Crops can be irrigated with lime-treated acid mine drainage

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Abstract

The possible use of lime-treated acid mine drainage (AMD) for irrigation of agricultural crops was investigated. A field screening trial of 20 agronomic and pasture crop species was established at Landau Colliery Kromdraai Opencast Section (near Witbank, Mpumalanga Province), on a sandy acid soil. The objectives were to monitor crop response to sprinkler irrigation with lime-treated AMD and changes in soil chemical properties due to irrigation with this saline (gypsiferous) water. Considerable increases in yield of irrigated crops were observed, compared with rainfed cropping. Shallow rooting depths were, however, recorded for most crops, possibly due to high soil acidity, soil compaction and P deficiency in deeper layers. No symptoms of foliar injury were noted. Fluctuations in soil salinity levels were recorded depending on rainfall pattern, whilst soil pH(H_2O) increased after three years of irrigation. Lime-treated AMD could be an additional resource in mining areas, provided that irrigation and fertilisation practices are managed correctly.

Introduction

The coalfields of the Eastern Highveld region of South Africa (Mpumalanga Province) underlie one of the most important high-potential agricultural areas in the country. This is of particular significance when viewed against the fact that South Africa has a very low percentage of arable land of which only a third (4.5 m. ha) is regarded as being of high potential. In addition, South Africa has a low and variable rainfall (66% of the country is classified as semi-arid to arid). Add to this the steady increase in population and the importance of sustainable utilisation of these agricultural areas becomes paramount.

The area in which the coalfields occur is a major catchment for rivers supplying water to the industrial and mining heartland of Gauteng, the national Eskom power grid, important irrigation schemes and the Kruger National Park. Most South African coal deposits contain pyritic formations. When exposed to oxygen, water and the catalytic action of *Thiobacillus ferrooxidans* bacteria, iron pyrite is oxidised to sulphuric acid and iron sulphate (Thompson, 1980). This results in large quantities of acid mine drainage (AMD) being formed. The extremely high acidity of this water (pH typically ranges from 2 to 4.4), prohibits discharge into natural streams as the environmental impact would be severe. This is not only a local problem, but occurs world-wide where similar deposits are found (coal and gold mines, old underground workings).

Current measures to prevent pollution of the environment include treatment of AMD with hydrated lime $Ca(OH)_2$ in order to neutralise acidity. The major portion of the $CaSO_4$ formed is precipitated in sedimentation basins, but the resulting effluent is saline (gypsiferous) water of which the electrical conductivity (EC) typically ranges between 130 and 290 $mS \cdot m^{-1}$, due mainly to Ca^{2+} and SO_4^{2-} in solution. Van Staden (1979) reported that East Rand Proprietary Mines alone, planned to treat 90 000 $m^3 \cdot d^{-1}$ of acid underground water.

Disposal of mine waste water has become a problem of increasing importance from an ecological point of view. If freely discharged into the natural environment, lime-treated AMD could cause salinisation of soils, rivers, dams and catchment areas. Lime-treated AMD has previously been used only for dust alleviation on dirt roads and irrigation of lawns. The possible utilisation of this water for irrigation of agricultural crops, however, shows some promise (Du Plessis, 1983). Large amounts of waste water could possibly be utilised for irrigation of high-potential soils on the highveld. Moreover, filtering saline water through the soil, and thereby precipitating gypsum in the profile, could limit environmental pollution. The high cost of AMD amelioration could also be offset to some extent by farming income.

One of the aims of this work was to monitor the response of several crops already cultivated in these regions to irrigation with saline lime-treated AMD. A further objective was to evaluate the effect of irrigation with this water on soil chemical properties.

Materials and methods

A field screening trial was established at Landau Colliery Kromdraai Opencast Section (25°48' S; 29°05' E; altitude 1 510 m) in the highveld region, close to Witbank (Mpumalanga Province). The climate of the region is one of summer rainfall with an average rainfall of about 690 $mm \cdot a^{-1}$. The soil is a sandy acid Hutton form 1200 (Soil Classification Working Group, 1991). It is over 2 m deep with good drainage characteristics. As there is a deep groundwater table, no salt feeding of the root zone was expected from deeper soil layers. The soil has not been cultivated before experimentation started. Average soil textural and chemical properties before the trial started are reported in Table 1.

