent. On the NaCl-dominated water the germination of only Diamond was significantly depressed by twelve percent (Table 6.5). As lucerne has been found to be sensitive during germination (Läuchli and Epstein, 1990), this is an indication of the tolerance of the remaining lucerne cultivars.

TABLE 6.5 The influence of two mine waters on the germination percentage of lucerne **cultivars**

Cultivars	Germination %			c.v. %	Relative germination %	
	Deionized water	Mine C	Mine B		Mine C	Mine B
1. PAN 4860	91	90	90	7.4	99	99
2. PAN 4581	93	96	94	3.9	104	102
3. Baronet	93	95	93	4.5	103	101
4. Topaz	71	63 *	75	9.8	89 *	106
5. Diamond	98	93	87 **	4.0	94	88 **

c.v. 5.9%

* Tendency to differ from control (P<0.10)

** Significant difference from control (P < 0.05)

Mine C 3/95 (2248 mgl^{-1} SO_4, EC 394 mSm^{-1})

Mine B 3/95 (40 $mmoll^{-1}$ Na, 26$mmoll^{-1}$ Cl, EC 534 mSm^{-1})

The germination of some crop cultivars seemed to be stimulated by the $CaSO_4$ water. The germination percentage was increased significantly for **cowpea** cv. Dr Saunders (Table 6.2) and **triticale** cv. PAN 299 (Table 6.6), and tended (P< 0.1) to increase in maize cv. PAN 6564 and sunflower cv. SNK 34 (Barnard et al., 1998).

TABLE 6.6 The influence of two mine waters on the germination percentage of triticale **cultivars**

Cultivars	Germination %			Relative germination %		c.v. %
	Deionized water	Mine C	Mine B	Mine C	Mine B	
1. Kiewiet	100	99	99	99	99	1.2
2. SShRI	88	88	89	100	101	3.5
3. Rex	98	98	98	100	100	2.3
4. PAN 299[1]	57	63 **	58	110 **	102	11.1
5. SSKR 626	98	96	96	98	98	1.9
6. SSKR 628	98	98	94	100	96	3.5
7. Cloc 1	91	91	92	100	101	3.9

c.v. 3.4%

1.These percentages included a marked number that had died when the radicle was *ca* 1 cm: more with the control than with the mine waters (Control 7.5-10 %. Mine C 2.5-5 % and Mine B 2.5 %) giving an apparent increase in germination.

Germination was influenced more where there was a black powdery infection, for instance with some soybean and oats cultivars (Tables 6.2 and 6.4) . With some cultivars of triticale and sorghum there seemed to be a sensitivity of very early seedling growth with the radicle dying after about one centimetre's growth (Tables 6.6 and 6.1).

Although the rate of germination was not measured no obvious indications of such a delay were observed except where infections had occurred.

6.2.3 CONCLUSION FOR GERMINATION

The germination percentages of most cultivars of both the subtropical and temperate annual crops were not influenced by either the $CaSO_4$- or NaCl-dominated mine waters used. There were, however, exceptions where germination percentages of some cultivars of sorghum, pearl millet and soybean were slightly suppressed with sulphate salinity, and also of soybean and lucerne with the NaCl-dominated water.

Germination should, however, not be a problem if these crops are irrigated with these waters; where it was suppressed, it ranged from 5 to 12 %, which could be compensated for by sowing more densely.

Generally it is thus not expected that the decreased osmotic potential of $CaSO_4$-dominated mine waters, will affect the germination percentage of the majority of cultivars of the crops that were evaluated. This is in agreement with findings for NaCl salinity that germination percentages of most crops are generally not affected at osmotic potentials below *ca* 700 mS m^{-1} (Francois & Maas, 1994).

6.3 VEGETATIVE GROWTH

6.3.1 ANNUAL SUBTROPICAL CROPS

6.3.1.1 Method and materials

Selected subtropical crops and cultivars were evaluated in the vegetative growth stage with a lime-treated acid mine drainage and a NaCl-dominated mine water in a sand culture experiment conducted in the glasshouse. Full strength salinization was imposed from the Day 26 after planting, when the plants had approximately four leaves. Plants were harvested on Day 52 after planting at the beginning of the tasselling stage, that is 26 days after full strength treatment had begun. The method is described in chapter 3 (3.2.3.2).

Chemical analyses were conducted on the composited material of the stems, leaves and spikes separately for each replicate (3.2.3.2). The individual mine waters used are indicated with the respective tables of which the analyses are given in Table 3.1. The following crops were evaluated: maize cv. SNK 2340, sorghum cv. PAN 888, pearl millet (babala) cv. SA Standard, soybean cv. Ibis, and cowpea cv. Dr Saunders.

6.3.1.2 Results for subtropical crops

Maize, sorghum and pearl millet

The total top growth of maize, sorghum and pearl millet was not depressed significantly in the vegetative growth stage by either the $CaSO_4$- or NaCl-dominated water but seemed to be less on the $CaSO_4$ water than with the controls for all three these crops (Table 6.7 and 6.8). There was a significant decrease in stem mass in the case of maize and sorghum with the $CaSO_4$-dominated water (Figure 6.1).

The vegetative growth of these three species generally seemed to be influenced to a lesser extent by the NaCl mine water than by the $CaSO_4$ water despite an apparently higher EC of the NaCl water (but, Σ anions 39 *vs* 39 $mmol_c\ L^{-1}$) (Figure 6.1) (Table 6.7). The significant increases of

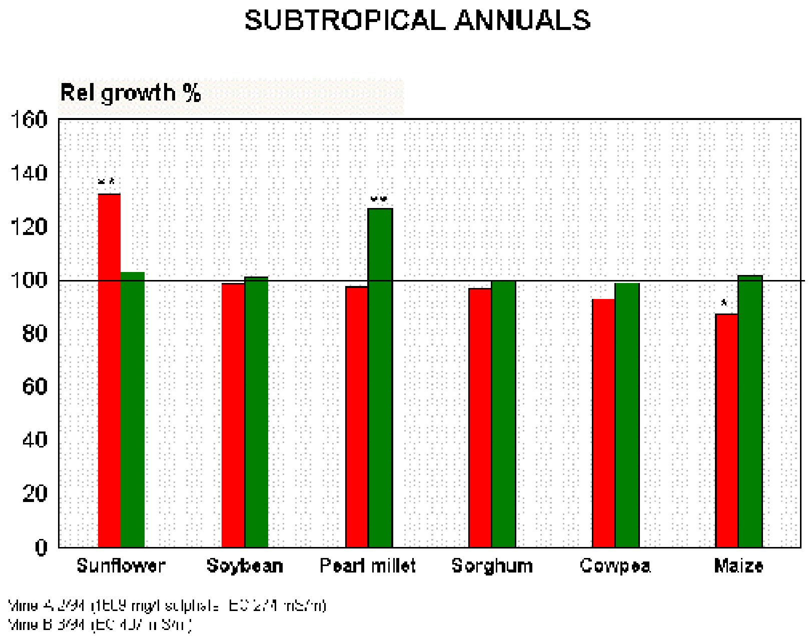
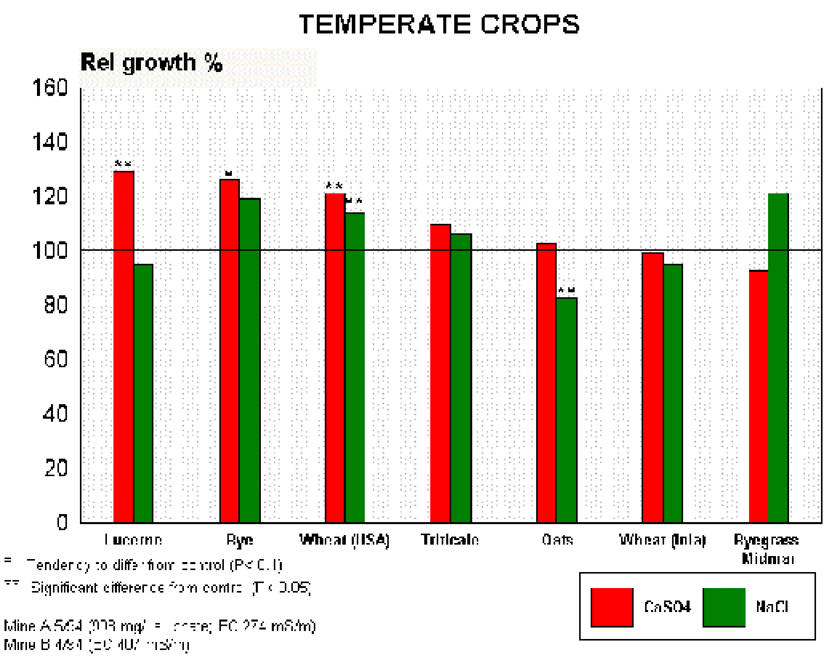


FIGURE 6.1 **The influence of $CaSO_4$ and NaCl mine water on the vegetative growth of subtropical and temperate crops.**



leaf area and succulence of maize on the NaCl water may indicate an osmotic adaptation to salinity (Table 6.7 and 6.8). This together with the increased tissue concentrations of Na, Cl and K in the maize hybrid (and possibly also in sorghum) with the NaCl-dominated mine water (Table 6.13), may indicate an osmotic adaptation by the uptake of these inorganic ions. The apparently higher growth masses may, however, also be due to earlier maturity with the NaCl water (Shannon, 1997). No symptoms indicating accumulation of toxic amounts of Na and Cl were observed and accumulation was therefore apparently not a major growth depressing mechanism in this more mature stage with the particular water and cultivars used.

