CHAPTER 4

CROP PRODUCTION AND PLANT NUTRITION

4.1 Introduction

In this chapter, *crop production* and *plant nutrition* aspects of the study are discussed. The *crop production* section presents the yields and biomass production obtained and discusses possible reasons for suboptimal performance in certain seasons. Yields were also compared to dry land crop production in the region. The *plant nutrition* section discusses results of plant analyses and the imbalances that could occur as a result of unfavourable nutrient interactions. The plant analysis results were interpreted by the Sufficiency Range (SR) approach; this is defined as the range in concentration that can result in 95 to 100% of maximum yield. Diagnosis Recommendation Integrated System (DRIS) was used to rank the most limiting nutrient in the gypsiferous water irrigated crops. In Syferfontein, the effect of the Na_2SO_4 rich irrigation water on forage quality was considered.

4.2 Crop production

The results of the measurements taken for each site are presented in the following discussions.

4.2.1 Kleinkopjé

The yield of maize obtained from fields irrigated with gypsiferous water (average 4 t ha^{-1}) was lower than the average yield usually obtained from fields irrigated with normal water (8 t ha^{-1}) (Du Plessis, 2003), but is higher than the yield of dry land farming (3 t ha^{-1}) (FAO, 2005) (Figure 4.1). According to Maas & Hoffman (1977), maize can still attain potential yield of 100% up to an EC_e (soil saturated paste extract) level of 200 mS m^{-1}. The yield obtained from Pivot TWF and Major, however, was lower than could be predicted from the Maas & Hoffman (1977) yield reduction function. Soil compaction at TWF and the existence of a plinthic layer, which causes limited drainage, at Major could be the possible reasons for the observed yield reduction. The yield reduction in Pivot Four can also be related to the low pH in the soil that could have restricted the availability of nutrients to the plants. Wheat is more tolerant to soil salinity than maize (Maas & Hoffman, 1977), so wheat yield produced on site Major, Pivot four and TWF were not affected by the EC of the irrigation water. According to Maas & Hoffman (1977), wheat can attain a yield of 100% as long as the EC_e threshold does not exceed 600 mS m^{-1}. There was a difference in yields obtained between seasons which could be related to pests and diseases, rainfall or amount of irrigation water applied. Maize crops were damaged in the 2000/01 season, when an excess of herbicide (up to 3 times the planned rate) was wrongly applied to all three pivots.

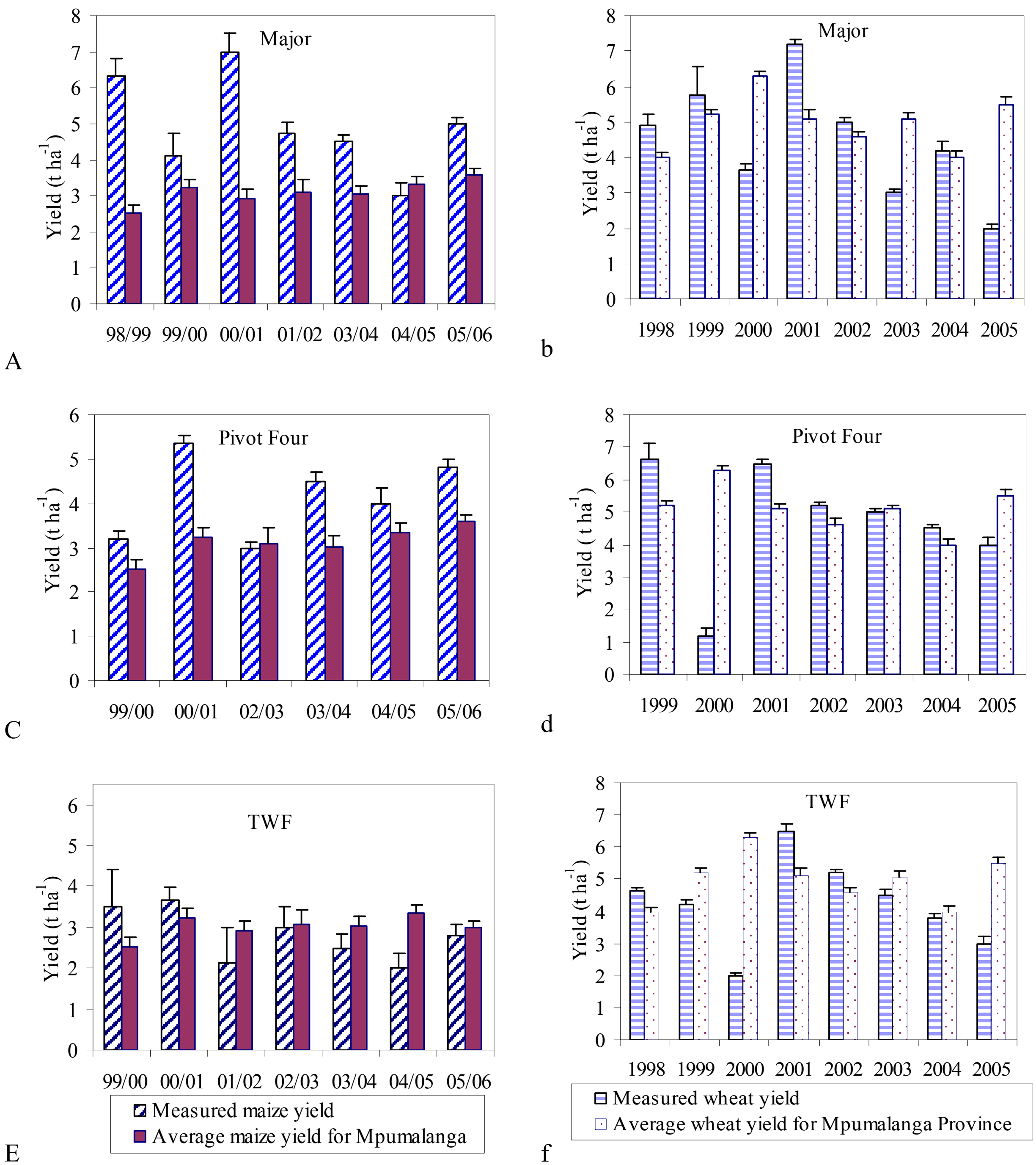


Figure 4.1 Mine water irrigated and dry land yield of maize (a,c and e) and wheat (b,d and f) grown at three pivots at Kleinkopjiè

The yield of maize obtained from Pivot Four was compared with average dry land yield in the region (personal communications, Department of Agriculture, South Africa). The yield obtained from the mine water irrigated soils was higher than the dry land yield (Figure 4.1c). In 2002/03 the yield obtained was lower than the dry land yield. In the same period of time high soluble [K]/[Ca] ratio was observed. The low yield of mine water irrigated maize was apparently related to low potassium for the growing period. K deficiency in these same soils has also been reported in Chapter 4, as Ca excluded K from exchange site. The yield of wheat obtained from Pivot Four was also compared with average yield of irrigated wheat in the Mpumalanga Province (personal communications, Department of Agriculture, South Africa). The yield was comparable to those irrigated with good quality water (Figure 4.1d). In winter 2000, crop failure occurred due to hail.