A large variety of species was selected for the screening trial according to their reported tolerance to salinity and climatic adaptation. Crops were divided into four groups and are summarised in Table 2. Each species was cropped on plots 20 x 15 m large. Cut-off berms facilitated drainage of excessive rain water into a shaped waterway down one side of the field. Before the beginning of the trial, 5 $t \cdot ha^{-1}$ dolomitic lime was mixed into the soil to a depth of 0.2 m in order to limit the effect of high soil acidity on the crops. The trial ran for three cropping seasons (1993 to 1996). Agronomic techniques commonly used in the area were

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TABLE 1 AVERAGE SOIL TEXTURAL AND CHEMICAL PROPERTIES AT KROMDRAAI				
Property		**Soil depth (cm)**		
		0 to 20	**20 to 40**	**40 to 60**
Sand coarse 2.0 to 0.5 mm (%)		44.3	36.8	35.1
Sand medium 0.5 to 0.25 mm (%)		28.8	32.5	30.0
Sand fine 0.25 to 0.05 mm (%)		10.2	11.8	12.2
Silt 0.05 to 0.002 mm (%)		4.9	5.3	6.6
Clay < 0.002 mm (%)		11.8	13.6	16.1
pH(H_2O)		4.45	4.15	4.2
Electrical resistance (ohm)		797	2632	1922
Bray I P (mg·kg^{-1})		32	4	3
Ammonium acetate extractable cations (mg·kg^{-1})	Ca	233	115	91
	Mg	10	8	9
	K	22	19	19
	Na	9	8	7

adopted. Details on planting dates, plant populations, fertilisation, weed control and cultivation practices were reported by Barnard et al. (1998). The forage crops were harvested during the growing season before reaching the flowering stage.

A stationary line source sprinkler irrigation system was set up on the experimental field. Each plot was provided with a solenoid valve, and managed on an individual basis being irrigated with three G-Type 2 Hunter sprinklers. The line source irrigation system allowed differentiation of three water and salt application treatments: wet, medium and dry. It was not possible to establish a control treatment irrigated with good quality water as lime-treated AMD is the only source of water available for irrigation in the area. Soil water content (SWC) of the wet treatment was maintained close to field capacity. SWC was measured with a neutron water meter, model CPN 503DR Hydroprobe (Campbell Pacific Nuclear, California, USA) [Mention of manufacturers is for the convenience of the reader only and implies no endorsement on the part of the authors, their sponsors or the University of Pretoria]. Soil water content was measured for each crop and treatment every 3 to 4 d in 0.2 m soil layers down to 1.2 m. Twice weekly, irrigations were applied to limit soil salinity effects on plants grown in the wet treatment. In order to increase irrigation efficiency, no leaching fraction (LF) was applied to the wet treatment as it was assumed that rainfall would leach a portion of the salts from the soil profile. The plots were irrigated under low wind conditions, generally in the late afternoon, in order to avoid water drift and improve distribution uniformity. Irrigation amounts (I) and precipitation (P) were measured with rain gauges.

Top dry matter (TDM) and harvestable dry matter (HDM) were measured for each crop and treatment at

TABLE 2 CROP SPECIES SCREENED AT KROMDRAAI LANDAU COLLIERY	
Annual subtropical:	
Maize	(*Zea mays* cv. SNK 2340)
Soybean	(*Glycine max.* cv. Ibis)
Sorghum	(*Sorghum bicolor* cv. Pan 888)
Pearl millet	(*Pennisetum glaucum* cv. SA standard)
Cowpeas	(*Vigna unguiculata* cv. Dr Saunders)
Annual temperate:	
Rye	(*Secale cereale* cv. SSR 1)
Oats	(*Avena sativa* cv. Overberg)
Triticale	(*Triticum x Secale* cv. Cloc 1)
Wheat	(*Triticum aestivum* cv. Inia)
Ryegrass	(*Lolium multiflorum* cv. Midmar)
Perennial temperate:	
Lucerne	(*Medicago sativa* cv. Pan 4860)
Fescue	(*Festuca arundinacea* cv. A.U. Triumph)
Crownvetch	(*Coronilla varia* cv. Penngift)
Cocksfoot	(*Dactylis glomerata* cv. Hera)
Milkvetch	(*Astragalus Cicer* cv. Windsor)
Perennial subtropical:	
Weeping love-grass	(*Eragrostis curvula* cv. Ermelo)
Smuts finger	(*Digitaria eriantha* cv. Irene)
Kikuyu	(*Pennisetum clandestinum*)
Panicum	(*Panicum maximum* cv. Gatton)
Rhodes	(*Chloris gayana* cv. Katambora)