Soybean, cowpea and dry bean

The relative top growth of soybean and cowpea was not significantly different from that of the control (Figure 6.2) (Table 6.7 and 6.8).

Soybean, however, developed a white marginal chlorosis on a few of the younger mature leaves after two to three weeks of salinisation (Figure 6.1). This could possibly be due to a Mo deficiency by sulphate competition; in the field trial where this cultivar was irrigated with a similar water, these symptoms did not occur (N.Z.Jovanovic, personal communication, 2000).The leaf area of **cowpea** decreased significantly together with a significant increase in succulence without the leaf mass being depressed; this could be an indication of a possible osmotic adaptation (2.2.2.2) (Table 6.7 and 6.8). Satisfactory yields were obtained with a similar water for soybean and cowpea in the field trial (Jovanovic et al., 1998).

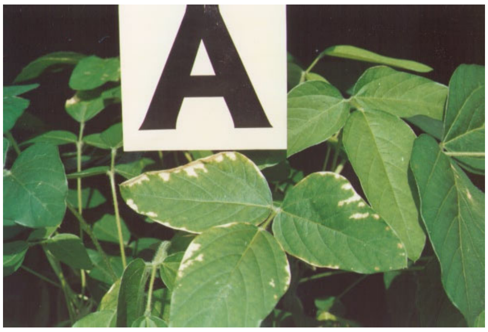


Figure 6.2 White marginal chlorosis on a few of the younger mature leaves of soybean on $CaSO_4$ water

Table 6.7 Growth parameters for subtropical annuals in the vegetative growth stage

Crop	Treat-Ment	Dry mass top growth g				Dry mass roots g	Leaf Area cm^2
		Stems	Leaves	Pods/ spikes	Total		
Maize SNK 2340	Control	47.64	41.26	3.92	92.81	26.45	8764
	Mine A	38.17**	39.00	3.51	80.68*	26.16	8571
	Mine B	46.29	43.70	4.45	94.43	29.77	9811**
c.v. %		13.08	7.13	25.72	9.54	13.62	5.75
Sorghum Hybrid PAN 888	Control	55.18	18.92	6.53	80.63	23.68	4872
	Mine A	51.84**	19.34	6.85	78.03	23.80	4980
	Mine B	54.34	19.91	6.31	80.55	21.87	5345
c.v. %		3.72	6.83	17.69	3.19	7.53	8.50
Soybean Ibis	Control	16.40	17.15	4.89	38.43	8.66	6158
	Mine A	16.36	16.75	4.67	37.78	7.11 *	6318
	Mine B	15.05	16.61	7.09***	38.75	6.72 **	5523*
c.v. %		15.60	9.33	16.24	9.09	15.68	7.33
Pearl millet ommon (babala)	Control	33.67	17.55	5.58	56.79	16.75	4229
	Mine A	31.27	17.32	6.50	55.09	15.96	3881
	Mine B	44.11 **	18.23	9.48	72.05***[1.]	14.00	4281
c.v. %		12.85	16.82	59.15	9.61	15.02	12.47
Cowpea Dr Saunders	Control	38.14	20.40	3.81	62.35	6.09	7606
	Mine A	34.33	19.58	4.14	58.04	6.89	6331***
	Mine B	35.73	21.34	4.50	61.56	6.70	6238***
c.v. %		10.84	9.95	16.93	9.38	17.64	5.39

* Tends to significant difference from control ($P<0.10$)
** Significant difference from control ($P<0.05$)
*** Highly significant difference from control ($P<0.01$)
Mine A 2/94
Mine B 3/94
1. This increase was due to earlier maturity of pearl millet on this water.

TABLE 6.8 Growth ratios of subtropical annuals in the vegetative growth stage

Species	Treat-Ment	Water % In top Growth	Succulence mg H_2O/cm^2 leaves	Leaves/ Stems	Top growth/ Roots	Relative growth % Leaves	Relative growth % Top growth
Maize	Control	83.91	16.69	0.87	3.59	100	100
SNK 2340	Mine A	84.08	17.36	1.03**	3.09	94.52	86.93*
	Mine B	85.77***	18.75***	0.96	3.18	105.91	101.43
Sorghum Hybrid PAN 888	Control	79.70	13.44	0.34	3.41	100	100
	Mine A	79.32	12.83	0.37	3.28	102.22	96.78
	Mine B	80.73	13.54	0.37	3.71	105.23	99.90
Soybean Ibis	Control	79.40	9.90	1.06	4.52	100	100
	Mine A	80.13	10.28	1.03	5.35	97.67	98.33
	Mine B	79.34	10.39	1.11	5.82**	96.85	100.83
Pearl millet Common (babala)	Control	81.36	22.27	0.53	3.40	100	100
	Mine A	82.71	21.88	0.56	3.49	98.69	97.01
	Mine B	81.05	21.15*	0.41	5.23***	103.87	126.87***
Cowpea Dr Saunders	Control	83.46	17.96	0.53	10.34	100	100
	Mine A	83.44	19.17**	0.57	8.50***	95.98	93.09
	Mine B	84.11	20.22***	0.61	9.53	104.60	98.73

Mine A 2/94 Mine B 3/94

TABLE 6.9 The influence of two mine waters on the vegetative top growth of sunflower cultivar SNK 43

Cultivar	Dry mass of topgrowth g/pot			Relative growth %		c.v. %
	Control	Mine C	Mine B	Mine C	Mine B[1.]	
SNK 43	41.85	55.38**	43.50	132**	103	5.2

Mine C 10/94; Mine B 7/94 & 11/94

TABLE 6.10 The influence of two mine waters on the yield of dry bean PAN 122

Cultivar	Yield (65□C) g/pot		Relative yield %	c.v.
	Control	Mine C	Mine C	%
PAN 122	34.17	45.71**	134*	26.7

Mine C 12/94
* Tends to significant difference from control (P<0.10)
** Significant difference from control (P<0.05)
*** Highly significant difference from control (P<0.01)

1 This particular sodic-saline water (Mine B 12/94), however seemed to 'improve' with time (2 months) probably due to the unusual presence of a black substance that settled, leaving a supernatant solution that was not at all saline with very low Na, Cl and SO_4 contents.

Dry bean cv. PAN 122 was evaluated separately on sand culture with a high sulphate Kleinkopje mine water (Mine C 12/94) but only dry seed yield was measured. The seed yield was increased by 34 % ($P<0.1$) on this water (Table 6.10).

As a relationship also exists between salt tolerance and the macro-nutrient accumulation in the vegetative organs of legumes (Cordovilla et al., 1995), the increased nutrients in the $CaSO_4$ water may have given rise to increased vegetative growth. Nutrient analyses of the top growth of **soybean** and **cowpea** confirmed an increased nutritional status with the $CaSO_4$ water: The N, P, K and total S tended to be increased above that of the control (Table 6.13 and 6.14). The dry matter content of all the nutrients except N was in the optimum range for soybean (Small & Ohlrogge, 1973).

Sunflower

The effect of the Kleinkopje mine water on sunflower growth from planting to 52 days (before flower buds appeared), was evaluated on sand culture in the glasshouse. The relative top growth was increased significantly by 32 % in the vegetative growth stage with the $CaSO_4$-dominated water (Table 6.9).

6.3.2 TEMPERATE CROPS

6.3.2.1 Method and materials

The vegetative growth of the following temperate crops was evaluated in water culture in a glasshouse. The method is described in Chapter 3 (3.2.3.3). The crops evaluated were: wheat cv. Inia and USA cultivar used on mine spoils, rye cv. SSR 1, oats cv. Overberg, triticale cv. Cloc 1, annual ryegrass cv. Midmar, and lucerne cv. PAN 4860.