The yield of maize and wheat obtained from Pivot Major were also compared with average dry land yield of maize and irrigated yield of wheat in the region. The yield obtained from mine water irrigated soils were higher than the average dry land yield for the region (Figure 4.1a), but lower than one could expect from good quality water irrigated crops (FAO, 2005). This is most likely due to the accumulation of salts in the soil above the threshold tolerance of maize especially in the last few years of monitoring, as EC of the irrigation water has climbed from 250 mS m^{-1} to 320 mS m^{-1} (Chapter 3). The plinthic layer at one-metre depth also caused poor drainage and waterlogging problems whenever high rainfall occurred during summer (on the positive side, these wet periods also assisted in leaching salts out of the root zone).

Pivot Major, a poorly drained site, has been irrigated for a longer period of time than Pivot Four, which is a well drained site. Nevertheless, the yield obtained from Pivot Major was comparable to that of Pivot Four. This is related to the high EC of the irrigation water Pivot Four received. The EC of the irrigation water used at Major was around 250 mS m^{-1} in 1997, but increased to a value of 320 mS m^{-1} by the end of 2005. The EC of the irrigation water in pivot Four, started at around 300 mS m^{-1} in 1998 and was fairly stable for several years until 2001, when a rapid increase in EC to a level of 500 mS m^{-1} was observed by the end of 2005. This had a significant effect on the yield of maize over the growing period (Figure 4.2c).

Wheat yield from Pivot Major was also compared to average yield of irrigated wheat in the region. Yield of wheat from mine water irrigated soils was low in the winters of 2000, 2003 and 2005 (Figure 4.1b). In winter 2000, crop failure occurred due to hail whilst in 2003 and 2005; the low yield is related to low amount of irrigation water applied. For example, only an average of 250 mm was applied in the winter seasons, while more water could have been applied (500 mm) to get better yield.

Pivot TWF is a rehabilitated site, and after heavy rain, waterlogging and ponding frequently occurred. A similar condition also arose in the lower lying regions of Pivot Major. The main cause of this is the low hydraulic conductivities of the spoil layer at TWF, and a natural limiting plinthic layer at Major. These are therefore not ideal irrigation sites. Maize yield from mine water irrigated soils in TWF, were often lower than the average dry land yield for the region (Figure 4.1e). This low yield is related to the accumulation of salts above the threshold tolerance for maize (Figure 4.2e) and the waterlogged conditions caused by the low hydraulic conductivities of the spoil layer. The EC of the irrigation water also showed a rapid increase from around 300 mS m^{-1} to a level of 500 mS m^{-1} from 2001-2005 (Chapter 2). In summer, 2004/05 extensive rust disease was also identified on the maize in the late maturity stage and yield was very low. The wheat yield obtained from Pivot TWF was also compared to the average irrigated yield for the region (Figure 4.1f). The yield obtained was usually closer to optimum yield than for the summer crops, as we have much better control over the water balance in winter than in summer.

In winter 2005, wheat was doing very well initially for all pivots and was expected to yield 7 t ha^{-1}. Unfortunately, the electricity supply by the mines to run the pivots was interrupted for six weeks, and as a result, the yield was less than half of what was expected. The yield of wheat obtained from Pivot TWF was observed to decrease from 2001-2005 with the increase in EC of the irrigation water (Figure 4.1f). In the same period of time, Mg in the irrigation water increased and the [K]/[Mg] ratio in the soil solution decreased, indicating the likelihood of potassium deficiency developing (Chapter 5).

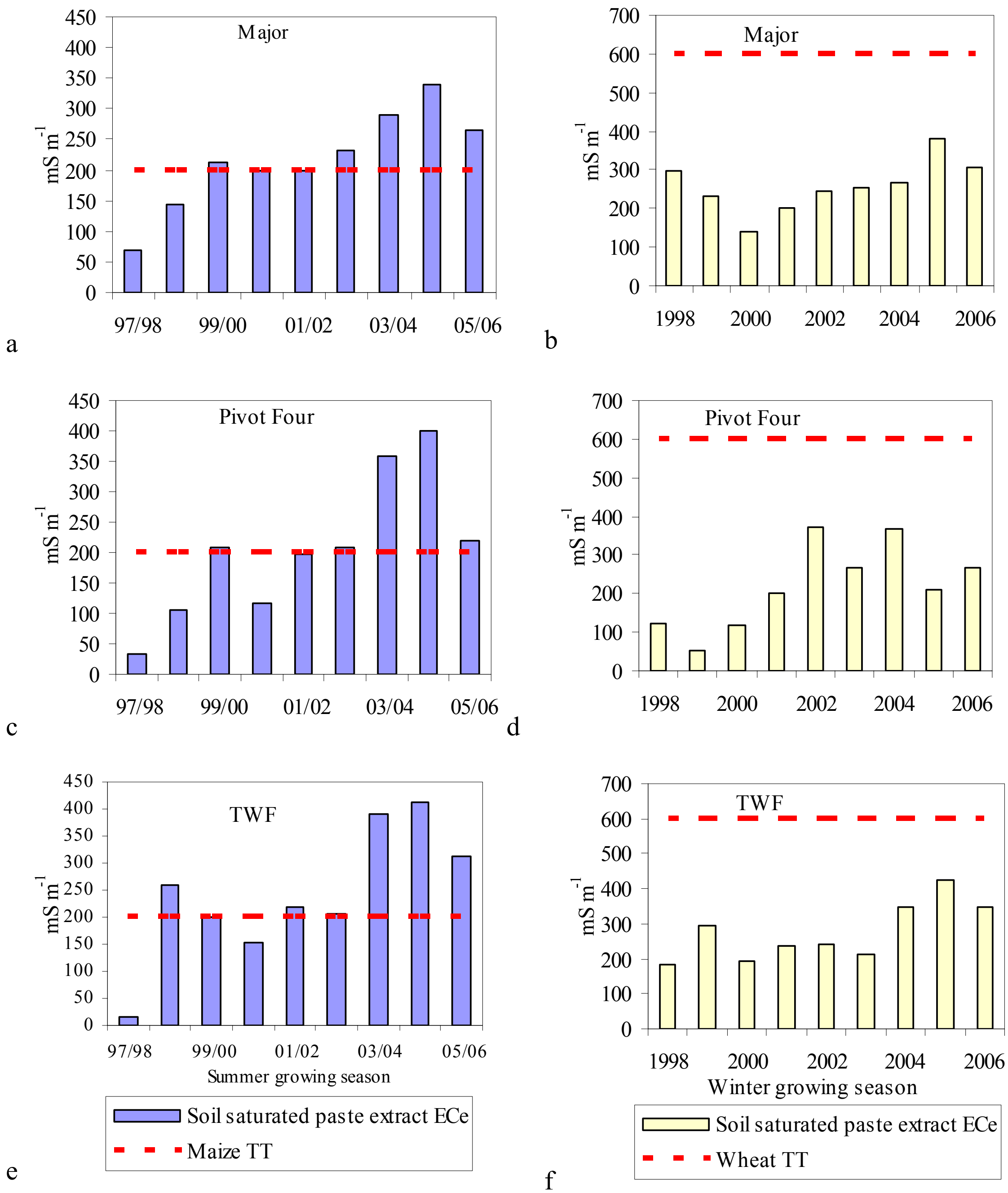


Figure 4.2 Average root zone soil saturated paste extract (EC_e) of soils irrigated with mine water during the growing period and salinity threshold tolerance (TT) for maize and wheat on three pivots at Kleinkopjiè

Potato seed pieces (*Solanum tuberosum* cv. Up-to-date) were planted in Pivot Four at the end of August 2001 and the crop was harvested in January 2002. The marketable potato yields attained was 52 t ha^{-1} in 2001/02 and for 2002/03 at Pivot Major, yields of 62 t ha^{-1} were produced. These can be regarded as good yields for the Mpumalanga Province. Unfortunately no control fields (irrigated with normal water) were available for comparison of crop yield but the yield obtained from mine water irrigation was expected to be better as a result of the dominance of Ca in the irrigation water.

