TOLERANCE OF SELECTED CROP AND PASTURE SPECIES TO LIME-TREATED ACID MINE WATER[1]

Wilma H. Mentz, Robin O. Barnard and Norman F.G. Rethman[2]

Abstract: The use of mine waters with high $CaSO_4$ loads creates problems for both the mining industry and the regulatory government departments. One of the alternative strategies is to use such water to irrigate crops on the mine property. To do this the relative sensitivity of different crops to such water and the long term effects on the soil need to be assessed. This report refers to pot studies conducted under glasshouse conditions using corn, sorghum, soybean, pearl millet, cowpeas, rye, oats, triticale, wheat and ryegrass. Although treated mine water had significant effects on different growth parameters and ratios (corn, soybean, rye and ryegrass being the most strongly affected), the most notable result was the uptake of large amounts of Ca, Mg, SO_4, Mn and Zn by virtually all species. Although the uptake was increased, the concentrations were still within acceptable limits for plant growth. These concentrations may, however, hold implications for animals and humans. There is an urgent need for such work to be continued to assess the influence of different levels of salt and the allocation of elements to different plant parts.

Additional key words: Calcium sulphate, irrigation, sub-tropical, temperate

Introduction

The coalfields of the eastern Transvaal Highveld (a plateau with an elevation of 1500-1800 m a.s.l.) have been the primary source of energy generation since the latter half of the 19th Century. Initially coal was mined using standard underground techniques. Since the early 1970's, however, mining has increasingly placed emphasis on total extraction using either strip mining or long wall mining. Whichever technique is used the quality of coal and/or the nature of the disturbed overburden results in problems with water quality in mined out areas. Because of the relatively high salt loads regulatory bodies have become increasingly reticent to grant permits for the release of such waters into public streams.

South Africa is characterized by a very low proportion of arable land (12%) and only one third of this (4%) may be regarded as prime farmland. In addition, S.A. has a low and variable rainfall (with 66% of the country being classified as semi-arid to arid). Irrigation water and especially good quality irrigation water is, therefore, of cardinal importance. The eastern Highveld is a major catchment area for a large percentage of the irrigation areas in S.A. Hence the sensitivity about high salt loads.

There are several different approaches to this problem. These include a range of technologies ranging from chemical treatments to wetlands. The *in situ* use of such water for irrigation is one of the alternative approaches. It is generally agreed that the ideal solution (for both mining and post-mining phases) will probably combine different approaches to aim for the sustainable and productive use of such water. To achieve this a program is being developed to evaluate the tolerance of a wide range of crop and pasture species to mine water and the effects this might have on the soil. This paper will report on aspects of the former.

---

1 Paper presented at the 1995 National Meeting of the American Society for Surface Mining and Reclamation, Gillette, Wyoming. June 5-8, 1995

2 Wilma H. Mentz, Research Assistant, Robin O. Barnard, Soil Scientist, Norman F.G. Rethman, Pasture Scientist, University of Pretoria, Pretoria 0002, SOUTH AFRICA

Proceedings America Society of Mining and Reclamation, 1995 pp 151-158
DOI: 10.21000/JASMR95010151

https://doi.org/10.21000/JASMR95010151

Procedure

Acid mine water (AMD) from the Kromdraai Colliery, near Witbank on the eastern Highveld, has a pH of approximately 2.5. After treatment with lime the pH was raised to approximately 6.5 (Table 1). This treatment had the effect of raising the calcium and sulphate levels by a factor of eight to ten relative to a balanced nutrient solution (Table 1). The electrical conductivity was three times as high.

Table 1. Analyses of control nutrient solution (A), lime treated mine water (B) and mine water with nutrients added (C).

	A	B	C
pH	5.15	6.54	5.86
EC mS/cm	0.92	2.25	2.78
Ca mg kg^{-1}	67	646	646
Mg mg kg^{-1}	16	16	32
K mg kg^{-1}	78	3	81
Na mg kg^{-1}	0	6	6
NH_4 mg kg^{-1}	30	0	30
NO_3 mg kg^{-1}	207	0	207
SO_4 mg kg^{-1}	224	1609	1609
P mg kg^{-1}	32	0	32

During 1994 two trials were conducted with annual sub-tropical and temperate crops to ascertain whether such lime treated mine water might be used for irrigation purposes on the mine property, as an alternative to releasing it into public streams. Conversely, if such water were released into streams, such research should give some indication of the possible impact it might have on downstream users. The "*in situ* scenario" would be the more extreme as the "down stream scenario" would, in some measure, be ameliorated by a dilution factor in the streams.