6.3.2.2 Results for temperate crops

The annual temperate crops produced very few significant growth responses. The notable exceptions were rye, the wheat cultivar bred as a nurse-crop for use on mine spoils, and lucerne. With **rye** lime-treated acid mine drainage water had a significant beneficial effect on total top growth, the mass of roots and leaves produced, and the top growth to root ratio. Lime-treated acid mine drainage water produced 24 % more leaf material and 26 % more top growth than the control nutrient solution. The nurse-crop responded with significant increases in most of the growth parameters except for root dry mass (Tables 6.11 and 6.12) (Figure 6.1).

Lucerne grew exceptionally well in the vegetative growth stage with this lime-treated acid mine drainage water. Lucerne leaf, stem and root masses increased significantly (there were, however, a few ‘cupped’ leaves with a thin marginal necrosis) (Table 6.11). The yield of lucerne in the field trial confirmed the tolerance in the vegetative growth stage (Jovanovic et al., 1998).

The $CaSO_4$-dominated water also improved the leaf yield of **oats** and the leaf to stem ratio of **ryegrass** Midmar, both aspects of importance where these crops are used as forages. **Triticale** was not significantly influenced in any way although most growth parameters seemed to improve on this lime-treated acid mine drainage water (Tables 6.11 and 6.12).

6.4 CHEMICAL ANALYSES OF TOP GROWTH

Chemical analyses were conducted on the top growth to establish whether the high Ca and SO_4 concentrations in the lime-treated acid mine drainage mine waters showed cation or anion antagonistic effects on nutrient uptake.

Nutrient analyses were conducted on the composited material of the total top growth separately for each replica for the subtropical crops; in the case of the temperate crops the replicates of the leaf and stem material respectively were combined (3.2.3.4). The concentration and total uptake of nutrient elements in the subtropical crops are given in Tables 6.13 and 6.14 respectively, and those of the temperate crops are given in Tables 6.15 and 6.16. Statistical analyses were conducted for the subtropical crops to determine the effect of these waters on the nutrient uptake (3.1.2), but was not possible for the temperate crops as replicates were combined.

6.4.1 CALCIUM INTERACTIONS

There were increased dry mass concentrations and total uptake of **Ca** in the top growth of all the crops (Tables 6.13 to 6.16), that compared well with the average Ca content of plants (0.5 to 3.0 %) (Marschner, 1986).

Although **K** uptake has been found to be competitively affected by Ca in maize roots (Elzam & Hodges, 1967), it was not significantly diminished in the shoots of maize or the other subtropical crops with the lime-treated acid mine drainage water. K uptake even seemed generally higher, with a significant increase in sorghum (Tables 6.13 and 6.14). In the seedling growth stage of maize cv. SNK 2340 nutrient analyses also revealed that the high Ca and Mg content of the Kleinkopje water did not significantly affect the K uptake (Table 5.29).

Antagonistic Ca effects were not evident in a decrease of **Mg** in the top growth of the subtropical crops with the lime treated acid mine drainage water; on the contrary Mg concentrations in the top growth of the subtropical crops generally *increased* significantly (Table 6.13). In contrast the Mg uptake in the temperate crops was *decreased* to about half that of the control in rye, oats, triticale and wheat Inia but was not influenced in ryegrass and the wheat nurse-crop (Table 6.15). The concentrations were low compared to the average 0,5 % of the dry mass of the vegetative parts for optimal plant growth (Marschner, 1986) (Table 6.15). Slight Mg deficiency in the vegetative growth stage of cereals does not, however, always result in a decreased yield (Mengel & Kirkby, 1987).

The Mg content in the lime treated acid mine drainage water was very low probably resulting in active uptake of Mg. The higher uptake of Mg in the summer crops compared to the suppressed uptake in the winter crops may possibly be due to the effect of the temperatures on the active uptake of Mg.

The greater uptake of Mg in ryegrass and the wheat nursecrop compared to the other crops, may be due to genetic characteristics such as osmotic adaptation, which may be partly responsible for the good growth of these crop cultivars on this water (Sagi, et al., 1997) (Table 6.15 and 6.16).

A high external **Ca:Mg** ratio has been found to decrease the photosynthetic rate and water use efficiency for maize (Plaut and Grieve, 1988). Although there were such indications in maize and sorghum, the high Ca:Mg ratio in the lime treated acid mine drainage water was, however, not accompanied by significantly suppressed growth in most of these crops (Table 6.7). The significant increase in Mg uptake with the NaCl water could be due to a higher external Mg:Ca ratio in this water (Mengel & Kirkby, 1987) (Table 6.13 and 6.15).

There was a significant increase in the **Mn** uptake with the lime-treated acid mine drainage water (Table6.13), but it was still well below toxicity levels (Chapman, 1966); however, for soybean, toxicity could be induced at only 160 mg kg^{-1} (Mengel & Kirkby, 1987). This increase was probably due to the higher Mn content of the water used in comparison to the control. Additional manganese was also given with the nutrients without which the uptake would probably have been less. With a water with a higher Mg content (as was the case with the Kleinkopje water used in the seedling experiments), Mn uptake would probably not be increased as Mg has an antagonistic effect on Mn uptake and can prevent Mn toxicity (Mengel & Kirkby, 1987). This was confirmed by the analyses of the seedling top growth of maize cv. SNK 2340 on the Kleinkopje water, where Mn uptake was significantly decreased (Table 5.29).

With the **NaCl**-dominated mine water (Mine B 4/94), the total **Ca**-uptake per pot was increased significantly for sorghum, cowpea and the wheat nursecrop indicating an efficient Ca uptake of these crop cultivars. The **Na** and **Cl** content of maize was the highest of the subtropical crops and together with the significantly *increased* leaf area and succulence it may be an indication of an inorganic osmotic adaptation of this maize cultivar via the uptake of Na and/or Cl (Cramer,

1994) (Table 6.13). The Na and Cl uptake was least for wheat cv. Inia and high for oats cv. Overberg. This corresponds with a tolerance of Inia and a sensitivity of oats for NaCl water (Table 6.11). The Cl content of the two wheat cultivars was furthermore the least of all the crops, which could be due to exclusion from the shoots. The vegetative growth of annual ryegrass seemed to be unaffected by the high concentrations of Na and Cl in the top growth (Tables 6.11), but ryegrass is generally tolerant to NaCl-dominated salinity at these concentrations (Marschner, 1995).

6.4.2 SULPHATE INTERACTIONS

The **total S** (given as SO_4) in the top growth of all crops evaluated was increased significantly with the high sulphate water (Tables 6.13 to 6.16). S concentration in the total top growth of the subtropical crops varied between 1.08 % of the dry mass for maize and 2.56 % for soybean. In the temperate crops S uptake was increased in both the leaves and stems; the S (given as SO_4) content in the leaves ranged from 1,92 % in ryegrass to 2,24 % in rye; this is higher than the critical requirement of cool season grasses of 0,2 to 0,26 % (Martin and Walker, 1966).These levels should, however, not be detrimental to plant growth (2.5.2.2).

Table 6.11 The influence of two types of mine water on the vegetative growth parameters of annual temperate crops

Crops		Treat-Ment	Leaves Wet mass g/pot[1.]	Leaves dry mass g/pot	Tillers/stems No.	Tillers/stems Dry mass g/pot	Total dry mass top growth g/pot	Rel. Growth %	Roots dry mass g/pot	Leaf area cm^2/pot
1	Rye	Control	185.91	20.99	75	13.03	34.01		3.41	7182.06
	SSR1	Mine A	187.27	26.01**	88	17.00	43.01*	126 *	5.38**	7544.38
		Mine B	195.81	25.50*	74	15.13	40.63	119	3.53	8966.92**
	c.v. %		8.93	12.56	19.34	21.33	14.51		27.22	6871.79
2	Oats	Control	188.56	24.85	23	30.81	55.66		5.05	6871.79
	Overberg	Mine A	189.35	27.18*	25	30.15	57.33	103	4.64	6935.84
		Mine B	180.98	22.09**	28 **	23.92*	46.01**	83 **	3.42***	6389.17
	c.v. %		6.21	6.50	11.51	15.63	10.91		15.90	7.16
3	Triticale	Control	172.38	19.28	102	6.47	25.75		4.17	6536.34
	Cloc 1	Mine A	177.01	21.14	111	7.18	28.32	110	3.99	6588.43
		Mine B	167.63	20.02	110	7.24	27.26	106	3.82	5880.44***
	c.v. %		5.47	8.11	8.63	13.42	9.29		19.57	6.63
4	Wheat	Control	43.24	8.81	26	14.80	28.23		3.26	2349.61
	Inia	Mine A	46.14	9.03	29	14.37	28.06	99	2.76*	2414.01
		Mine B	48.67	9.95*	34 ***	13.39	26.68	95	2.76*	2527.73
	c.v. %		10.23	9.09	5.53	10.7	10.48		10.99	10.51
5.	Ryegrass	Control	137.50	15.63	173	7.50	23.13		4.31	4985.77
	Midmar	Mine A	140.48	15.18	167	6.22	21.40	93	4.04	5756.82
		Mine B	173.59**	18.47	173	9.57*	28.04	121	4.97	7256.26
	c.v. %		13.15	18.39	26.17	22.65	19.16		37.61	26.69
6	Wheat (USA)	Control	127.81	17.50	45	8.05	25.55		3.55	4178.19
	Nursecrop for mine	Mine A	163.16***	20.58**	51	10.37**	30.95***	121 ***	3.98	5724.85 **
	Spoils	Mine B	143.53*	19.49*	72 ***	9.68*	29.17 **	114 **	3.61	4918.81
	c.v %		7.58	7.22	10.41	11.42	7.41		12.58	14.46