Certainly, crops can be produced with gypsiferous mine waters, but site selection is critical. Pivot Four was always the best site as there were no drainage problems. It is important, therefore, to note that poor crop performance must not automatically be attributed to the quality of the irrigation water.

4.2.2 New Vaal

At New Vaal field crops of maize, wheat and soybean, and vegetables like peas, sweetcorn and pumpkin were planted. The yields obtained were not satisfactory for the trial period, which is related to poor irrigation site selection. The yields from the pea and pumpkin harvests were also low because of very high rainfall late in the season, causing high volumes of water in the dam. The dam is located near to the irrigation site and water was moving laterally in the very sandy soil from the dam, as the dam was unlined and porous. Waterlogging was evident over large areas of the pivot and this influenced the growth of the peas and pumpkins negatively, which caused yield losses (Figure 3.16). To alleviate this problem, a cut-off trench between the dam and the pivot area was excavated in August 2004, and the pivot was planted to soybean in summer 2004/05. The total yields obtained from the crops from 2001 to 2005 are summarized in Table 4.1.

Table 4.1 Crops, cultivars and yields irrigated with gypsiferous mine water (at New Vaal)

Season	Crops and cultivars	Yield ($Mg\ ha^{-1}$)	Comments
2001/02	Maize(cv. PHI 32P75)	7.8	Wet areas
2002	Wheat(cv. SST 825)	3.3	Pollination problems due to hot period
2002/03	Maize(cv. PHI 32P75)	5	Low stand
2003	Peas	1.1	Temperature, low stand
2004	Sweet corn	6.9	Waterlogging
2004	Pumpkin	2.5	Waterlogging
2004/2005	Soya bean	3	Waterlogging

In summer 2001/2002, the maize yield was satisfactory, however crop growth was not uniform throughout the field, as the water table rise resulted in periodic saturation of the soil.

In winter 2002, yield loss occurred as wheat was planted late, which caused late maturity and exposure to hot dry weather during the pollination and grain filling periods. The poor pollination therefore, reduced the silk and resulted in lower yields, even though plant population, fertility, and water availability were optimal.

In summer 2002/2003, a very poor stand was observed for the maize as the rising water table kept the sandy soil continuously wet, resulting in anaerobic conditions. In addition, chemical weed control by the farmer was not satisfactory.

Starting from winter 2003, the farmer decided to attempt to produce higher value vegetable crops like peas, pumpkins and sweetcorn. Unfortunately, after a little irrigation, the water table started to rise and the drainage became limited, even though it is a very sandy soil. As a result, the anaerobic conditions in the root zone resulted in poor germination.

In summer 2004/05, a drainage canal that was meant to cut the field off from the dam was trenched. This was an attempt to limit the lateral water flow from the dam to the field but the improvement seems to have been minimal. Thus, a poor stand and yield of soybean was obtained and the farmer in conjunction with the research team and mine decided to cease operations. Clearly, site selection for irrigation is crucial, and we are confident that it was not the water quality that resulted in these failure, but rather the long periods of waterlogging (Figure 3.16).

4.2.3 Syferfontein

In Syferfontein annual and perennial pasture crops were grown and the yields obtained were satisfactory for the trial period. The pastures grown and the yields obtained throughout the trial period are indicated in Table 3.1 and Figures 4.3.

There were nine harvests during the 2001-2004 growing period. As the planted pastures emerged from seed, they were observed to grow slowly at first and then their growth accelerated until they reached the flowering stage, after which growth slowed. A plateau was also observed during their growing periods, particularly in Lucerne. This was not related to the irrigation water quality. The growth of grasses usually follows a sigmoidal curve from the time of establishment until death in annuals and until a steady condition is reached in perennials (Tainton, 2000).

The regrowth of pastures after mowing should follow the same sigmoidal growth pattern as in the previous cycle (Dovrat, 1993). However, after mechanical harvest and an extended cutting interval, the recovery of Fescue (cv. Iewag), Fescue (cv. Demeter), Eragrostis and Kikuyu was slow. Cutting the grasses extremely short, and dry periods after mowing caused this slow growth. According to Dovrat (1993), small numbers of tillers may have remained after cutting that enabled the regrowth. It could also be due to the decrease in capacity to capture solar radiation. Accordingly, the plants depleted the stored carbohydrate reserves and slow regrowth was observed. Maintaining adequate irrigation and water levels in the soil is also effective in maintaining humidity in the green leafy canopy, so that the grass can continue to transpire and photosynthesise.

Since the pastures were harvested to a height of 3-7 cm above the ground, the apical meristem might have been removed, which could be another reason for the slow recovery of the grasses. Lucerne, a perennial legume, unlike the grasses has a lignified stem, and has the capacity to develop secondary stems from the axillary buds of the lower leaves on the original primary stem (Tainton, 2000). Lateral tillering or branching becomes necessary before continuation of leaf production in grasses. Thus, the height of cutting changes the location of shoots that support regrowth (Dovrat, 1993).

The remaining TDM and leaf area after cutting are the most important factors in determining regrowth (Dovrat, 1993). The regrowth of Lucerne was observed to be faster than the grasses. This might be due to the apex of grasses being higher from the ground while in legumes apical meristem (terminal growing point) remains low to the ground during their vegetative growth (Tainton, 2000).

In this study, the idea was to grow a mixture of grasses and legumes but the tall growing pastures such as Eragrostis and Lucerne formed a canopy that covered the slow growing species. As a result, after the first cut the taller plants crowded out the shorter plants, resulting in pure stands of Lucerne and Eragrostis. This could be due to the capturing of most of the solar radiation by the tall growing grasses, while the slow growing grasses remained shaded (Tainton, 2000).

The average yield and above ground dry matter of Fescue (cv. Iewag) was greater than that of Lucerne, Fescue (cv. Demeter) and Eragrostis. This could be due to the tolerance of Fescue (cv. Iewag) to salinity. According to Tanji (1990), the EC_e threshold of Fescue is 390 mS m^{-1}, while for Kikuyu it is 300 mS m^{-1}. In addition, Tanji (1990) also reported a salinity threshold of 200 mS m^{-1} for Lucerne and Eragrostis. The difference in yield between the two Fescue cultivars could be due to cultivar differences. However, the yields of all the planted pastures were lower than those that could normally be expected (Taiton, 2000) Figure 4.3.