In the **first trial**, a sand culture experiment was conducted with corn (*Zea mays* cv. SNK 2340), sorghum (*Sorghum sudanense* cv. PAN 888), soybean (*Glycine max* cv. Ibis), pearl millet (*Pennisetum glaucum* cv. Common babala) and cowpea (*Vigna unguiculata* cv. Doc Saunders). This trial was conducted on a rotating table in a glasshouse, using 6 kg of quartz sand (washed with deionized water) in plastic buckets placed inside Mitscherlich vegetation vessels. The lime treated mine water with added nutrients was compared with a third (⅓) strength Hoagland No. 2 (NH_4^+ and NO_3^-) solution over four replications. The seeds were germinated in quartz sand with half strength Hoagland No. 2. The seedlings, after thinning to three plants per pot at the three leaf stage, were allowed to grow in the same nutrient solution for a further two weeks before the commencement of the comparative study. During the study solutions were replenished and circulated twice daily, and replaced weekly to maintain salinity and nutrient levels. The water content was thus kept at "field capacity" throughout the experiment. Plants were harvested after 25 days after treatment. Fresh mass was determined directly after clipping at ground level. Leaf areas were determined using the LI 3100 leaf area meter. Dry mass of both top growth and root components was determined after oven drying at 65°C for 48 hours. The total top growth was milled, wet ashed and N, P, K, Ca, Mg, Na, sulphates and chlorides (percentages), as well as Fe, Mn, Cu and Zn (mg/kg DM) determined by atomic absorption spectrophotometric techniques. The ratios of top growth:roots and leaves:stems were calculated, as well as the moisture content in the fresh material and the relative growth (as a percentage of control) of both leaf and total top growth.

In the fall a **second trial**, using water culture to evaluate the tolerance of rye (*Secale cereale* cv. SSR 1), oats (*Avena sativa* cv. Overberg), Triticale (*Tritcosecale* cv. CLOC 1), wheat (*Triticum aestivum* cv. Inia) and ryegrass (*Lolium multiflorum* cv. Midmar) to lime treated water with added nutrients relative to one third strength Hoagland No. 2 nutrient solution (Table 2), was conducted. This experiment was also conducted on rotating tables in a glasshouse. Mitscherlich pots (5ℓ), lined with plastic bags, and with black plastic covers, were used. The solutions were aerated for three minutes every 30 minutes. Seeds were sown in vermiculite and three seedlings were "planted" in each pot (5 species, 2 solutions and 4 replicates) ten days later. Plants were grown out to the four-leaf stage in a half strength Hoagland No. 2 nutrient solution. Treatments with treated mine water with added nutrients and one third strength Hoagland No. 2 (see Table 2) were started four weeks after planting. Nutrient solutions were replaced weekly. The water level was topped up twice daily to keep the concentrations constant. After four weeks of treatment (eight weeks of growth) top growth was harvested. Fresh mass, dry mass and leaf areas were determined as in the first trial and ratios between different components were determined. Statistical analyses were executed with the SAS (Statistical Analyses System) computer package using the GLM procedures and Duncan's test.

Table 2. Nutrients contained in (A) control nutrient solution and (C) lime-treated mine water with nutrients added

	A	C
pH	5.01	7.00
EC ms/m	96	284
Ca me/ℓ	3.3	20
Mg me/ℓ	2.3	2.9
K me/ℓ	2.0	2.0
Na me/ℓ	0.7	0.3
NH_4 me/ℓ	1.7	1.7
NO_3 me/ℓ	5.0	5.0
SO_4 me/ℓ	4.6	20.8
P me/ℓ	0.3	0.3
Micro elements		

Results and Discussion

The growth parameters and growth ratios for the annual sub-tropical species are presented in Tables 3 and 4.

