CHAPTER 1

INTRODUCTION

The disposal of large amounts of gypsiferous water, generated in coal mining operations in the Mpumalanga Highveld region in South Africa, has become a problem of increasing importance. This water is unsuitable for direct uncontrolled discharge into watercourses where it may become a threat to the environment and a problem to potential users. There are several different approaches to this problem. One alternative approach currently being investigated is the use of these waters for the irrigation of agronomic crops and pastures. In this way, large amounts of waste water could become economically useful for irrigation.

This thesis arose out of a screening project to determine the tolerance of crops and pastures to such gypsiferous waters for possible use in irrigation (Barnard, Rethman, Annandale, Mentz & Jovanovic, 1998).

South Africa has a low and variable rainfall with two thirds of the country classified as semi-arid to arid (Department of Water Affairs, 1986). The region in which the coal fields occur has a subtropical summer rainfall climate but is subject to periodic droughts. The area is a major catchment area and rivers originating here supply water to the largest industrial and mining heartland of South Africa, a national power grid and several important irrigation schemes. Due to the increasing use of water by these operations, the disposal of waste water has become a problem that requires constant attention (Kempe, 1983; Van Niekerk, 1992).

These coal fields have been a primary source of energy generation in the country since the latter half of the 19th century. Most South African coal deposits contain pyritic formations (Kempe, 1983). When exposed, iron pyrite is oxidised to sulphuric acid and iron sulphate. This results in the occurrence of large quantities of acid mine drainage water (AMD) being formed, which may be neutralized by other strata present, but where it occurs as a seep, extremely high acidity precludes discharge into natural streams. This is, of course, not only a local problem, but occurs world-wide, where similar deposits are found.

Current measures to prevent pollution of the environment include, inter alia, treatment with calcitic or hydrated lime in order to neutralize the acidity. The major portion of gypsum formed is precipitated in sedimentation basins, but the resulting effluent is a $CaSO_4$-dominated saline water. The estimation that 34 % of the lime mined in South Africa was used for the neutralization of acid mine waters in 1985, is an indication of the volumes of such water being produced (Hart, 1985). There are also other gypsiferous waters emanating from coal mining areas, such as is pumped from old underground workings at the Kleinkopje mine. The volumes of gypsiferous water generated daily on the Mpumalanga Highveld have been estimated at between 14 and 30 ML (P. Tanner, AMCOAL Environmental Services, personal communication, 1999). So far these waters have been used for dust alleviation on dirt roads and irrigation of lawns, but if they can be used for irrigation, large amounts of waste water could become economically useful.

These coal fields underlie one of the most important high potential agricultural areas in South Africa (Schoeman & MacVicar, 1978). This is of particular significance when viewed against the fact that the country has a very low percentage of arable land - some 14 out of 120 million hectares - of which only 4.5 million hectares are regarded as being of high potential. In view of the steady increase in population - 0,2 ha arable land per capita is already being approached whereas 0,4 ha per capita is considered desirable - responsible and effective utilization of the agricultural potential and water resources is very important (Laker, M.C., personal communication, 1996). Moreover, filtering saline water through the soil and precipitating gypsum in the profile could limit environmental pollution hazards. Contamination of water supplies for other potential users could be minimized.

The use of gypsiferous water for irrigation may have several advantages for crop growth:

- Gypsum can be an important S fertilizing agent in this climatic region where excessive summer rainfall has been known to lead to S deficiency in the subsequent seasons; irrigation of the winter crops with this water could replace the leached S. This is of special importance to crops that have a very high demand for S, such as those with a high production of organic material, for example maize. It is also important for protein rich crops such as lucerne and for the Cruciferae family (Marschner, 1995).

- Gypsum may have several positive influences when applied to acidified soils:

  - In humid and subhumid climatic conditions acidification and Ca loss by leaching occur simultaneously. The influence of low Ca is furthermore intensified by the inhibition of Ca-uptake from acid soils by the high H^+ concentration and the strongly competing influence of the phytotoxic Al^{3+} ion. Increasing the external Ca concentration, by the application of gypsum, may replenish the Ca of such a soil and also reduce Al-induced inhibition of root elongation (Rengel, 1992a; Rhue & Grogan, 1977). The increased Ca may also stimulate nodulation of legumes which is inhibited by high H^+ together with low Ca^{2+} and high Al^{3+} (Marschner, 1995).

  - An important benefit of gypsum application to growth in acid soils may be the formation of the non-phytotoxic $AlSO_4^+$ ion (Marschner, 1995).

  - With increasing soil acidification and a lower Ca/Al ratio, root penetration into the subsoil can be inhibited. This may lead to a shallow root system and thus a lower utilisation of nutrients and water. Owing to its solubility, gypsum may contribute to the alleviation of subsoil acidity.

- A major concern about the prolonged use of a gypsiferous irrigation water is, however, that the exchange complex may become depleted of Mg and K and dominated by Ca, which may cause nutrient imbalances.

- The most well-known use of gypsum is for the reclamation of sodium-affected soils; the Ca replaces Na adsorbed on the soil colloids, inducing flocculation and thus improving soil structure.