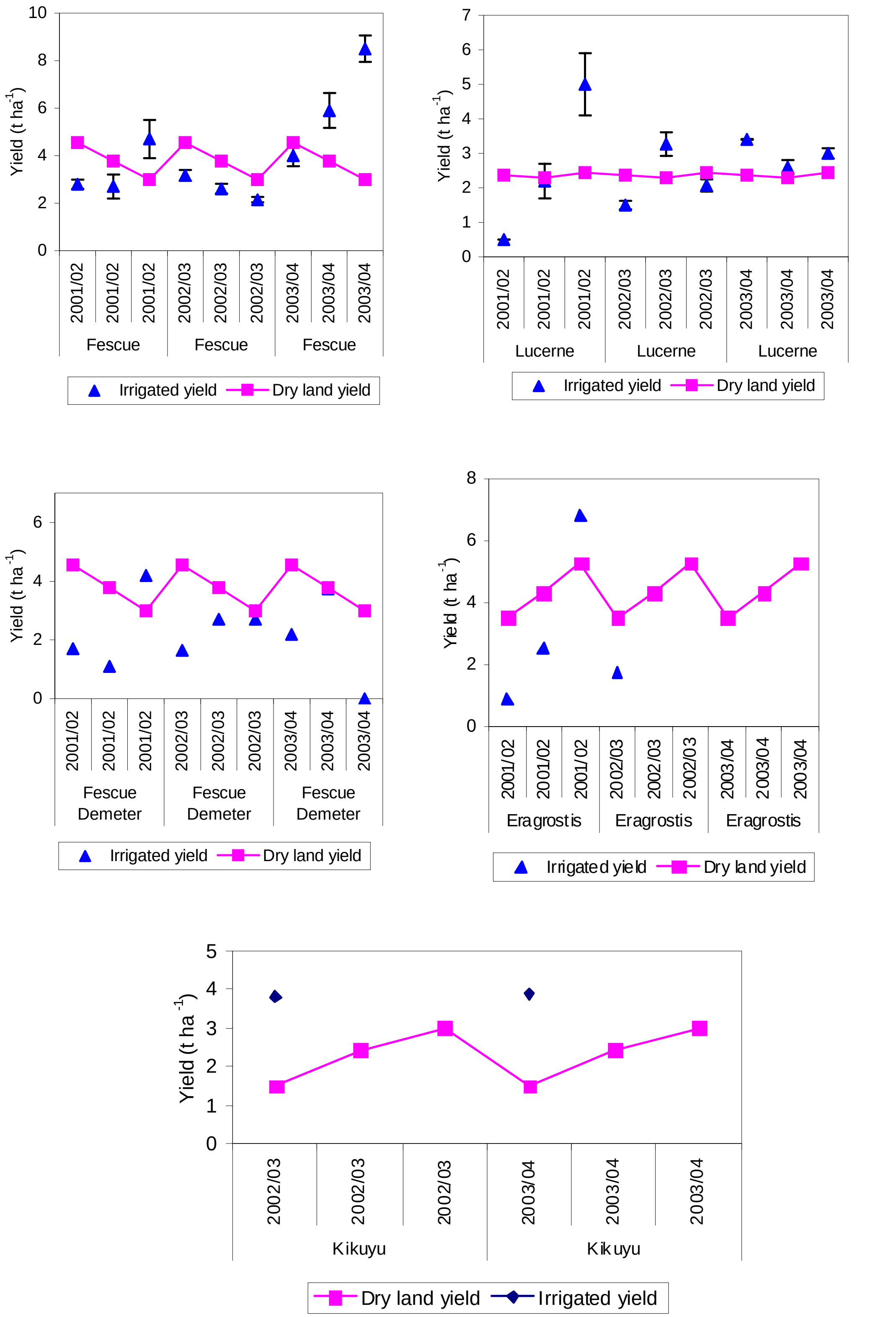


Figure 4.3 Yields of pastures irrigated with Na_2SO_4 rich mine effluent and typical dry land

Although the pastures were all harvested at the same time, the regrowth of Lucerne was observed to be much faster. The basal cover of Fescue (cv. Iewag), Fescue (cv. Demeter) and Kikuyu was outstanding. In the growth cycles, there was no sign of leaf burn due to the mine effluent. The leaves of Lucerne were, however small, which could be due to the high EC of the irrigation water and periodic water logging, as Lucerne is adapted to well drained soils.

4.2.4 Waterberg

Effect of $NaHCO_3$ water on biomass production of barley and ryegrass seemed negligible for the first six weeks of irrigation in the winter 2005 experiment. Although comparable data with good quality water were not available, barley irrigated at a leaching fraction of 23% showed a higher LAI and biomass production than the LF46% and FC treatments (Figure 4.4).

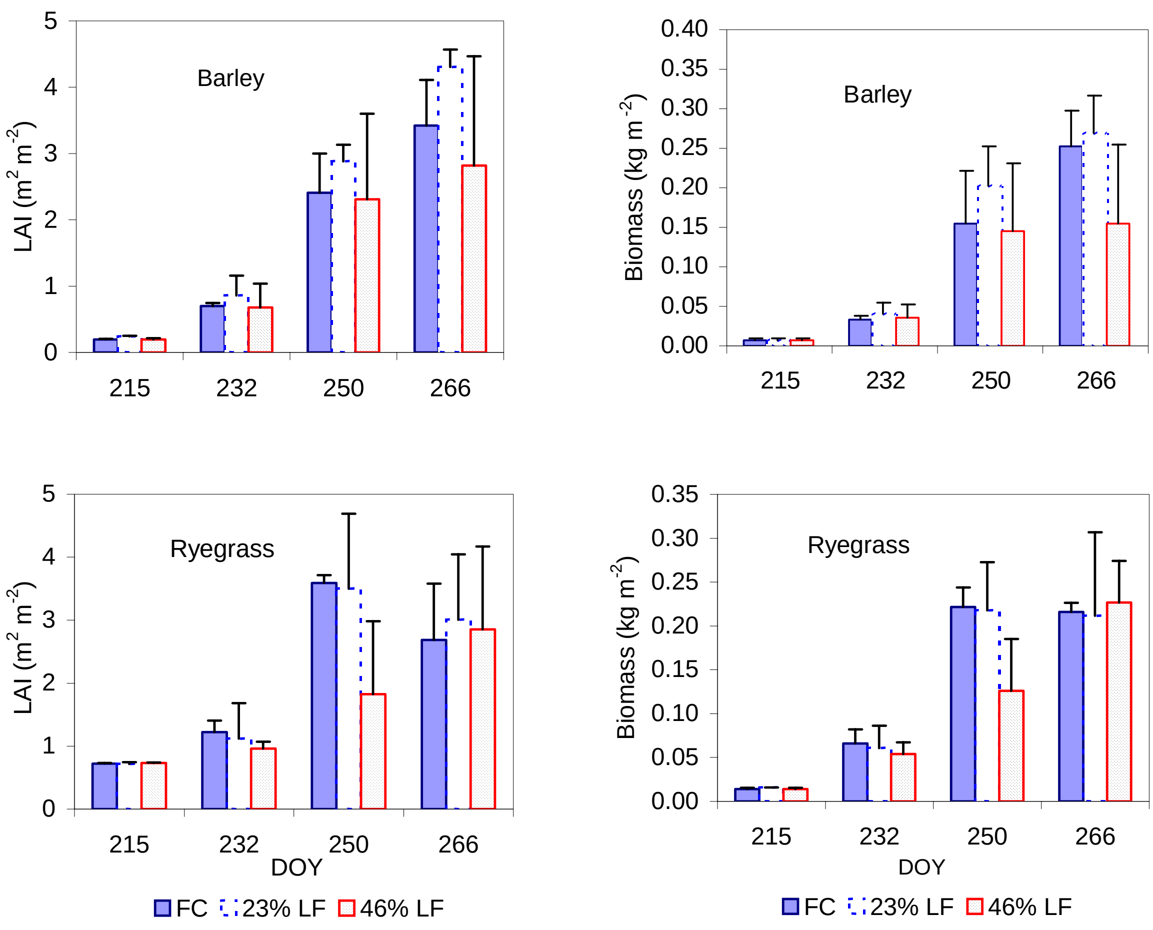


Figure 4.4 Leaf area index and biomass production of the salt tolerant winter crops under different irrigation management strategies