Treated mine water appeared to have a significantly depressing effect on the mass of stem material produced by **corn** plants. This is reflected in the total mass of top growth, the leaf:stem ratio and the growth relative to the control. A similar effect was noted with the **fodder sorghum** although a significant depressing effect was only noted in the mass of stem material produced. In the case of **soybeans** observations on the presence of wilting and marginal chlorosis of leaves did not appear to be reflected in the data on growth parameters. It is, however, possible that the tendency for lime treated mine water to reduce the mass of roots produced by this species might compound an apparent sensitivity to water stress under field conditions. **Pearl millet** appeared to be the only species that was unaffected in any significant measure by the treated mine water. In contrast the **cowpeas** appeared to be affected in several different ways. In the latter species lime treated mine water had a highly significant effect on the ratio of top growth:roots, which was probably caused by a tendency to depress top growth and increase root mass (although neither of these effects was significant). More interesting was the apparent adaptation of leaves under these conditions. Cowpeas were the only plants to record a highly significant reduction in leaf area although this was not reflected in either the mass of leaves produced or the leaf growth relative to the control (96%). This is probably because the smaller leaf area was compensated for by a greater leaf thickness (reflected in the succulence data), which was significantly increased by treated mine water.

Table 3. Growth parameters of five annual sub-tropical species after 25 days of vegetative growth in a control nutrient solution (A) and lime-treated mine water with nutrients added (C)

Species	Treat.	Dry mass of top growth (g)				Dry mass	Leaf
		Stems	Leaves	Pods/Spikes	Total	roots (g)	area (cm^2)
Corn	A	47.6	41.3	3.9	92.8	26.5	8764
	C	38.2**	39.0	3.5	80.7*	26.2	8571
Sorghum	A	55.2	18.9	6.5	80.6	23.7	4872
	C	51.8**	19.3	6.9	78.0	23.8	4980
Soybean	A	16.4	17.2	4.9	38.4	8.7	6158
	C	16.4	16.8	4.7	37.8	7.1*	6318
Pearl millet	A	33.7	17.6	5.6	56.8	16.8	4229
	C	31.3	17.3	6.5	55.1	16.0	3881
Cowpea	A	38.1	20.4	3.8	62.4	6.1	7606
	C	34.3	19.6	4.1	58.0	6.9	6331***

* P < 0.10 according to Duncan's test
** Significant; P < 0.05
*** Highly significant; P < 0.01

Table 4. Growth ratios of five annual sub-tropical species after 25 days of vegetative growth in a control nutrient solution (A) and lime-treated mine water with nutrients added (C).

Species	Treat.	% Water in top growth	Succulence of leaves mgH_2O/cm^2	Leaf: stem	Topgrowth :root	Rel. growth % of Leaves	Rel. growth % of Topgrowth
Corn	A	84	16.7	0.87	3.6	100	100
	C	84	17.4	1.03**	3.1	95	87*
Sorghum	A	80	13.4	0.34	3.4	100	100
	C	79	12.8	0.37	3.3	102	97
Soybean	A	79	9.9	1.06	4.5	100	100
	C	80	10.3	1.03	5.4	98	98
Millet	A	81	22.3	0.53	3.4	100	100
	C	83	21.9	0.56	3.5	99	97
Cowpea	A	83	18.0	0.52	10.3	100	100
	C	83	19.2**	0.57	8.5***	96	93

* P <0.10 according to Duncan's test
** Significant: P < 0.05
*** Highly significant: P < 0.01

Table 5. Concentration of nutrients in the topgrowth of five annual sub-tropical species after 25 days of vegetative growth in (A) a control nutrient solution and (C) lime treated mine water with nutrients added.

		Percentage										mg/kg	
Species	Treat	N	P	K	Ca	Mg	Na	SO^4	Cℓ	Fe	Mn	Cu	Zn
Corn	A	0.96	0.15	0.98	0.17	0.14	-	0.81	0.07	18	45	3	6
		***		*	***	***		***			***		***
	C	0.82	0.14	1.18	0.34	0.16	-	1.08	0.16	21	131	2	12
Sorghum	A	1.09	0.15	0.86	0.21	0.17	-	0.97	0.08	30	89	6	13
				***	***	***		***	*	***	***		
	C	0.94	0.14	1.12	0.37	0.25	-	1.43	0.14	51	221	6	25
Soybean	A	2.23	0.26	1.65	0.70	0.33	-	1.41	0.83	68	188	8	29
					***	***		***		***	***		
	C	2.46	0.29	1.87	1.49	0.41	-	2.57	0.12	77	316	8	52
Millet	A	1.30	0.21	1.53	0.24	0.27	-	1.41	0.09	47	128	4	17
					***	***		***	***		***		**
	C	1.26	0.22	1.76	0.38	0.44	0.10	1.76	0.18	41	350	4	33
Cowpea	A	2.52	0.20	1.43	0.69	0.24	-	1.61	0.08	71	302	5	21
		**			***	***		***	**		***	***	***
	C	3.24	0.22	1.43	1.14	0.31	-	2.21	0.13	72	486	2	37