A literature survey on the influence of salinity on plant and crop growth revealed a vast body of literature on plant response to mainly NaCl and other highly soluble salts such as Mg and Na sulphates. Maas and Hoffman (1977) reviewed all available salt tolerance literature and concluded that "in general, yield was not decreased significantly until a threshold salinity level was exceeded, and that yield decreased approximately linearly as salinity increased beyond the threshold". Gypsiferous waters are generally not considered as detrimental to growth as waters with highly soluble salts, because potentially extreme salinity increases are controlled by the precipitation of gypsum. It is thus expected that crop yield would not decrease to the same extent after the solubility product of Ca and SO_4 has been reached in the soil solution. Very little has, however, been reported on growth responses to increasing concentrations of gypsiferous water or the effect that the precipitation of gypsum during evapotranspiration may have on growth responses.

Crop research with $CaSO_4$-dominated water has been very limited and has mainly focussed on yield components and the influence of such an irrigation water on soil chemical properties (du Plessis, 1983; Papadopoulos, 1986; MacAdam, Drost, Dudley and Soltani, 1997; Jovanovic, Barnard, Rethman & Annandale, 1998). The yield and/or quality of moderately sensitive crops such as tomato, bell pepper and eggfruit were decreased (Papadopoulos, 1986), but the moderately tolerant lucerne and tall fescue increased when irrigated with a gypsiferous water (MacAdam et al., 1997). The latter was confirmed by field trials that were conducted simultaneously with the experiments reported in this study (Barnard et al., 1998; Jovanovic et al., 1998). These field trials under irrigation with lime-treated acid mine drainage water, also showed satisfactory yields with soybean, pearl millet, cowpeas and the winter cereals; maize and sorghum, however, suffered from nutrient deficiency which was attributed to shallow rooting depths due to subsoil acidity; lucerne showed K-deficiency symptoms which were corrected by fertilization (Jovanovic et al., 1998).

As salt-tolerance is a multifaceted concept, varying with many environmental and biological factors, the use of such waters for irrigation warranted more information than only the yield response. The influence of biological factors - such as cultivar diversity and growth stage - and the influence of precipitation of gypsum on growth curves, with increasing concentrations of Ca and SO_4 were therefore investigated. Possible nutrient interactions peculiar to this type of saline water were also considered.

The present study focuses purely on the plant and its growth response to $CaSO_4$-dominated growth conditions. Most of the experiments conducted were therefore with water and sand cultures. For obvious reasons some extrapolations to soil conditions are considered.

The seedling stage was used for most of the experiments. The tolerance of crops during the seedling stage is important as it is the most sensitive growth stage and effective establishment is necessary for optimum yield. Growth differences are also likely to be clearest at this stage. Some authors have argued that in this growth stage it is the decreased osmotic potential that causes growth decreases (Munns, 1993; Neumann, 1997). This was, however, concluded against the background of osmotic potential versus accumulation of salts being the major suppressing properties of mostly NaCl-dominated saline waters. Other sensitivity mechanisms, such as nutrient imbalances or other ionic effects, were not addressed in these reviews.

The wide range of crops screened afforded an opportunity to investigate whether the physiological salt sensitivity or tolerance mechanisms, which had previously been found for the respective crops, were related to growth responses to this gypsiferous type of water. This may lead to some indication of which properties of such a water are mainly responsible for suppressing growth of crop species.

Seedling growth responses, of a wide variety of crops and cultivars, were firstly investigated in water culture under glasshouse conditions with actual 'worst case' saturated gypsiferous water from the Kleinkopje mine (Chapter 4). The crops and cultivars were selected on the basis of good yields under irrigation and the climatic conditions of the region; they could therefore be expected to possess a measure of tolerance to NaCl saline conditions.

Subsequently a tolerant cultivar of each crop was selected for growth curve investigations with increasing concentrations of Ca, Mg and SO_4 in a simulated $CaSO_4$ mine water; sand culture in growth chambers under controlled environmental conditions was used (Chapter 5). Treatments also included saturated solutions with increasing amounts of undissolved gypsum crystals in order to gain information on growth responses when gypsum had precipitated, and ranges of NaCl, and Na_2SO_4 saturated with $CaSO_4$.

Comparisons of growth responses to the NaCl, Na_2SO_4 and $CaSO_4$ treatments plotted at similar osmotic potentials could possibly be used to determine sensitivity to ionic effects of Na and Cl.

The tolerance of the different growth stages is compared in Chapter 6. Germination trials in paper rolls were conducted in a growth chamber and the vegetative growth stage was investigated on sand culture in the glasshouse. Nutrient analyses of the top growth were conducted to determine possible nutrient interaction problems (Chapter 6).

The main challenges of these investigations were:

- to compare the tolerances of the different recommended *cultivars* of the crops in the sensitive seedling stage in order to facilitate the choice of suitably tolerant cultivars to ensure agricultural productivity when irrigating with $CaSO_4$-dominated waters

- to determine the seedling growth responses of the crops to increasing Ca, Mg and SO_4 concentrations, with special attention to the question of how increasing amounts of precipitated gypsum may influence growth

- to acquire knowledge of the sensitivities/tolerances of the different *growth stages* of the respective crops to $CaSO_4$-dominated water which may be important for irrigation management

- and finally to gain some insight into which property or properties of a $CaSO_4$- dominated water are mainly responsible for suppressing (or stimulating!) growth.