Barley irrigated at a 46%LF showed the lowest performance in terms of biomass production, as the high leaching fraction reached high ESP more rapidly, which caused waterlogging and leaching of nutrients. Low LAI and biomass production in the FC treatment could be due to the accumulation of salts in the root zone (Figure 4.4). Stooling rye did not establish well, which could be due to the late planting date, as it is actually an autumn crop. Italian rye grass, on the other hand, established well with a full ground cover. No difference in biomass and LAI was observed for the Italian ryegrass irrigated to FC and that with a 23%LF. Barley and Italian ryegrass died after six weeks of irrigation as a result of waterlogging, related to the decrease in infiltration rate with the increase in exchangeable sodium in the soil. This is a common effect on certain soils when irrigating with sodium-rich waters (Shainberg & Letey, 1984; Oster *et al.*, 1996). Sprinkler irrigated barley and Italian ryegrass did not exhibit foliage scorching symptoms, but senesced early due to ponding.

The biomass yields and above ground dry matter of cotton and Bermuda grass were satisfactory. Cotton irrigated at an LF of 23%, as in the case for the winter season crops, showed higher LAI and biomass production than the 46% leaching fraction and FC treatments (Figure 4.5). A similar tendency was observed for the second sampling of Bermuda grass, although differences were minor (Figure 4.6).

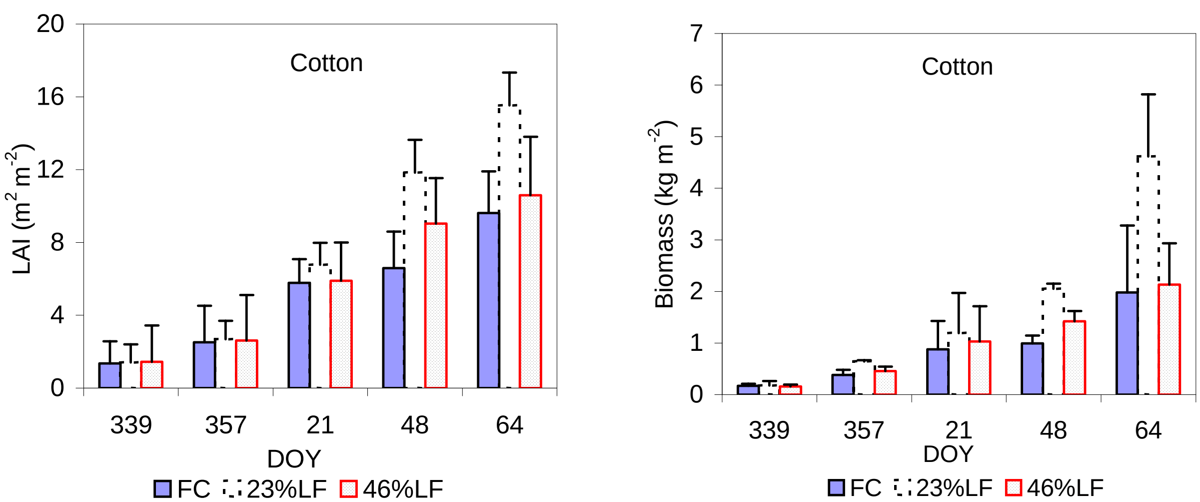
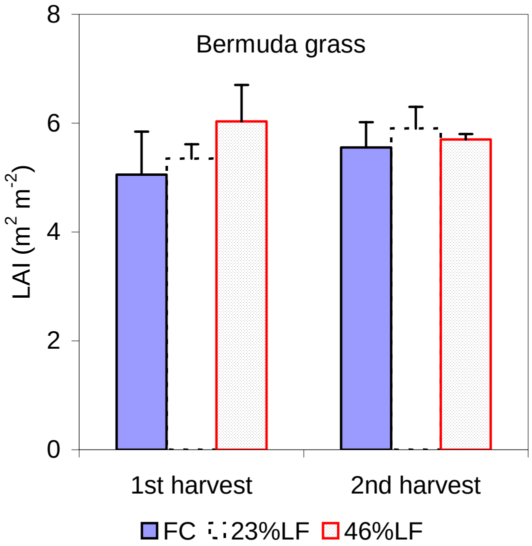


Figure 4.5 Leaf area index and biomass production of cotton under different irrigation management strategies



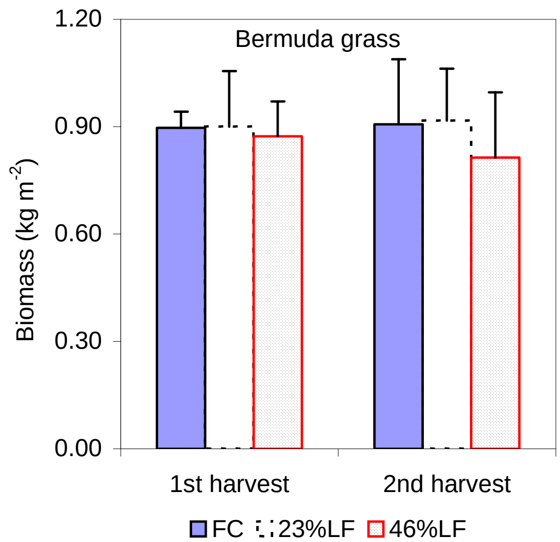


Figure 4.6 LAI and biomass production of Bermuda grass under different irrigation management strategies. First harvest received less saline water, whilst the second harvest was irrigated with 800 mS m^{-1} $NaHCO_3$ water

Table 4.2 Cotton yield and fibre quality obtained from the CBM deep aquifer water irrigated fields

	Cotton				
Irrigation treatment	Yield (t ha^{-1})	Lint uniformity (%)	seed mass (g)	Length (cm)	Micronair (micro g cm^{-2})
FC	5.3(±2.3)	83.3%	390	1.13	4.0
LF-23%	7.0 (±2.4)	84.0%	400	1.17	3.9
LF-46%	5.5 (±2.3)	83.0%	250	1.15	3.2

The cotton yield obtained with this saline water was higher than the average dry land crop production in the area, which is only 0.5-2 t ha^{-1} (Cotton SA, 2006). In this trial periods, the 23%LF seem to have struck a good balance between sufficient salt leaching without excessive nutrient leaching, as several small N top dressings were applied to minimize such losses.

Conclusions

Maize and wheat were irrigated with Ca, Mg and SO_4 rich mine water for several seasons at Kleinkopjé Colliery. Yields of maize obtained at all the sites were depressed below the optimum as salt accumulated in the root zone above the threshold tolerance of the crop. These yields, however, were higher than average dryland yields for the region. Wheat reportedly is more tolerant to salinity than maize and optimal yield was obtained as can be seen by comparing yields with that of irrigated wheat for the region as a whole.

At New Vaal, field crops of maize, wheat and soybean, and vegetables like peas, sweetcorn and pumpkin were planted. The yields obtained were not satisfactory for the trial period, which could be related to poor irrigation site selection. No symptoms of foliar injury due to centre pivot sprinkler irrigation with gypsiferous mine water were observed for all crops. The major problem experienced was waterlogging due to poor site selection, especially during the summer months, when control over the soil water regime is difficult due to rainfall. The problem was not related to the chemistry of the water used for irrigation, as it was observed that crop performance was good in well-drained areas of the fields. Crop production under irrigation with mine water rich in Ca, Mg and SO_4 is, therefore, feasible and sustainable if properly managed.