* Tendency to differ from control (P < 0.1) ** Significant difference from control (P < 0.05) *** Highly significant difference from control (P < 0.01)

Mine A 5/94 Mine B 4/94 (Both waters diluted by rain)

1. 3 Plants per pot

Lucerne PAN 4860	Control	51.73	8.65	30	7.68	16.33	100	3.97	2969.67
	Mine A	60.06 *	11.55 **	31	9.32*	20.87**	129 **	5.85**	3364.25
	Mine B	42.80	7.66	24	6.49	14.15	95	2.91**	2412.36
c.v. %		14.64	14.79		16.02	13.77		12.47	24.1

* Tendency to differ from control (P < 0.1) ** Significant difference from control (P < 0.05) *** Highly significant difference from control (P < 0.01)

Mine A 5/94 Mine B 4/94 (Both waters diluted by rain)
1. 3 Plants per pot

Table 6.12 Growth ratios for temperate annuals

Crops	Treat-Ment	Leaves/ Stems	Tops/ Roots	leaf area mg H_2O/cm^2	Relative top growth %
1. Rye SSR1	Control	1.62	10.59	23.00	100
	Mine A	1.60	8.23**	21.48	126
	Mine B	1.69	11.97	19.51*	119
2. Oats Overberg	Control	0.81	11.19	23.81	
	Mine A	0.91	12.40	23.46	103
	Mine B	0.95	13.58**	24.87	83 *
3. Triticale Cloc 1	Control	3.00	6.24	23.51	100
	Mine A	2.99	7.42	23.65	110
	Mine B	2.77	7.35	30.25***	106
4. Wheat Inia	Control	0.60	8.70	14.66	100
	Mine A	0.63	10.31	15.17	99
	Mine B	0.74	9.71	15.33	95
5. Ryegrass Midmar	Control	2.11	5.92	25.96	100
	Mine A	2.49*	5.61	23.20	93
	Mine B	1.95	5.74	22.14*	121
6. Wheat (USA) Nursecrop on mine spoils	Control	2.18	7.20	26.46	100
	Mine A	1.99	7.84	25.04	121 **
	Mine B	2.04	8.21	25.60	114 *
c.v. %		11.55	16.24	12.55	
Lucerne PAN 4860	Control	0.95	7.63	12.49	100
	Mine A	1.06	7.90	13.96	129 *
	Mine B	0.89	9.87***	14.78**	95
c.v. %		20.26	15.59	12.89	12.89

* Tends to significant difference from control(P<0.10)
** Significant difference from control (P<0.05)
*** Highly significant difference from control(P<0.01)

Table 6.13 Concentration of nutrient elements in the top growth of subtropical annuals with two mine waters in the vegetative growth stage

Species	Treatment	N	P	K	Ca	Mg	Na	Sulphate	Cl	Fe	Mn	Cu	Zn
		%								mg kg^{-1}			
Maize SNK 2340	Control	0.955	0.145	0.983	0.173	0.138	0.00	0.813	0.072	18	45	3	6
	Mine A	0.820*	0.140	1.183	0.337*	0.163	0.00	1.080*	0.158	21	131 *	2	12 *
	Mine B	0.688*	0.118*	1.178	0.213	0.323*	0.63*	0.210*	2.752*	35 *	30 *	3	3
	c.v. %	7.01	6.92	12.27	12.59	12.51	30.00	14.45	20.0	50.78	9.17	42.42	34.62
Sorghum Hybrid PAN 888	Control	1.088	0.145	0.855	0.213	0.165	0.00	0.965	0.079	30	89	6	13
	Mine A	0.943	0.140	1.123*	0.370*	0.250*	0.00	1.428*	0.144	51	221 *	6	25 *
	Mine B	1.100	0.155	1.033*	0.283*	0.443*	0.058*	0.240*	2.634*	59 *	33 *	5	11
	c.v. %	13.09	9.64	7.64	9.21	10.67	45.18	12.27	4.41	48	8.03	25.53	17.89
Soybean Ibis	Control	2.23	0.263	1.648	0.703	0.330	0.00	1.410	0.077	68	188	8	29
	Mine A	2.46	0.293	1.868	1.493*	0.408*	0.00	2.565*	0.122	77	316 *	8	52 *
	Mine B	2.29	0.308	1.995*	1.263*	0.625*	0.058*	0.518*	0.800*	75	99 *	6	26
	c.v. %	14.01	9.15	11.58	4.31	6.47	66.79	4.99	10.96	12.81	6.64	17.00	10.85
Pearl millet SA Standard Common (Babala)	Control	1.298	0.208	1.525	0.243	0.268	0.00	1.405	0.088	47	128	4	17
	Mine A	1.258	0.215	1.763	0.383*	0.435*	0.10*	1.755*	0.180	41	350 *	4	33 *
	Mine B	1.178	0.193	1.595	0.218	0.423*	0.24*	0.385*	2.12*	31 *	55 *	4	11
	c.v. %	20.65	14.03	17.24	22.34	16.45	27.84	11.22	16.64	31.70	20.96	19.76	36.69
Cowpea Dr Saunders	Control	2.523	0.198	1.425	0.685	0.235	0.00	1.613	0.077	71	302	5	21
	Mine A	3.235*	0.215	1.428	1.143*	0.308*	0.00	2.205*	0.134*	72	486 *	2*	37 *
	Mine B	3.060	0.193	1.490	1.048*	0.465*	0.255*	0.973*	0.866*	67	132 *	4	12 *
	c.v. %	12.40	9.71	9.59	18.01	9.76	19.61	7.87	9.52	18.65	16.22	15.38	18.96

*Significant difference from control ($P < 0.05$)

TABLE 6.14 Total uptake of nutrients in the top growth of subtropical annuals with two mine waters in the vegetative growth stage

Crop	Treatment	N	P	K	Ca	Mg	Na	Sulphate	Chloride	Fe	Mn	Cu	Zn
		g/pot								mg/pot			
Maize SNK 2340	Control	0.884	0.135	0.909	0.159	0.127	0.00	0.748	0.067	1.63	4.17	0.24	0.58
	Mine A	0.662*	0.113*	0.940	0.270*	0.132	0.00	0.869*	0.127	1.68	10.57*	0.18	0.97
	Mine B	0.648*	0.111*	1.105*	0.199	0.303*	0.591*	0.196*	2.580*	3.18*	2.78	0.24	0.24
Sorghum Hybrid PAN 888	Control	0.877	0.117	0.689	0.171	0.133	0.00	0.777	0.063	2.39	7.12	0.51	1.07
	Mine A	0.733	0.109	0.875	0.289*	0.195*	0.00	1.113*	0.112	3.38	17.25*	0.44	1.96*
	Mine B	0.889	0.125	0.831	0.228*	0.356*	0.046*	0.193*	2.121*	4.78*	2.69*	0.39*	0.85
Soybean Ibis	Control	0.861	0.101	0.624	0.269	0.126	0.00	0.543	0.031	2.61	7.26	0.32	1.08
	Mine A	0.928	0.110	0.705	0.564*	0.154	0.00	0.969*	0.046	2.90	11.94*	0.30	1.97*
	Mine B	0.882	0.118	0.768	0.488*	0.241*	0.022	0.198*	0.308*	2.92	3.85*	0.25	1.01
Pearl millet common (Babala)	Control	0.742	0.117	0.857	0.135	0.150	0.00	0.786	0.049	2.56	7.19	0.23	0.94
	Mine A	0.699	0.119	0.978	0.210*	0.241*	0.056*	0.969*	0.100	2.26	19.40*	0.21	0.84
	Mine B	0.843	0.138*	1.144*	0.157	0.305*	0.170*	0.277*	1.525*	2.22	3.96*	0.30	0.82
Cowpea Dr Saunders	Control	1.577	0.123	0.883	0.423	0.146	0.00	1.002	0.048	4.40	18.62	0.28	1.33
	Mine A	1.875	0.125	0.828	0.663*	0.178	0.00	1.280*	0.077	4.18	28.21*	0.09*	2.15*
	Mine B	1.868	0.117	0.913	0.633*	0.283*	0.159*	0.598*	0.531*	4.12	8.12*	0.23	0.75

*Significant difference from control ($P < 0.05$).