TABLE 3 IRRIGATION WATER CHEMICAL ANALYSES DURING THE 1993/94 SEASON					
	Date	**20-01-1994**	**25-02-1994**	**10-03-1994**	**15-03-1994**
pH	Mean Std error	6.5 ± 0.2	6.8 ± 0.2	5.3 ± 0.2	5.5 ± 0.4
EC $(mS \cdot m^{-1})$	Mean Std error	200.7 ± 3.9	143.0 ± 7.0	149.0 ± 4.7	132.0 ± 18.3
Ca^{2+} $(mg \cdot \ell^{-1})$	Mean Std error	398.1 ± 0.7	249.2 ± 1.4	271.0 ± 7.0	229.5 ± 30.0
Mg^{2+} $(mg \cdot \ell^{-1})$	Mean Std error	22.7 ± 1.4	18.1 ± 2.3	14.1 ± 1.0	20.6 ± 8.3
K^+ $(mg \cdot \ell^{-1})$	Mean Std error	4.7 ± 0.1	26.5 ± 30.3	8.0 ± 2.8	4.3 ± 0.9
Na^+ $(mg \cdot \ell^{-1})$	Mean Std error	7.0 ± 0.5	5.7 ± 0.4	6.2 ± 0.4	7.3 ± 3.3
CO_3^{2-} $(mg \cdot \ell^{-1})$	Mean Std error	Negligible -			
HCO_3^- $(mg \cdot \ell^{-1})$	Mean Std error	12.1 ± 1.8	12.1 ± 3.8	7.9 ± 0.2	8.5 ± 0.7
Cl^- $(mg \cdot \ell^{-1})$	Mean Std error	0.2 ± 0.3	5.7 ± 7.8	3.6 ± 2.1	1.5 ± 1.4
SO_4^{2-} $(mg \cdot \ell^{-1})$	Mean Std error	1321.9 ± 33.7	941.9 ± 6.7	1010.4 ± 31.8	716.1 ± 105.7

harvest, by sampling 1 m^2 at representative sites, with no replications due to the large number of crops and options to be monitored. Root depth was estimated during the growing season from SWC measurement. At the end of the season profile pits were dug and root depths measured.

Soil saturation electrical conductivity (EC_e) and pH(H_2O) were measured in soil profiles of soybean (wet and dry treatment). Soil samples were collected by augering 0.2 m soil layers down to 1 m depth, at the end of each growing season. As soil EC_e was not measured before the trial commenced, soil samples were collected and analysed at a later stage from a non-irrigated area adjacent to the experimental site. These EC_e measurements were used as a background reference to indicate possible increases in soil salinity of the irrigated soybean plot.

Irrigation water chemical analyses were done on four occasions during the 1993/94 season, in order to take cognizance of water quality variability. Six samples were analysed for concentrations of Ca^{2+}, Mg^{2+}, K^+, Na^+, CO_3^{2-}, HCO_3^-, Cl^- and SO_4^{2-}, as well as for EC and pH. Irrigation water quality analyses for the remaining period of the trial were provided by Landau Colliery.

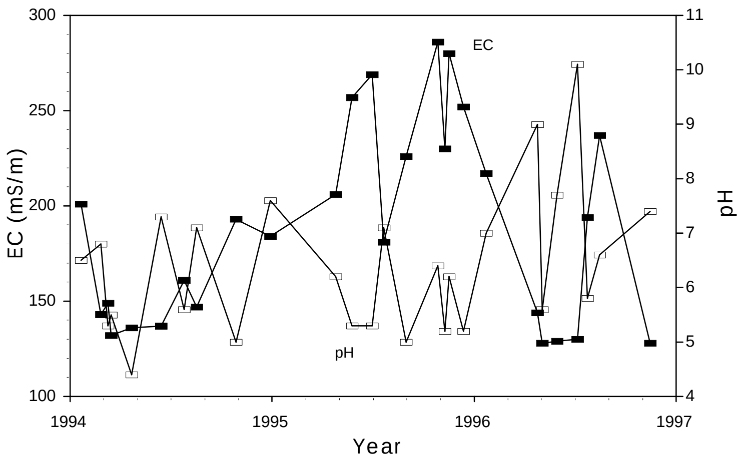

Figure 1
Measured electrical conductivity (EC) and pH of irrigation water during the trial