* P < 0.10 According to Duncan's test
** Significant; P <0.056
*** Highly significant; P <0.01

An examination of the data on the concentration of nutrients in the top growth (Table 5) and the total uptake of nutrients per pot (Table 6), reveals that these sub-tropical crops have highly significant increases in Ca, Mg, SO_4, Mn and Zn, when grown on lime treated mine water. In isolated cases the N, P, K, Na, and Cu uptake was also significantly affected, but the major effects were with respect to the former group. Calcium and Mg may possibly play a significant role (especially with respect to nutrient imbalances) where such crops are used for fodder purposes. Although the Mn and Zn levels were still well below the common toxicity levels (Mn >1000 ppm; Zn in the general order of 100 ppm), the relatively high levels might also create problematical inbalances between nutrients. In extrapolating these data to field conditions it must, however, be remembered that these crops are produced during the summer growing season. In an area which receives 600-700 mm of summer rainfall this "clean" water will have a diluting effect and reduce the need for supplementary irrigation except for periodic drought conditions. Under field conditions irrigation with lime treated mine water will also be an open system, with probable movement of $CaSO_4$ through the profile, as compared with the "closed" system maintained in the pot trial.

In contrast to the results obtained with summer crops the second trial, evaluating the relative tolerance of annual temperate species, produced very few significant effects on either growth parameters (Table 7) or growth ratios (Table 8). The notable exception was **rye** where irrigation with lime treated water had a significant beneficial effect on total top growth, the mass of roots produced, the mass of leaves produced and the top growth:root ratio. Treated water yielded 24% more leaf material and 26% more top growth than the control nutrient solution. This treatment also improved the leaf yield of **oats** and the leaf:stem ratio of **ryegrass**, both aspects of importance where these crops are used as forages. **Triticale** was not significantly influenced in any way, although virtually all growth parameters tended to improve on treated mine water.

Table 6. Total uptake of nutrients per pot of five annual sub-tropical species after 25 days of vegetative growth in (A) a control nutrient solution or (C) lime treated mine water with nutrients added.

		g/pot (3 plants/pot)								mg/pot			
Species	Treat	N	P	K	Ca	Mg	Na	SO^4	Cℓ	Fe	Mn	Cu	Zn
Corn	A	0.88	0.13	0.91	0.16	0.13	0	0.75	0.07	1.6	4.2	0.24	0.58
			**		***			**		***	***	**	
	C	0.66	0.11	0.94	0.27	0.13	0	0.87	0.13	1.7	10.6	0.18	0.97
Sorghum	A	0.88	0.12	0.69	0.17	0.13	0	0.78	0.06	2.4	7.1	0.51	1.07
					***	***		***			***		**
	C	0.73	0.11	0.88	0.29	0.20	0	1.11	0.11	2.4	17.3	0.44	1.96
Soybean	A	0.86	0.10	0.62	0.27	0.13	0	0.54	0.03	2.6	7.3	0.32	1.08
					***			***			***	**	
	C	0.93	0.11	0.71	0.56	0.15	0	0.97	0.05	2.9	11.9	0.30	1.97
Millet	A	0.74	0.12	0.86	0.14	0.15	0	0.79	0.05	2.6	7.2	0.23	0.94
					***	***		***	***		***	***	
	C	0.70	0.12	0.98	0.21	0.24	0.06	0.97	0.10	2.3	19.4	0.21	1.84
Cowpea	A	1.58	0.12	0.88	0.42	0.15	0	1.00	0.05	4.4	18.6	0.28	1.33
		***			***	*		***			***	***	**
	C	1.88	0.13	0.83	0.66	0.18	0	1.28	0.08	4.2	28.2	0.09	2.15

* $P < 0.10$ According to Duncan's test
** Significant; $P < 0.05$
*** Highly significant; $P < 0.01$

Table 7. Growth parameters of five annual temperate species after 28 days of vegetative growth in (A) control nutrient solution or (C) lime treated mine water with nutrients added.