Table 6.15 Concentration of some nutrient elements in the top growth of annual temperate crops with two types of mine water

Crops	Treat-ment	Ca		Mg		SO_4		Na		Cl	
		%									
		Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems
1. Rye SSR 1	Control	1.43	0.92	0.62	0.44	1.51	0.9	0.03	0.03	0.05	0.05
	Mine A	1.99	1.37	0.35	0.27	2.24	1.68			0.20	0.19
	Mine B	1.05	0.77	0.13	0.36	1.27	0.69	1.10	0.72	2.60	3.20
2. Oats Overberg	Control	0.70	0.40	0.42	0.26	1.47	0.66	0.14	0.44	0.02	0.04
	Mine A	1.28	0.85	0.20	0.16	2.12	1.40			0.10	0.17
	Mine B	0.63	0.51	0.38	0.26	1.62	0.69	1.94	3.34	2.88	4.44
3. Triticale Cloc 1	Control	0.85	0.69	0.40	0.38	1.59	1.03	0.02	0.04	0.06	0.07
	Mine A	1.51	1.27	0.20	0.25	2.20	1.80			0.20	0.20
	Mine B	0.73	0.50	0.33	0.28	1.48	0.79	1.12	1.06	2.09	2.73
4. Wheat Inia	Control	1.31	0.37	0.45	0.14	1.57	0.87	0.01	0.02	0.03	0.06
	Mine A	2.03	0.67	0.22	0.09	2.00	1.52			0.14	0.23
	Mine B	0.99	0.37	0.65	0.26	1.65	0.96	0.39	0.33	0.99	1.27
5. Ryegrass Midmar	Control	0.81	0.62	0.41	0.27	1.39	0.76	0.12	0.38	0.06	0.07
	Mine A	1.35	1.06	0.32	0.31	1.92	1.48			0.19	0.19
	Mine B	0.87	0.51	0.39	0.24	1.24	0.63	1.96	2.27	3.08	3.84
6. Wheat (USA) Nursecrop for mine spoils	Control	2.19	1.20	0.28	0.13	1.49	0.60	0.06	0.06	0.05	0.04
	Mine A	3.17	1.86	0.22	0.25	2.12	1.52			0.26	0.21
	Mine B	3.29	1.37	0.38	0.27	1.06	0.90	1.95	1.93	0.59	0.62
Lucerne PAN 4860	Control	0.83	0.49	0.53	0.44	1.03	0.56	0.04	0.1	0.04	0.05
	Mine A	1.10	0.63	0.42	0.11	1.68	1.40	0.25		0.25	-
	Mine B	0.77	0.57	0.44	0.40	0.98	0.79		1.67	2.79	2.53

Mine A 5/94
Mine B 4/94

1. Both these waters were diluted by heavy rain.

Table 6.16 Total uptake of nutrient elements by annual winter crops

Crops	Treat-ment	Ca		Mg		SO_4		Na		Cl	
		g/pot[1.]									
		Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems	Leaves	Stems
1. Rye SSR 1	Control	0.30	0.12	0.13	0.06	0.32	0.12	0.006	0.004	0.01	0.007
	Mine A	0.52	0.23	0.09	0.05	0.58	0.28			0.05	0.03
	Mine B	0.27	0.12	0.03	0.05	0.32	0.10	0.28	0.11	0.66	0.48
2. Oats Overberg	Control	0.17	0.12	0.10	0.08	0.37	0.20	0.03	0.14	0.005	0.01
	Mine A	0.35	0.26	0.05	0.05	0.58	0.42			0.027	0.05
	Mine B	0.14	0.12	0.08	0.06	0.36	0.17	0.43	0.80	0.64	1.06
3. Triticale Cloc 1	Control	0.16	0.04	0.08	0.02	0.31	0.07	0.004	0.002	0.01	0.005
	Mine A	0.32	0.09	0.04	0.02	0.47	0.13			0.04	0.01
	Mine B	0.15	0.04	0.07	0.02	0.30	0.06	0.22	0.08	0.42	0.20
4. Wheat Inia	Control	0.12	0.05	0.04	0.02	0.14	0.13	0.001	0.003	0.003	0.009
	Mine A	0.18	0.10	0.02	0.01	0.18	0.22			0.013	0.03
	Mine B	0.10	0.05	0.06	0.03	0.16	0.13	0.04	0.04	0.10	0.17
5. Ryegrass Midmar	Control	0.13	0.05	0.06	0.02	0.22	0.06	0.02	0.03	0.009	0.005
	Mine A	0.20	0.07	0.05	0.02	0.29	0.09			0.03	0.01
	Mine B	0.16	0.05	0.07	0.02	0.23	0.06	0.36	0.23	0.57	0.37
6. Wheat (USA)	Control	0.38	0.10	0.05	0.10	0.26	0.05	0.01	0.005	0.009	0.003
Nursecrop for mine spoils	Mine A	0.65	0.19	0.05	0.03	0.44	0.16			0.05	0.02
	Mine B	0.64	0.13	0.07	0.03	0.21	0.09	0.38	0.19	0.11	0.06
Lucerne PAN 4860	Control	0.12	0.08	0.08	0.07	0.15	0.09	0.01	0.02	0.007	0.01
	Mine A	0.22	0.12	0.08	0.02	0.33	0.27			0.02	0.04
	Mine B	0.10	0.09	0.06	0.06	0.13	0.12	0.27	0.25	0.11	0.17

Mine A 5/94

Mine B 4/94

1. 3 plants per pot

Anion antagonistic effects have been evident where Cl, SO_4 and H_2PO_4 uptake were stimulated when the NO_3 uptake was strongly depressed (Kirkby & Knight, 1977). Although the most common anion antagonism is between NO_3 and Cl, such an effect of high SO_4 concentrations on the uptake of H_2PO_4 and NO_3 is not excluded.

N nutrition

The **N** uptake of **maize** cv. SNK 2340 was significantly decreased by 0,135 % which may indicate a possible competition of SO_4 more probably with MoO_4 than with NO_3 . The **N** content was in the low range for maize (Chapman, 1966), but even though there were significant decreases of N on both waters, there were no obvious symptoms of deficiency except in the decreased stem masses.

Although N x S interaction has generally been found to be positive or additive (Tandon, 1992), a large difference in SO_4 and NO_3 concentrations may possibly result in a N-deficiency due to competition between these anions. In the seedling growth trials (4.2.2.1) wheat seedlings growing on an actual $CaSO_4$-dominated mine water with an NH_4:NO_3 ratio of 1:2 showed no deficiency symptoms (4.2.2). This was in contrast to severe chlorosis when less NH_4 was given but with similar solution concentrations of N (46,8 $mmol_c\ L^{-1}$ SO_4 , 4.1 $mmol_c\ L^{-1}$ NO_3 and *ca.* 1 $mmol_c\ L^{-1}$ NH_4) (Table 4.8). Ammonium could therefore have provided additional N where a ratio of 1:2 was used.

The influence of NH_4 was confirmed by a subsequent study where the effect of differential levels of K, NO_3 and NH_4 on the top growth of wheat with Ca/Mg/SO_4 salinity was investigated (Ströhmenger, et al., 1999). Top dry matter was improved with K and NH_4 treatments. The data suggest enhanced NH_4 nutrition under SO_4 salinity. The following possible reasons for this are suggested: an antagonistic effect of NH_4 on plant Mg concentration, a synergistic effect on K uptake and/or to NH_4 being a supplementary N source when large SO_4 concentrations suppressed NO_3 uptake. N utilization efficiency was also higher with NH_4 than with NO_3 at similar solution concentrations of N (Ströhmengher, P. H. F., personal communication, 2000).

There were indications that the N uptake in cowpea may have been favourably influenced by the $CaSO_4$ water (Tables 6.13 and 6.14). In the exploratory trial (3.2.3.1), the growth of root nodules with a similar lime-treated acid mine drainage water (but with a lesser nutrient content) was exceptional. The $CaSO_4$ water may thus possibly have influenced N uptake of legumes via a positive effect on nodule growth.

The greater decrease of N content generally found with the NaCl water could be due to competition between chloride and nitrate ions (Table 6.13 and 6.15).