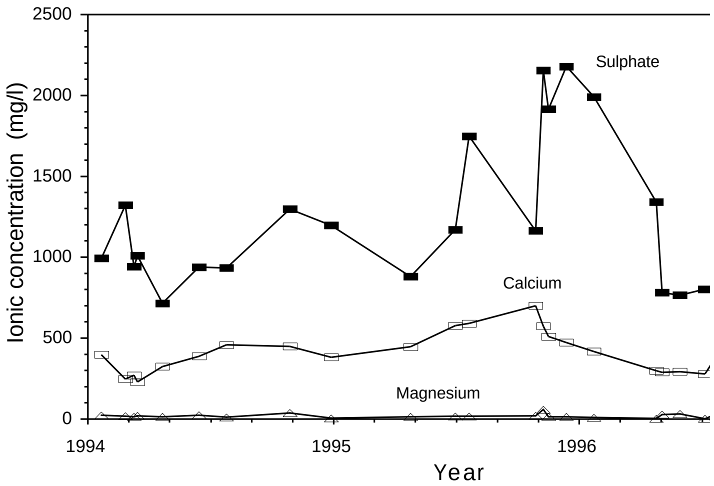

Figure 2
Measured concentrations of sulphate, calcium and magnesium in irrigation water during the trial

Results and discussion

Irrigation water quality

Table 3 represents irrigation water qualities measured at Kromdraai. Large amounts of Ca^{2+} and SO_4^{2-} in lime-treated AMD were measured. Among the other ionic species, Mg^{2+} generally had the highest concentrations. According to the Department of Water Affairs and Forestry (1993), use of water of such quality for irrigation is to be matched with LF applications of up to 0.15 and wetting of the foliage of salt sensitive crops should be prevented. Optimal yields can nevertheless be expected irrigating moderately salt-tolerant crops at low frequency. Measured pH, EC and ionic concentrations were generally in the range of those estimated by Du Plessis (1983).

EC and pH of irrigation water for the period of the trial are reported in Fig. 1. The quality of outflow water used for irrigation depended mainly on the rate of AMD flowing into the liming plant, the liming rate and the time for sedimentation. High EC and low pH values were recorded at the end of 1995 due to high rainfall and large quantities of AMD to be treated in the liming plant. During the first half of 1996, the pH of outflow water increased up to 10, due to a high liming rate per unit volume AMD applied in the liming plant. A decrease in concentration of SO_4^{2-} in irrigation water was recorded during this period (Fig. 2).

Crop salt tolerance

The three-year screening trial at Kromdraai indicated which crop species are most suitable to be grown under the specific environmental conditions. TDM, HDM and seasonal amounts of irrigation and precipitation are reported for subtropical annual (Table 4), temperate annual (Table 5), temperate perennial (Table 6) and subtropical perennial species (Table 7). When the crops were harvested more than once during the season, TDM and HDM represented the sum of the harvests. Variations in the crops' growing seasons resulted in differences in seasonal rainfall. Considerable yield increases of irrigated crops were observed compared to the dry treatments. In particular, large increases in yields of perennial temperate grasses were recorded. Due to windy conditions and irrigation water drift, it was not always possible to maintain the dry treatments under rainfed conditions throughout the season. In fact, in a few cases, crops yielded better in the dry than in the medium irrigated treatment. An extremely rainy 1995/96 season limited the differentiation of water treatments in that season.

Previous work has indicated that soil salinity suppresses top growth more than root growth (Eaton, 1942; Bernstein and Pearson, 1954; Ayers and Eberhard, 1960; Meiri and Poljakoff-Mayber, 1970). In this study, the root systems of most cropped species did not develop below 0.5 m. The most probable reasons could have been unameliorated soil acidity during seedbed preparation, soil compaction and P deficiency in deeper layers which are difficult to correct in small plots.