Pasture production with Na_2SO_4 rich mine effluent was also feasible, at least in the short term (three years), but would need a well-drained profile and a large leaching fraction to prevent unsustainable salt build up in the soil. Unfortunately, the waters did not present much of an opportunity for gypsum precipitation, which is able to drastically reduce the salt load of the receiving waters in the case of Ca and SO_4 rich mine waters. The application of $Ca(NO_3)_2$ as a source of Ca to the soil could remove some SO_4 from the water system and enhance gypsum precipitation.

The highly concentrated $NaHCO_3$ Coal Bed Methane deep aquifer water is of very poor quality for irrigation. Salt tolerant crops of barley, Italian ryegrass, cotton and Bermuda grass, however, can be grown with very skilful irrigation and crop management. Crop production under sprinkler irrigation clearly showed that barley, Italian ryegrass and Bermuda grass were able to grow without leaf burn and toxicity problems. However, cotton foliage was scorched due to the high levels of Na in the irrigation water. It is recommended that with water of this quality, irrigation systems that apply water directly to the soil surface would be preferable. This is especially prudent if one also considers the likely mechanical impact of sprinkler irrigation on surface crusting and on salt accumulation.

4.3 Plant nutrition

Two methods, sufficiency range (SR) and DRIS system were used in the interpretation of the nutrient concentration in the leaves. The sufficiency range (norms) compares the nutrient levels found in plant tissue, while the DRIS system indicates the most limiting nutrient during crop production. The results of the two interpretations are discussed as follows.

4.3.1 Kleinkopjé

Sufficiency range

The interesting observation in this study was that the N content was below the normal range throughout the study period (Figure 4.7). This could be due to poor fertilization management. EC of the irrigation water could have also played a role as similar results were obtained by Feigin (1985). Most salinity and N interaction studies in the field were conducted on soils deficient in N, thus additions of N improved growth and/or yield (Grattan & Grieve, 1998). However, the form in which N supplied to salt-stressed plants can influence salinity-N relations as well as affect salinity's relation with other nutrients (Lewis *et al*., 1989; Martinez & Cerdá, 1989).

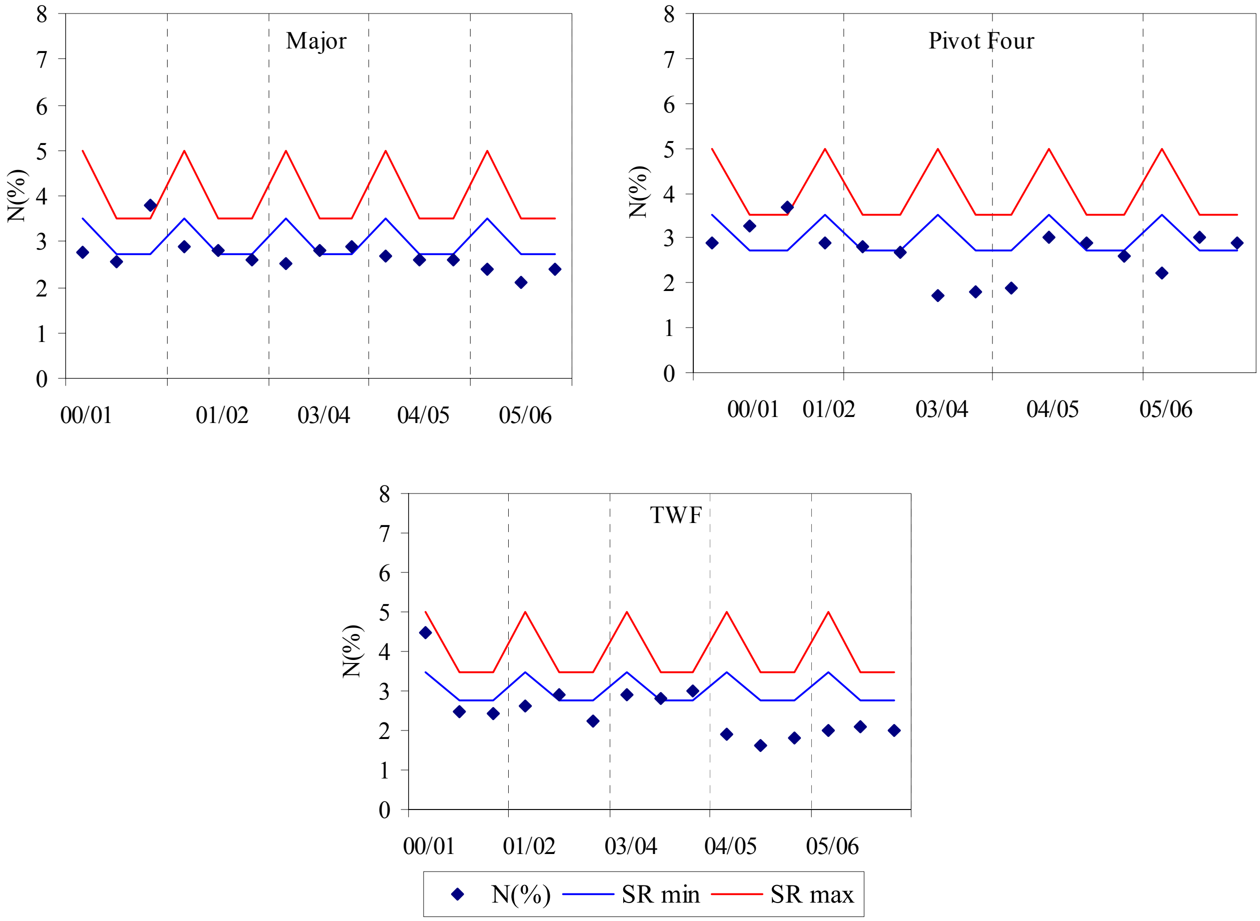


Figure 4.7 N content of maize leaf irrigated with coal mine-water for sites Major, Pivot Four and TWF, and sufficiency range of maize leave irrigated with fresh water

K contents on most samples were higher in the early stages and decreased 67 to 69 days after planting, as it was translocated from old leaves to new growth. In the summer seasons of 2003/04, 2004/05 and 2005/06, K was below the normal range and marginal leaf burn was also observed (Figure 4.8). Other research also has demonstrated that the presence of adequate Ca in the soil influences the uptake of K by favouring the selectivity of K (Grattan & Grieve, 1998). The beneficial effects of Ca on the K status of saline water irrigated crops could be more evident in root tissue rather than the shoots e.g. maize (Izzo *et al.*, 1993).