Sulphate can also compete with **molybdate** for uptake (Stout et al., 1951). As molybdate is necessary for protein synthesis this could reduce growth (Barnard, 1978; Albasel & Pratt, 1989). Growth reduction was, however, not evident in the top growth of most of the crops evaluated with the $CaSO_4$ water (Tables 6.7 and 6.11). Analysis for Mo was conducted only in the case of soybean, where a few leaves showed possible deficiency symptoms (Figure 6.1). The Mo content of the total top growth was, however, 2 mg kg^{-1} which is generally sufficient (Chapman, 1966).

P uptake

The high SO_4 concentrations in the lime-treated acid mine drainage waters were not generally accompanied by P decreases in the top growth concentration of the subtropical crops. The significant decrease in the total uptake of P in maize was an exception, but may be due to the decreased growth (Table 6.14).The P concentration was not significantly affected (Table 6.13).

Studies with maize in solution cultures have shown that P concentrations that are optimal under non-saline conditions, could be toxic to and adversely affect the growth of maize when grown under saline conditions (Nieman & Clark, 1976). This was not the case in the current investigation for the vegetative growth stage of most crops on either the high sulphate lime-treated acid mine drainage or NaCl water. The P uptake was less for maize with the NaCl water relative to the control, indicating competitive effects with the Cl (Table 6.13).

In conclusion it can be said that the high Ca and SO_4 concentrations and uptake with the lime-treated acid mine drainage water did not generally affect the uptake of other nutrients. There were two exceptions: Mg plant concentrations were increased in summer crops and decreased in the winter crops, and the N concentration in maize top growth was significantly decreased.

This research was not designed to investigate nutrient interactions. Further research into the possible interactions of especially Ca, Mg and SO_4 with other macro- and micronutrients is therefore recommended with soil chemistry also taken into account.

6.5 COMPARISON OF THE SEEDLING AND VEGETATIVE GROWTH STAGE WITH GYPSIFEROUS MINE WATER

The vegetative growth stage in this investigation cannot be compared per se to that of the germination and seedling stages as the lime-treated acid mine drainage waters available at the time of the vegetative experiments were diluted by heavy rain. The seedling and germination growth stages, and also the vegetative growth of sunflower and the yield of dry bean, were subsequently investigated on Kleinkopje mine water with higher Ca, Mg and SO_4 concentrations than those initially used for the vegetative growth (3.1.2).

The vegetative growth may, however, be compared to the seedling growth in the gradient trials plotted at the appropriate total anion concentration values (indicative of osmotic potential) of the respective mine waters used (Figures 6.3 to 6.5).

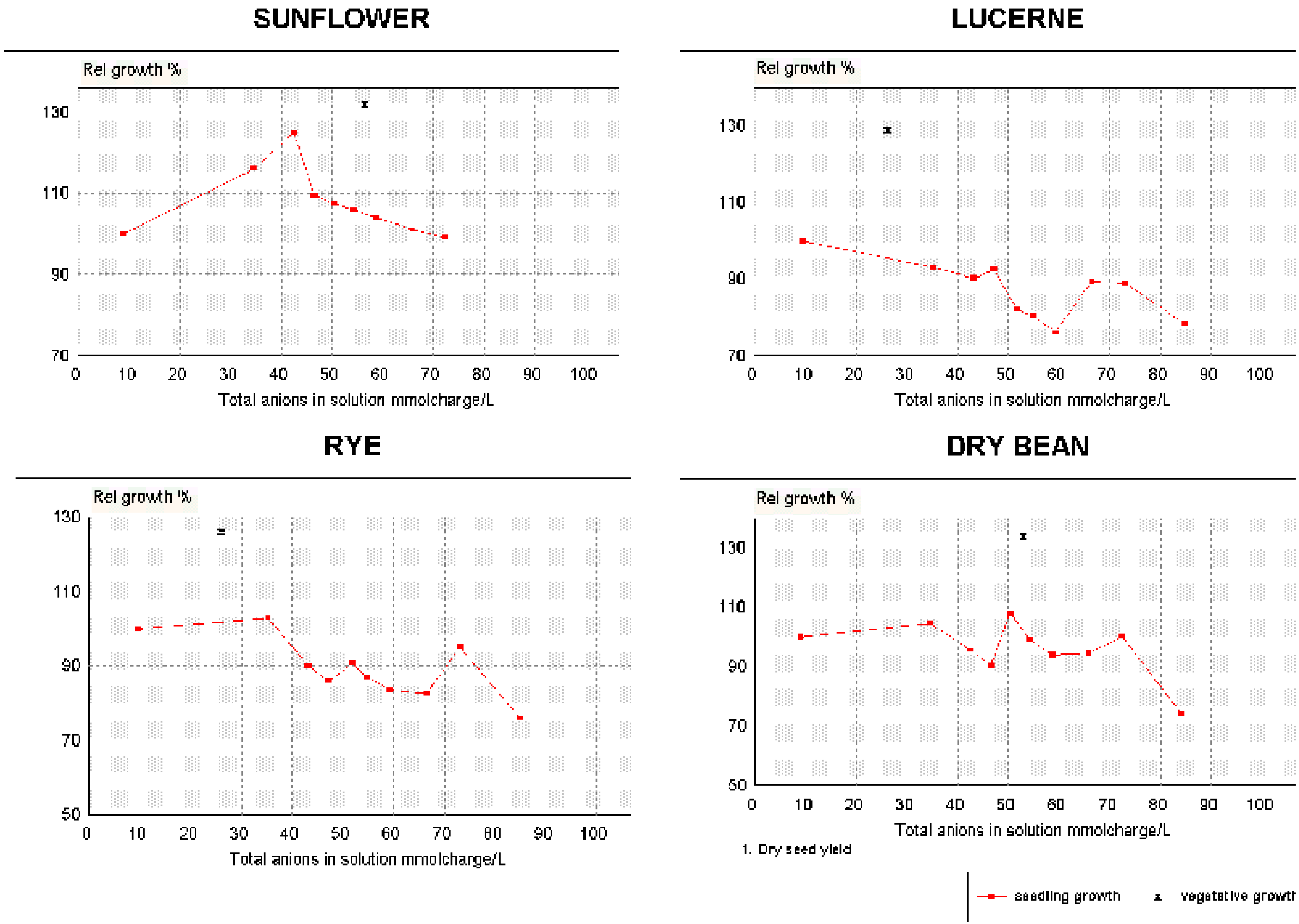


FIGURE 6.3 Crops where the vegetative growth was greater than the seedling growth at similar osmotic potentials.

These comparisons revealed that crops could be divided into three groups, namely:

1. Crops where the relative *vegetative growth* and thus the tolerance was very much *greater than* that of the *seedling growth* at similar osmotic potentials; this was the case for **sunflower**, **lucerne** and **rye**, and the relative *yield* of **dry bean** (Figure 6.3). It is probable that the major mechanism by which salinity affects seedling and vegetative growth of these crops differs, and that decreased osmotic potential is less suppressing in the vegetative than in the seedling growth stage.

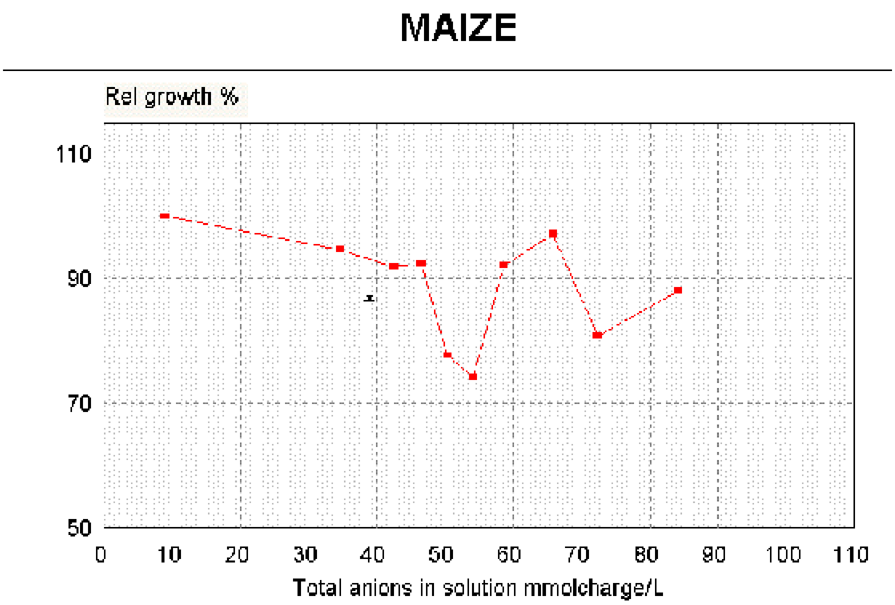
Sunflower possesses the capacity for osmotic adjustment (Chimenti & Hall, 1993, 1994), which moderates stomatal closure, thus allowing continued photosynthetic activity under drought conditions (Conroy, Virgona, Smillie & Barlow, 1997). This characteristic would be advantageous for tolerance to the $CaSO_4$ water where it is increasingly evident from the present study that osmotic potential is the major suppressing quality of this type of saline water. The ability for osmotic adjustment together with its high stomatal conductance, even under drying conditions (Robinson, 1978), probably explains why both seedling and vegetative growth were increased on this water. The high stomatal conductances of sunflower lead to a lavish water use (Rawson & Constable, 1980), which together with the tolerance shown for the $CaSO_4$ saline water both during seedling and vegetative growth stages, make it a prime candidate for water disposal via irrigation.