Nutritional problems were experienced for some crops due to shallow rooting depths. Sorghum, and in particular maize, were the crops that suffered most from nutrient deficiency. Symptoms of K deficiency were observed in lucerne, before corrective fertilisation was applied at the beginning of the 1995/96 season. High-frequency irrigation and careful fertilisation practices are recommended to provide crops with the right amounts of available soil water and nutrients throughout the growing season. In particular, K and Mg fertilisation are critical due to the low content of these elements in the soil and the competition for uptake by Ca which tends to saturate the exchange complex.

Satisfactory yields were obtained for irrigated soybean, pearl millet, cowpeas (Table 4) and winter cereals (Table 5). No second yield was obtained for sorghum and pearl millet during the 1993/94 season due to the late planting date. High yields of pearl millet were measured in all three treatments during the 1993/94 and 1994/95 seasons, indicating that this crop adapted better than others to water stress and the specific environmental conditions. Cowpeas flowered poorly in the 1994/95 and 1995/96 seasons. Oats, triticale and ryegrass never reached the flowering stage as they were harvested during the growing season. Ryegrass did not emerge in the dry treatment during the 1994 season as the soil was very dry. At the beginning of the 1995 season, the plot for dry treatment of ryegrass was well watered before planting to ensure emergence.

Although comparable yield data with good quality water are not available, the yields of perennial species obtained in the wet treatment were generally comparable to, or better than, yields registered in the area (Dickinson et al., 1990). Among the temperate pastures, lucerne and fescue yielded better than cocksfoot (Table 6). Difficulties in establishment were experienced for crownvetch and milkvetch resulting in very uneven plant populations, but the crops yielded well during the 1995/96 season. Excellent yields of subtropical perennial pastures were achieved during the 1995/96 season, after full establishment (Table 7). Weeping love-grass, Smuts and kikuyu were the only species with root systems reaching depths below 1.4 m. Differentiation between water treatments was difficult as the root systems

TABLE 4
TOP DRY MATTER (TDM), HARVESTABLE DRY MATTER (HDM), IRRIGATION (I) AND PRECIPITATION (P) FOR SUBTROPICAL CROP SPECIES

Crop	Season	Treatment	TDM ($t \cdot ha^{-1}$)	HDM* ($t \cdot ha^{-1}$)	I (mm)	P (mm)
Maize	1993/94	Wet Medium Dry	10.92 10.36 6.90	3.14 2.93 0.62	468 194 80	357
	1994/95	Wet Medium Dry	13.10 7.57 5.90	5.87 3.00 1.12	457 195 90	323
	1995/96	Wet Medium Dry	16.52 18.60 10.75	6.52 6.98 3.54	297 91 37	828
Soybean	1993/94	Wet Medium Dry	12.30 9.50 7.70	5.01 3.94 2.09	472 191 74	357
	1994/95	Wet Medium Dry	14.60 11.50 4.00	6.20 4.56 0.92	508 231 95	379
	1995/96	Wet Medium Dry	15.03 14.26 11.39	5.88 4.96 3.92	290 161 34	782
Sorghum	1993/94	Wet Medium Dry	9.95 7.59 6.65	- - -	357 155 62	357
	1994/95 (2 harvests)	Wet Medium Dry	18.47 11.80 7.27	- - -	560 284 105	379
	1995/96 (2 harvests)	Wet Medium Dry	13.55 7.19 4.78	- - -	325 118 43	793
Pearl millet	1993/94	Wet Medium Dry	20.60 19.50 18.30	- - -	323 126 51	357
	1994/95 (2 harvests)	Wet Medium Dry	29.20 22.50 27.40	- - -	649 308 137	379
	1995/96 (2 harvests)	Wet Medium Dry	20.76 12.44 9.24	- - -	343 136 38	793
Cowpeas	1993/94	Wet Medium Dry	9.11 7.94 4.87	3.28 2.61 1.53	497 218 54	357
	1994/95	Wet Medium Dry	9.70 7.80 5.00	- - -	522 231 50	379
	1995/96	Wet Medium Dry	9.57 6.22 9.50	- - -	286 120 16	782

* Dry matter of cobs for maize, pods for soybean and cowpeas

TABLE 5
TOP DRY MATTER (TDM), HARVESTABLE DRY MATTER (HDM), IRRIGATION (I) AND PRECIPITATION (P) FOR TEMPERATE CROP SPECIES