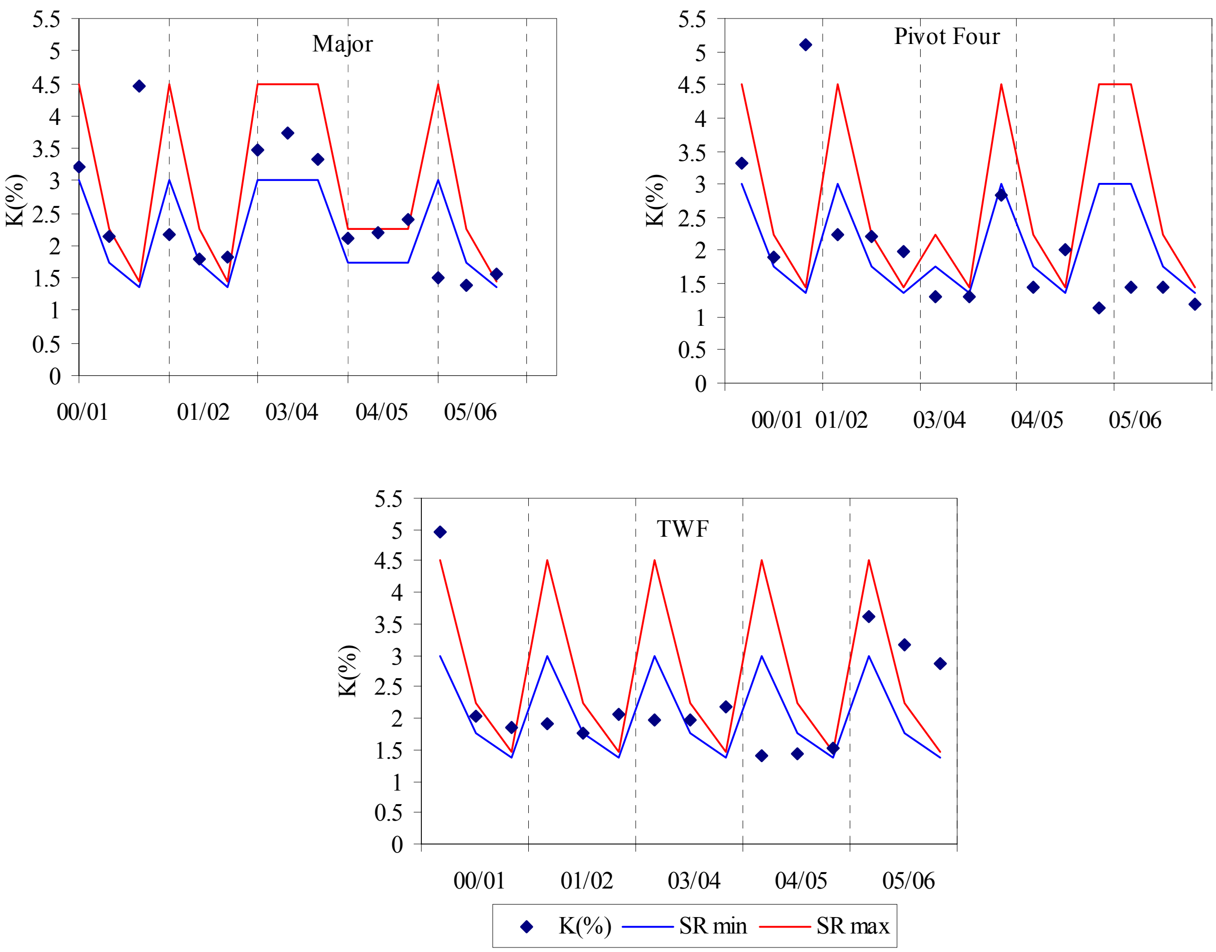


Figure 4.8 Maize leaf K content for sites Major, Pivot Four and TWF

Magnesium content in the plant tissue was with in the normal range in most of observations (Figure 4.9). Pivots Four, TWF, and Major received irrigation water with Mg content that ranged between 150 and 300 mg ℓ^{-1} (Chapter 3). This confirms that no Mg fertilization is required. According to Marschner (1995), Ca is a strong competitor with Mg and the binding sites on the root plasma membrane appear to have less affinity for the highly hydrated Mg than for Ca.

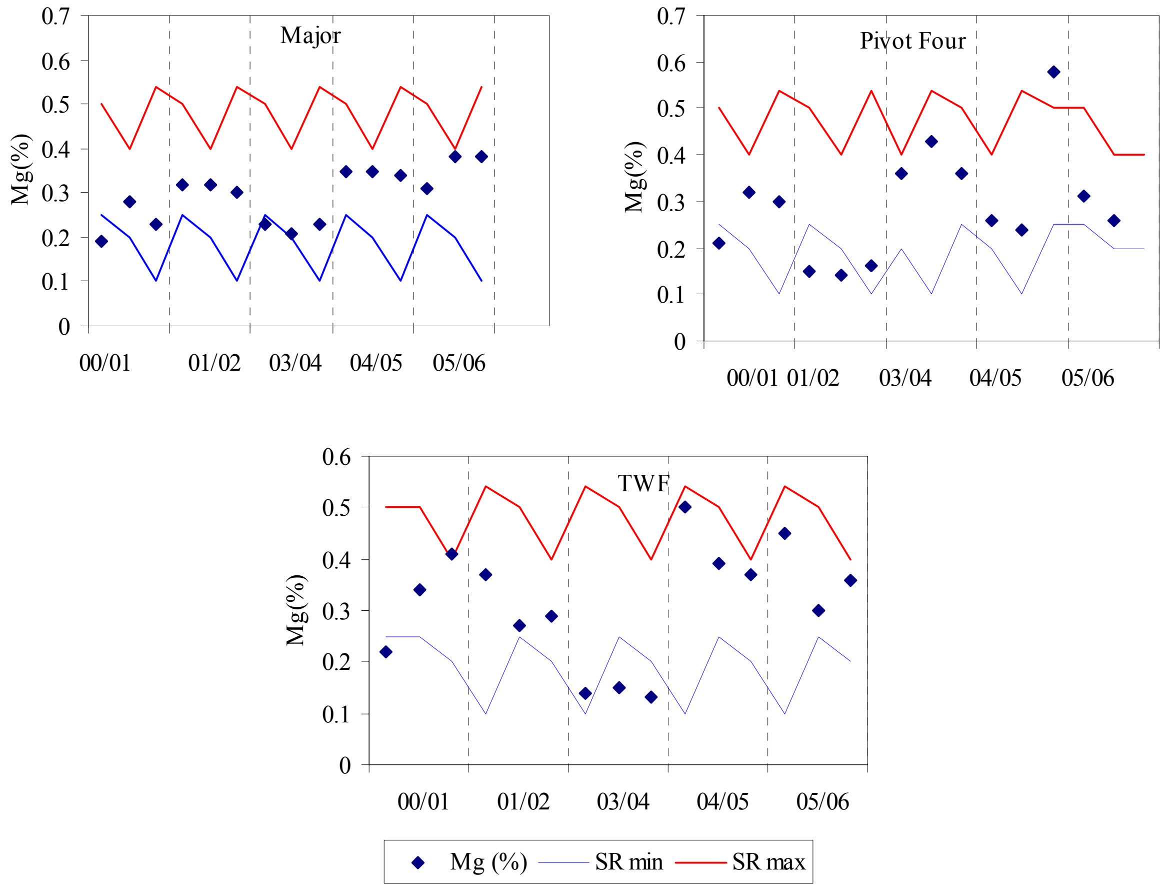


Figure 4.9 Maize leaf Mg content for sites Major, Pivot Four and TWF

The Ca content in the plant leaves was observed in the normal range, except for Pivot Four (Figure 4.10). This could be related to the ion interactions, precipitation of gypsum, and increase in ionic strength that depress the uptake of Ca from the soil solution. According to Suarez & Grieve (1988), these factors reduce the activity of Ca in solution, thereby decreasing Ca availability to the plant. The results obtained in this study agrees to the concept of Gerard (1971) and Bernstein (1975), that says with the increase in salt concentration in a root zone, plant requirement for Ca also increases.