In the case of **lucerne** the seedling growth is mainly affected by osmotic potential and the mature growth by Cl toxicity; tolerance is associated with the exclusion of Cl or the level of Cl tolerated (Noble, Halloran & West, 1984). Salt tolerance of lucerne is also associated with rapid increases of proline - especially in roots - which is an adaptation to a decrease in external osmotic potential (Petrusa & Wincov, 1997). The increased vegetative growth on this water may also be due to increased nutrient levels above those of the one-third Hoagland control, as legumes have a high Ca and S requirement (Cordovilla et al., 1995). A $CaSO_4$-dominated water may thus lead to decreased seedling growth but increased vegetative production of lucerne, due to the absence of Cl, osmoregulation and nutrient effects.

The tolerance of **rye** has been mainly connected to the Na/Ca ratio in the growth medium (Grattan & Grieve, 1994), and the exclusion of Na from the leaves (Francois et al., 1989). It is thus understandable why rye grew so well on this water where Na and Cl were virtually absent and Ca abundantly present; it can be expected that vegetative growth and yield should not decrease to the same extent on a $CaSO_4$ water as on a NaCl water with low Ca content. The good vegetative growth with the NaCl water (Table 6.11), may possibly be ascribed to an ability of this particular cultivar to restrict Na and/or Cl from the leaves.

In **dry bean** growth suppression is mainly connected to high Na concentrations (Benlloch, Ojeda, Ramos & Rodriguez-Navarro, 1994), and Na toxicity has been found to be a greater growth suppressing factor than osmotic potential (Awada et al., 1995). Under constant salinity dry bean also showed a slight adaptation to saline conditions (Meiri & Poljakoff-Mayber, 1970). Wignarajah (1990) found that dry bean plants adjusted osmotically to salt stress and suggested that "two major physiological traits enable plants to tolerate salinity: (a) compensatory growth following adjustment to salinity, and (b) ability to increase both leaf area ratio (LAR) and net assimilation rate (NAR) to achieve this increased growth". As mentioned previously, a relationship has also been suggested to exist in legumes between NaCl-salt tolerance and the macro-nutrient accumulation in the vegetative organs (Cordovilla et al., 1995).The low Na content, as well as osmotic adaptation and the increased nutrients in the Kleinkopje $CaSO_4$-dominated water could thus have given rise to the increased yield of dry bean and possibly also to better vegetative growth (Figure 6.2, Table 6.10).

2. Crops where the relative *vegetative* growth and thus the tolerance was apparently *less* than that of the *seedling* growth at similar osmotic potentials, namely with **maize** cv. SNK 2340 and **cowpea** (Figure 6.4).



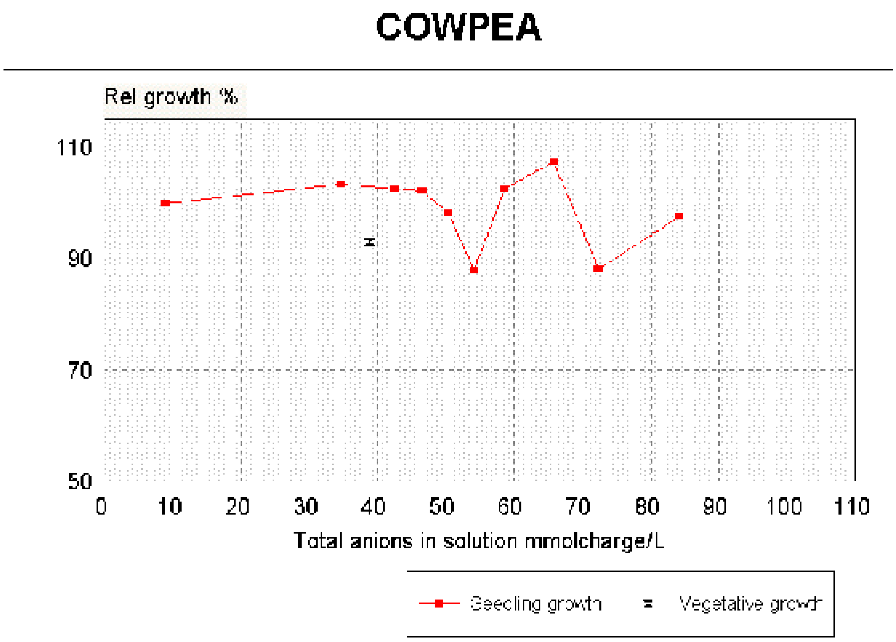


FIGURE 6.4 **Crops where the vegetative growth was less than that of the seedling growth at similar potentials**.

This is in contrast to the studies of Maas et al. (1983) on the sensitivities of the growth stages of **maize** with NaCl salinity where the seedling growth stage up to 21 days was the most sensitive. The salt tolerance thresholds for growth after 21 days, and for the ear and grain yields were, however, higher than for seedling growth.

Cramer (1994) concluded that the reduction of growth in maize by salinity appears to be caused by a reduced leaf area, primarily caused by an osmotic potential effect. The greater suppression of vegetative growth compared to the seedling growth (Figure 6.5), can possibly be attributed to a cumulative effect of the osmotic potential on the leaf area as the number of leaves increased, leading to a reduction of total photosynthesis and growth. Although the leaf area of maize was not significantly decreased, it did tend to be less (Table 6.7). Alternatively the growth decrease may also be due to antagonistic cation and anion effects (6.4.2). A further possibility is that the difference between the seedling and the vegetative growth of maize may also be due to the difference in composition, especially the Ca and Mg contents and ratios, of the two waters used (Mine C 3/95 vs. Mine A 2/94, Table 3.1).

Although the tolerance of **cowpea** has been connected to Cl exclusion (Keating, 1986), decreased osmotic potential may be an additional growth-retarding factor. As the lime-treated acid mine drainage water resulted in a significant reduction of the leaf area in the vegetative growth stage (Table 6.7), it is possible that the vegetative growth of cowpea was affected in a similar manner to that attributed to maize by Cramer (1994).

It is therefore possible that if osmotic potential suppresses the vegetative growth of a particular crop or cultivar, mainly via decreasing the leaf area, this could result in greater sensitivity of such crops in the vegetative growth stage compared to the seedling stage.

3. Crops where the relative *vegetative growth* and thus the tolerance was *similar to* the seedling growth. This seemed the case with **sorghum**, **pearl millet** and **wheat**, and probably also **oats**, **triticale** and **ryegrass**, although there were indications of better growth in the vegetative stage of these last mentioned crops, but to a much lesser extent than with lucerne, rye and sunflower (Figure 6.5). With these crops osmotic potential seems to have a similar effect in both the seedling and vegetative stage.

The decrease of the osmotic potential has been shown to be the major property of salinity by which the growth of **maize**, **sorghum** and **pearl millet** is suppressed (Cramer, 1994, maize; Ashraf & Idrees, 1995, pearl millet; and Shannon, 1997, sorghum). The relative leaf growth of sorghum in the vegetative stage tended to be affected less than that of maize (Table 6.7). This is possibly one reason why the growth of sorghum was affected to a lesser extent than that of maize in the vegetative growth stage. The seedling growth of sorghum and maize did not differ markedly.

The seedling and vegetative growth stages of wheat and other cereals are the most sensitive in the case of NaCl salinity (Maas & Poss, 1989). Generally the sensitivity of wheat, as of other cereals, decreases with age (Francois & Maas, 1994; Maas & Poss, 1989). This sensitivity is mainly connected to Cl toxicity with osmotic potential exerting a lesser influence, which may be why seedling and vegetative growth are affected in a similar way by the $CaSO_4$ water.

Vegetative growth at higher concentrations of SO_4 water?

When interpreting the results of the vegetative growth stage, it must be taken into account that it was evaluated at much lower concentrations than that used for the seedling growth stage (Mine A *ca* 1000 or 1600 vs. Mine C *ca* 2500 mg L^{-1} SO_4). These evaluations may thus not be representative of vegetative growth in the higher concentration range especially between 2000 and 2500 mg L^{-1} SO_4.