Crop	Season	Treatment	TDM ($t \cdot ha^{-1}$)	HDM* ($t \cdot ha^{-1}$)	I (mm)	P (mm)
Rye	1994	Wet Medium Dry	8.00 4.60 3.10	2.81 1.50 0.95	471 288 85	24
	1995 (3 harvests)	Wet Medium Dry	4.61 3.25 3.54	- - -	284 176 144	72
Oats	1994 (3 harvests)	Wet Medium Dry	14.82 9.05 5.68	- - -	572 274 143	75
	1995 (3 harvests)	Wet Medium Dry	5.29 3.88 2.09	- - -	347 172 134	276
Triticale	1994 (2 harvests)	Wet Medium Dry	10.05 6.10 4.67	- - -	567 257 103	47
	1995 (2 harvests)	Wet Medium Dry	4.24 3.55 3.45	- - -	369 218 130	269
Wheat	1994	Wet Medium Dry	6.50 3.10 2.60	3.47 1.24 1.02	484 191 118	26
	1995 (3 harvests)	Wet Medium Dry	6.72 4.61 3.27	- - -	303 151 111	37
Ryegrass	1994 (4 harvests)	Wet Medium Dry	8.91 3.85 -	- - -	436 186 -	75
	1995 (3 harvests)	Wet Medium Dry	5.59 3.63 1.96	- - -	422 166 30	351

* Ear dry matter

of these species in the medium and dry treatments were able to reach soil water in deeper layers. Panicum was planted at the beginning of the 1995/96 season and did not establish properly until the trial was terminated.

For the purpose of lime-treated AMD utilisation, it is important to have as large a transpiring canopy as possible throughout the year. The choice of cropping system depends mainly on crop salt tolerance, land capability and length of growing period. Fast-growing species that use a lot of water are recommended (pearl millet in combination with a winter cereal). If the subsoil problems experienced in the field trial could be solved, maize harvested for silage would likely be a more economical crop choice. High soil water consumption is also expected from an irrigated lucerne-fescue mixed pasture, both during the dry winter and the rainy summer season. At the same time, dry matter production can be expected throughout the year as lucerne is the dominant species during summer, and fescue is in winter.

Maas (1986) warns of the risk of foliar injury due to sprinkling with saline water. A wide range of crops suffered due to foliar absorption of Na and Cl (Ehlig and Bernstein, 1959; Gornat et al., 1973; Francois and Clark, 1979; Maas et al., 1982a, b). No symptoms of foliar injury due to irrigation with virtually a saturated $CaSO_4$ solution were, however, noted in this work.

TABLE 6
TOP DRY MATTER (TDM), IRRIGATION (I) AND PRECIPITATION (P) FOR TEMPERATE PASTURE SPECIES

Species	Season	Treatment	TDM ($t \cdot ha^{-1}$)	I (mm)	P (mm)
Lucerne	From 13-09-1994 to 05-10-1995 (6 harvests)	Wet Medium Dry	23.79 15.37 6.67	1016 546 212	404
	From 05-10-1995 to 29-04-1996 (5 harvests)	Wet Medium Dry	16.90 14.81 8.74	555 332 110	894
Fescue	From 13-09-1994 to 05-10-1995 (5 harvests)	Wet Medium Dry	21.35 15.11 5.25	916 501 194	404
	From 05-10-1995 to 29-04-1996 (5 harvests)	Wet Medium Dry	21.64 23.62 17.78	505 304 101	894
Crownvetch	From 15-09-1995 to 29-04-1996 (4 harvests)	Wet Medium Dry	25.01 15.63 20.24	515 326 134	894
Cocksfoot	From 13-09-1994 to 05-10-1995 (4 harvests)	Wet Medium Dry	8.09 5.46 3.14	920 496 189	404
	From 05-10-1995 to 29-04-1996 (5 harvests)	Wet Medium Dry	14.51 13.46 6.26	503 296 111	894
Milkvetch	From 15-09-1995 to 29-04-1996 (4 harvests)	Wet Medium Dry	26.41 13.35 8.15	526 342 32	894

Soil chemical properties

Figure 3 represents measured values of EC_e in the soil profile of soybean (wet and dry treatment) at the end of the 1994/95 and 1995/96 seasons. EC_e increased due to irrigation with lime-treated AMD compared to the non-irrigated soil. The values, however, were below those typical for a saturated gypsum solution. A decrease in EC_e in the dry treatment at the end of the extremely rainy 1995/96 season, indicates that fluctuations in soil salinity levels could be expected depending on rainfall pattern.