Species	Treat.	Dry mass of top growth (g) Stems	Leaves	Spikes	Total	Drymass roots (g)	Leaf area (cm^2)
Rye	A	13.0	21.0	-	34.0	3.4	7182
	C	17.0	26.0**	-	43.0*	5.4**	7544
Oats	A	30.8	24.9	-	55.7	5.1	6872
	C	30.2	27.2*	-	57.3	4.6	6936
Triticale	A	6.5	19.3	-	25.8	4.2	6536
	C	7.2	21.1	-	28.3	4.0	6588
Wheat	A	14.8	8.8	4.6	28.2	3.3	2350
	C	14.4	9.0	4.7	28.1	2.8*	2414
Ryegrass	A	7.5	15.6	-	23.1	4.3	4986
	C	6.2	15.2	-	21.4	4.0	5757

* $P < 0.10$ According to Duncan's test
** Significant; $P < 0.05$
*** Highly significant; $P < 0.01$

Table 8. Growth ratios of five annual temperate species after 28 days of vegetative growth in (A) control nutrient solution or (C) lime treated mine water with nutrients added.

Species	Treat.	Succulence mgH_2O/cm^2 leaves	Leaf: stem ratio	Top growth :root ratio	Rel. growth % leaves	Rel. growth % Top growth
Rye	A	23.0	1.62	10.6	100	100
	C	21.5	1.60	8.2*	124**	126*
Oats	A	23.8	0.81	11.2	100	100
	C	23.5	0.91	12.4	109	103
Triticale	A	23.5	3.00	6.2	100	100
	C	23.7	2.99	7.4	110	110
Wheat	A	14.7	0.60	8.7	100	100
	C	15.2	0.63	10.3	102	99
Ryegrass	A	16.0	2.11	5.9	100	100
	C	23.2	2.49*	5.6	97	93

* $P < 0.10$ According to Duncan's test

** Significant; $P < 0.056$

*** Highly significant; $P < 0.10$

It is anticipated that as in the case of sub-tropical species, the uptake of significant amounts of Ca, Mg. SO_4, Mn and Zn might create problems for either plant and/or animal nutrition. Under field conditions this is more likely to be a problem than with summer growing species, as the growth period of such temperate species (fall, winter and spring) coincides with the dry season. As a result such crops will be virtually totally dependent on irrigation and precipitation is unlikely to have any appreciable diluting effect.

Conclusions

When interpreting these results it must be remembered that vegetative growth (as measured in these trials, where the emphasis was on the use of such crops forage) is not always a reliable guide for predicting seed or grain yields. Kaddah and Ghowail (1964) found that grain yield of corn was in fact more sensitive, whilst West and Francois (1982) reported that the seed yield of cowpeas was relatively unaffected. Although most reported salt tolerances for crops are for the vegetative stage of growth (Maas and Hoffman, 1977) it must be recognized that germination, establishment and reproductive stages might in fact be more, or less, sensitive.

Other aspects which have been identified as warranting further research are : investigations where the growth on different concentrations, of especially sulphate, is assessed to determine threshhold values where growth starts to decrease (Maas & Hoffman, 1977); investigations into the allocation of nutrients to stem, leaf and seed, with a view to the effect on human food, animal feed/forage and/or the removal of excess amounts of minerals through crop harvesting. The latter aspect is particularly important in determining the water and mineral balances in the field situation, as these may have a profound influence on the long term effects on the soil.

Acknowledgement

This work was supported by funds from the Water Research Commission of South Africa.

References

Kaddah, M.T. and S.I. Ghowail. 1964. Salinity effects on the growth of corn at different stages of development. Agronomy J. 56:214-217. http://dx.doi.org/10.2134/agronj1964.00021962005600020028x

Maas, E.V. and G.J. Hoffmann. 1977. Crop salt tolerance - current assessment. J. Irrig. A.S.C.E. 103:115-134.

West, D.W. and L.E. Francois. 1982. Effects of salinity on germination, growth and yield of cowpeas. Irrig. Sci. 3:169-175. http://dx.doi.org/10.1007/BF00446005