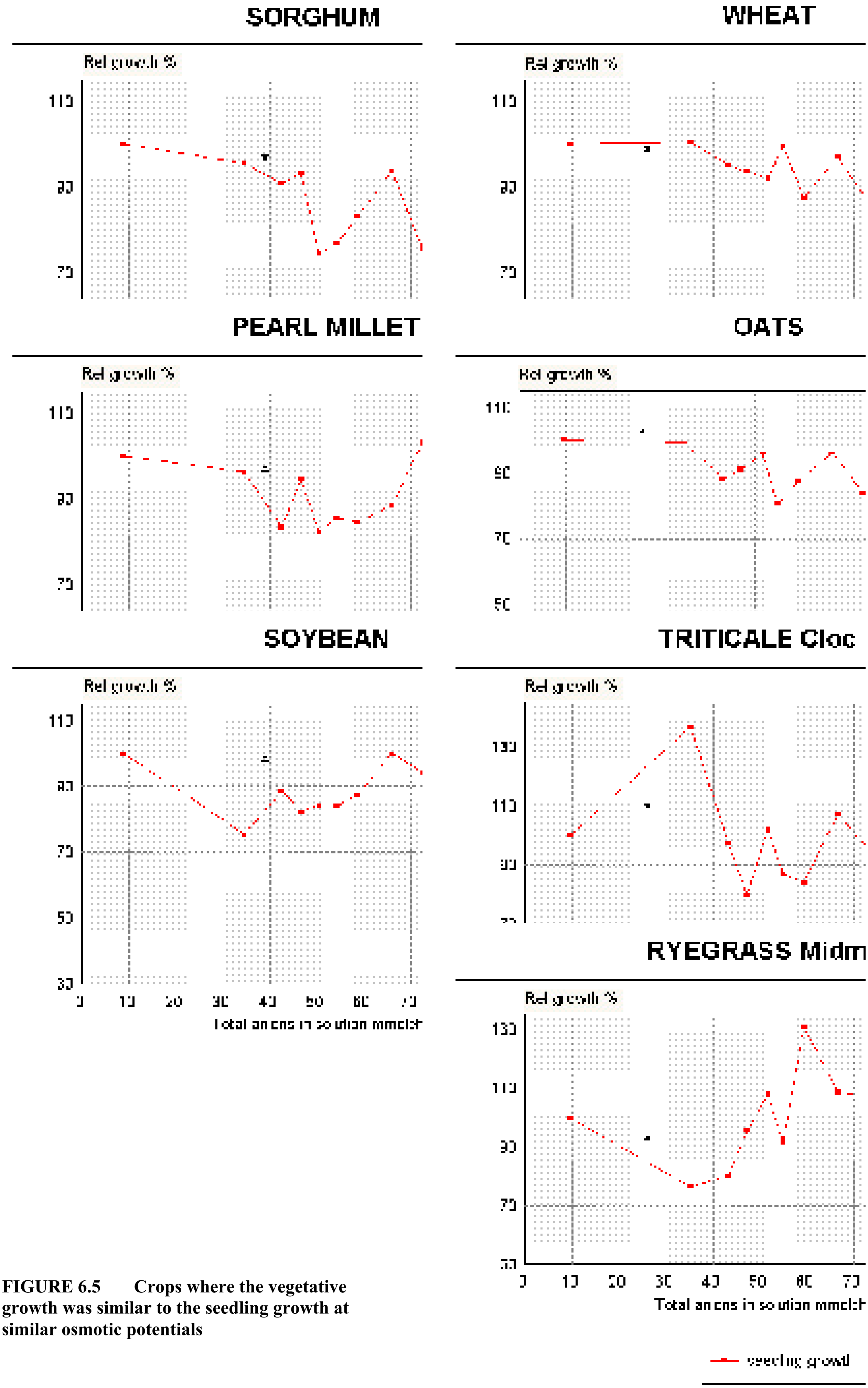


FIGURE 6.5 Crops where the vegetative growth was similar to the seedling growth at similar osmotic potentials

These responses together with that of the *seedling* growth at the higher concentrations may, however, serve as indications of what might be expected in the vegetative growth stage at higher concentrations; this would, however, depend greatly on whether the mechanisms by which growth is affected or adapted to salinity are similar in these two growth stages. The tolerance of cereals to NaCl-salinity has generally been found to increase with ontological development (Francois & Maas, 1994). This too would depend on the mechanism by which growth is suppressed or adapted in a high SO_4 water compared to that of NaCl water in the two growth stages.

If the mechanisms of the adverse effects of salinity, and of adaptation are known, it may serve as indications by which the vegetative growth may be predicted:

In **maize** where the decreased osmotic potential has been found to be the major suppressing quality of salinity in both the seedling and vegetative growth stages (Cramer, 1994), the vegetative growth can also be expected to decrease further with increasing concentrations of $CaSO_4$ mine water. If the particular cultivar possesses an osmotic adaptation mechanism, this may be less marked.

In contrast the seedling growth of **lucerne** is mainly affected by osmotic potential and the mature growth by Cl toxicity (Noble et al., 1984), Na content (Ashraf & O'Leary, 1995) and osmoregulation (Petrusa & Wincov, 1997). A $CaSO_4$-dominated water at the higher concentrations may thus result in decreased seedling growth but increased vegetative production due to the absence of Cl, and the presence of osmoregulation and nutrient effects.

In the case of **annual ryegrass** osmoregulation is stimulated by an increase of cations in the external medium (Sagi et al., 1997); it is therefore possible that at higher concentrations of the Ca/Mg/SO_4 water (Kleinkopje) the vegetative growth will also increase, as was the case with the seedling growth on simulated Kleinkopje water (Figure 6.5).

Although salt tolerance of the Tritiaceae tribe has been found to be poligenic (Zong & Dvorak, 1995), **temperate cereals** generally tolerate saline waters by Na and/or Cl exclusion or are affected by a Na/Ca imbalance (Francois et al., 1989). The tolerance for $CaSO_4$ water would thus depend on the Na/Cl content of such a water and also, but to a lesser extent, on the sensitivity of a particular crop cultivar for osmotic potential decreases.

These examples suffice to illustrate that the tolerance of the vegetative stage to $CaSO_4$-dominated water will mainly depend on the adverse and adaptive mechanisms in this growth stage. As Na and Cl are virtually absent in this water, the vegetative growth of the crops where ionic effects are the main cause of sensitivity, should be more tolerant to these $CaSO_4$-dominated waters. Where osmotic potential is the main suppressive mechanism, the vegetative growth is also expected to be sensitive. The response to this water will also depend on the ability and degree of osmotic adaptation in the particular crop or cultivar.

6.6 CONCLUSION

The relative germination percentage of most of the cultivars of both the subtropical and temperate annual crops was not influenced by either the $CaSO_4$- or NaCl-dominated mine waters used. Some cultivars of sorghum, pearl millet and soybean were moderately sensitive to the $CaSO_4$ water, but significant decreases for these did not exceed 12 % which could be easily compensated for by sowing more densely.

A comparison of seedling and vegetative growth at similar osmotic potentials of $CaSO_4$-dominated waters revealed that:

- the vegetative growth of sunflower cv. SNK 43, rye cv. SSR 1, lucerne cv. PAN 4860 and the yield of dry bean cv. PAN 122, was increased on this water, and that the tolerances of the vegetative growth stage were much *greater* than that of the seedling growth stage;

- maize cv. SNK 2340 and cowpea cv. Dr Saunders were possibly *more sensitive* in the vegetative than in the seedling growth stage; and

- the tolerance of sorghum cv. PAN 888, pearl millet cv.SA Standard, soybean cv. Ibis, wheat cv. Inia, oats cv. Overberg, triticale cv. Cloc 1 and annual ryegrass cv. Midmar *did not differ* markedly in these two growth stages.

It is suggested that the vegetative growth may be

- *more tolerant than seedling* growth in crops where tolerance in the vegetative stage is generally correlated to ionic effects and/or osmotic adaptation, rather than to a sensitivity to osmotic potential effects as is probably the case in the seedling stage. Nutrient effects may be responsible for stimulation of growth or of osmotic adaptation.

- *more sensitive than seedling growth* in crops where a reduction of growth appears to be due to the decreased osmotic potential reducing the leaf area. Where osmotic potential is nevertheless the growth reducing mechanism in the vegetative stage, but without affecting leaf area, vegetative growth may be influenced in a similar way to the seedling growth.

It is concluded that if the concentration of Na, Cl, or other possibly toxic ions, are negligible in a $CaSO_4$-dominated water, the tolerance of crops is mainly connected to the degree in which growth in the respective growth stages is affected by external osmotic potential decreases.