Figure 4 represents measured pH(H_2O) in the soil profile of soybean (wet and dry treatment) at the end of the growing season. A dramatic increase in soil pH was observed at the end of the 1995/96 season, indicating that acid soils could be ameliorated using lime-treated AMD for irrigation. The increase in soil pH was due to an increased pH of irrigation water supplied by the Kromdraai liming plant (Fig. 1).

Conclusions

Lime-treated AMD proved to be an additional resource in mining areas, particularly where prolonged drought periods are likely to occur. The use of this water for irrigation of agricultural crops could partially solve water shortage problems and produce considerable benefits to local communities.

From a potential production point of view, legumes (soybean, cowpeas and lucerne), pearl millet, winter cereals, fescue and subtropical perennial species proved to be suitable for irrigation with lime-treated AMD. For the purpose of lime-treated AMD utilisation, fast-growing species that use a lot of water are recommended (pearl millet or maize in combination with a winter cereal, or a lucerne-fescue mixed pasture). It is important to have as large a transpiring canopy as possible throughout the year.

Deep cultivation with deep placement of lime and phosphorus is essential to ensure success on sandy acid soils. Alternatively, some perennial subtropical species that develop a deep root system could be selected. High frequency irrigation and application of fertilisers several times during the growing season in small amounts are recommended. In particular, K and Mg fertilisation is critical due to excessive Ca concentrations. No symptoms of foliar injury due to irrigation with saline water rich in $CaSO_4$ were noted.

Soil salinity increased during the three years of the trial compared to the non-irrigated soil. EC_e in the soil profile fluctu-

TABLE 7
TOP DRY MATTER (TDM), IRRIGATION (I) AND PRECIPITATION (P) FOR SUBTROPICAL PASTURE SPECIES

Species	Season	Treatment	TDM ($t{\cdot}ha^{-1}$)	I (mm)	P (mm)
Weeping love-grass	From 13-09-1994 to 15-09-1995 (4 harvests)	Wet Medium Dry	14.99 13.81 12.91	918 488 175	404
	From 15-09-1995 to 29-04-1996 (5 harvests)	Wet Medium Dry	33.71 29.16 27.55	501 312 121	894
Smuts	From 13-09-1994 to 15-09-1995 (4 harvests)	Wet Medium Dry	21.37 16.53 9.93	938 492 189	404
	From 15-09-1995 to 29-04-1996 (5 harvests)	Wet Medium Dry	36.51 31.09 24.65	515 326 123	894
Kikuyu	From 13-09-1994 to 15-09-1995 (4 harvests)	Wet Medium Dry	18.47 18.25 15.37	942 496 181	404
	From 15-09-1995 to 29-04-1996 (5 harvests)	Wet Medium Dry	31.99 30.63 22.11	519 322 139	894
Panicum	From 05-10-1995 to 29-04-1996 (3 harvests)	Wet Medium Dry	13.19 15.27 8.36	492 300 121	894
Rhodes	From 13-09-1994 to 15-09-1995 (4 harvests)	Wet Medium Dry	17.42 11.79 9.80	928 490 52	404
	From 15-09-1995 to 29-04-1996 (5 harvests)	Wet Medium Dry	34.16 26.31 17.28	522 328 18	894

ated depending on seasonal rains and did not reach values above 200 $mS{\cdot}m^{-1}$. It is not expected therefore, in the short-term, that soil salinity will represent a problem for crop growth when lime-treated AMD is used for irrigation. On the other hand, soil pH can be considerably increased when gypsiferous water is used for irrigation.

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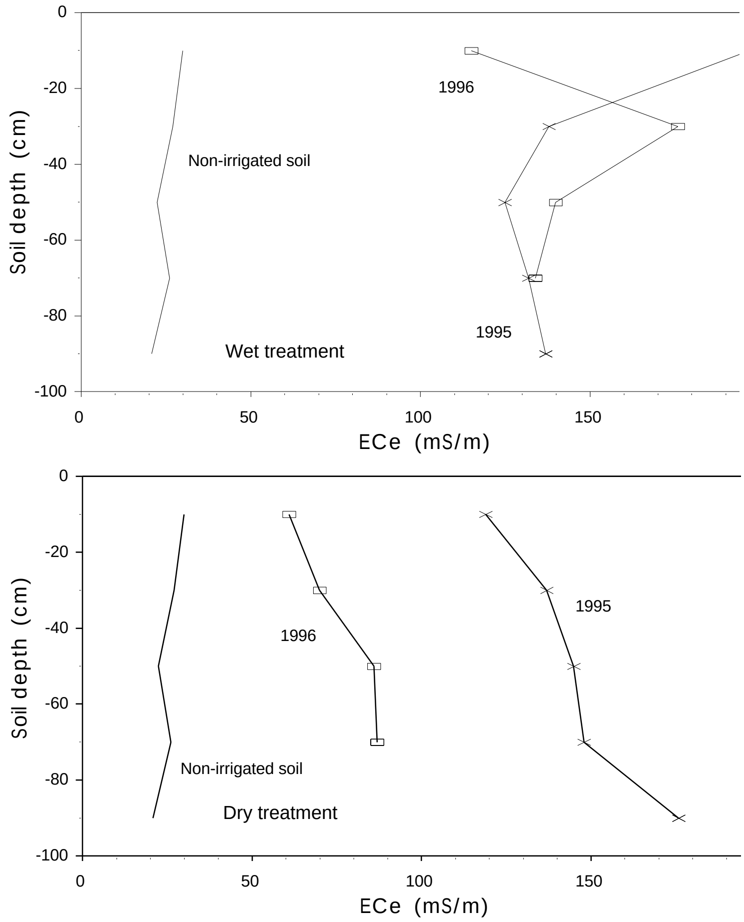

Figure 3
Measured electrical conductivity of saturated extract (EC_e) in the soil profile of soybean (wet and dry treatment) at the end of the 1994/95 and 1995/96 irrigation seasons. EC_e values for a non-irrigated soil are also presented

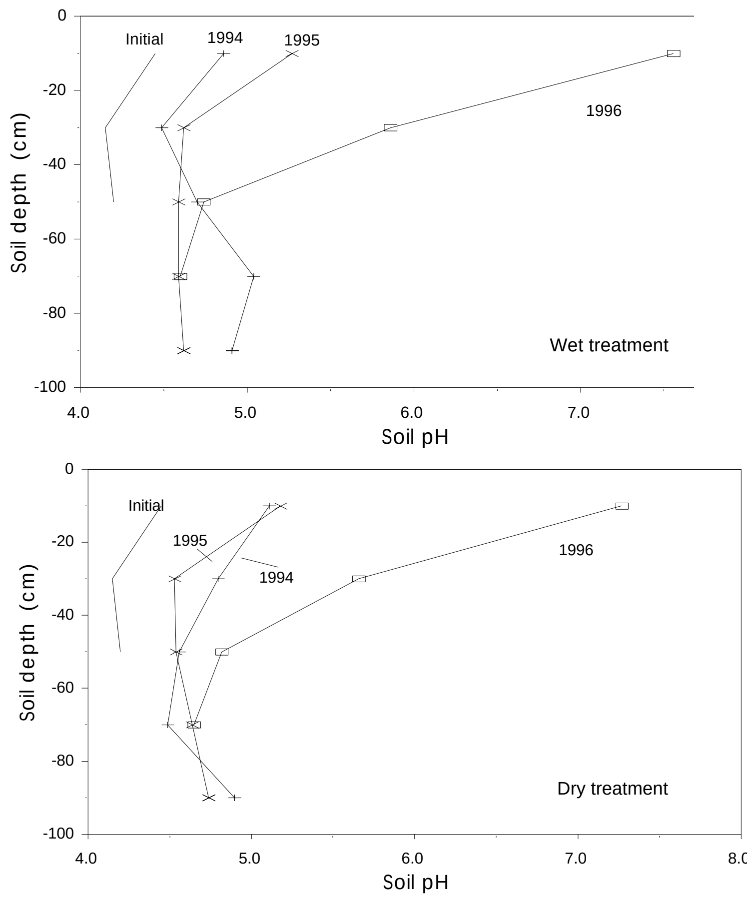

Figure 4
Measured soil pH(H_2O) in the soil profile of soybean (wet and dry treatment) at the end of three irrigation seasons

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