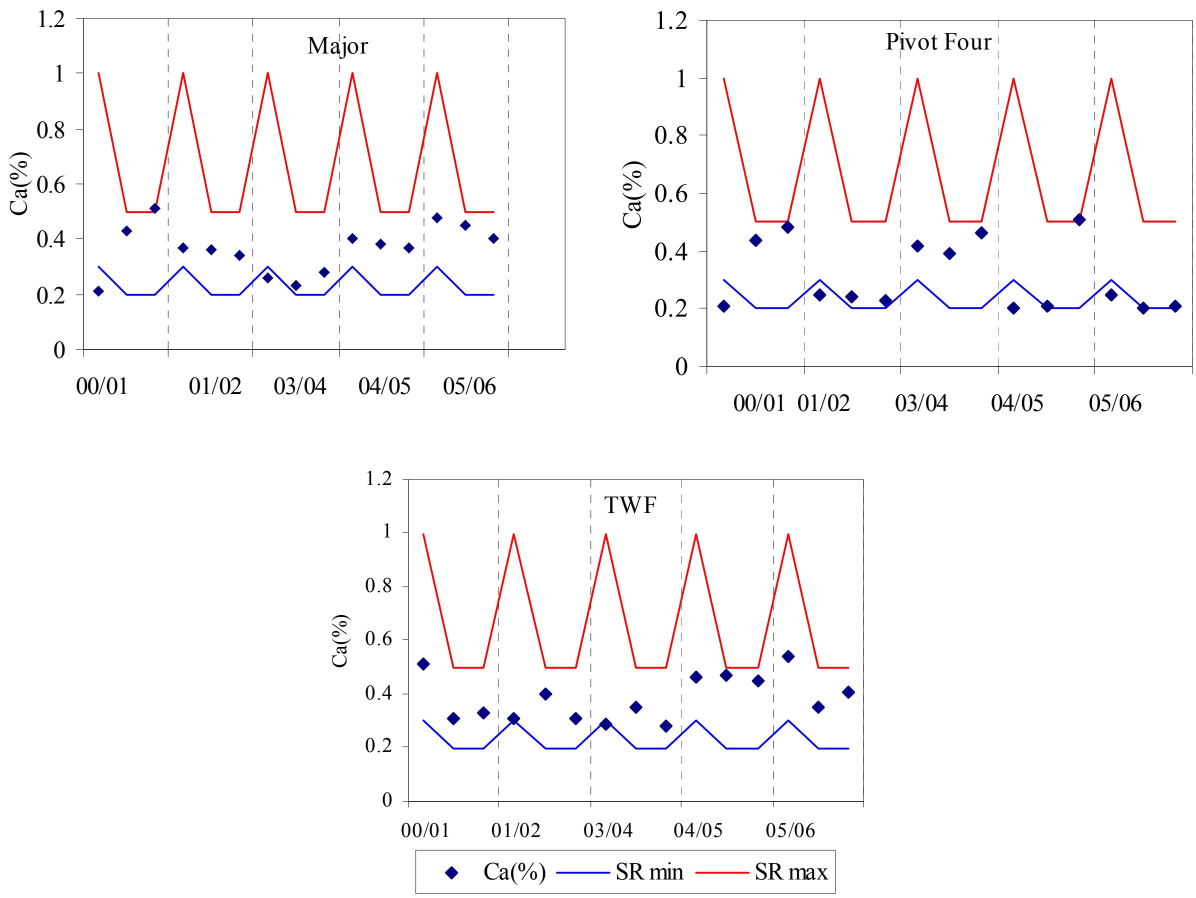


Figure 4.10 Maize leaf Ca content for sites Major, Pivot Four and TWF

SO_4 levels were often above the sufficiency range at Pivot Four and TWF (Figure 4.11). The high SO_4 in the plant tissue was likely due to the high SO_4 levels in the soil solution coming from the irrigation water. The presence of high SO_4 did not bring any problem to crop production throughout the trial period. According to Grattan & Grieve, (1998), many crops are generally more tolerant to sulphate-salinity than chloride-salinity. Other sulphate-salinity studies have also shown that SO_4 have the advantage of reducing the accumulation of potentially toxic oxyanion, molybdate (Läuchli & Grattan, 1993) on plant tissues.

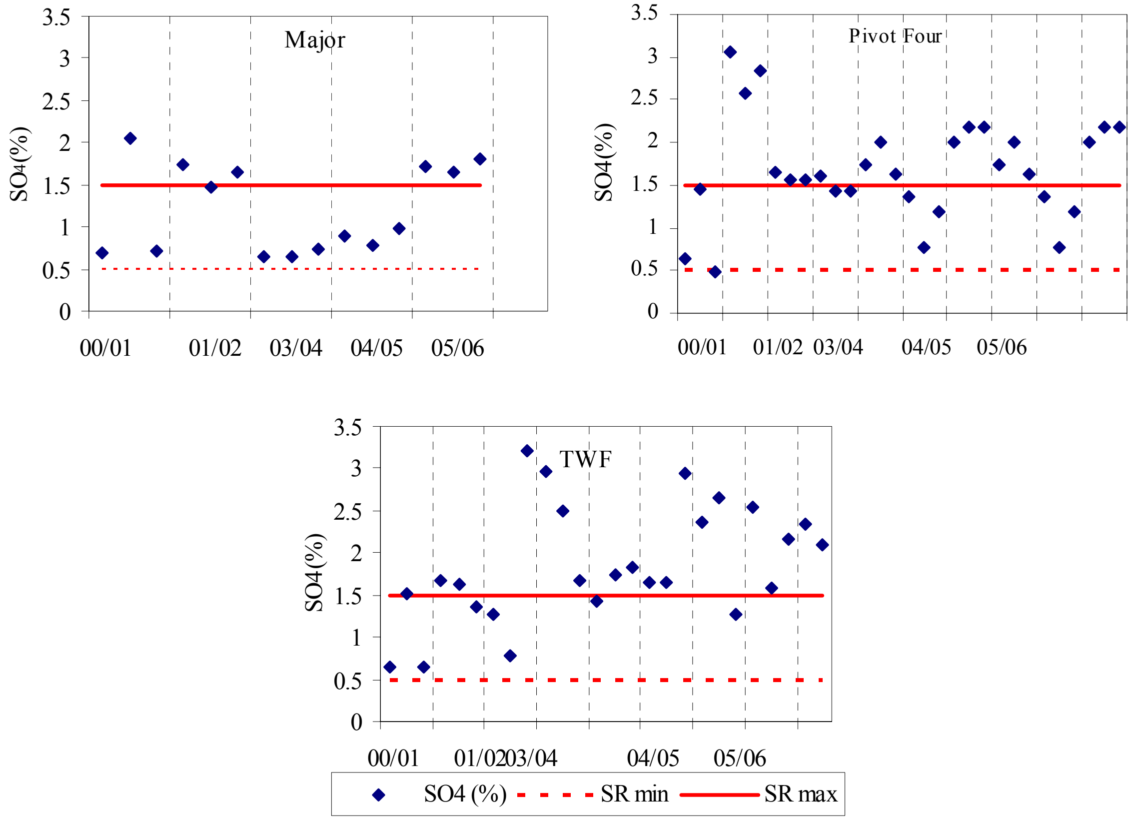


Figure 4.11 Maize leaf SO_4 content for sites Major, Pivot Four and TWF

Diagnosis Recommendation Integrated System (DRIS)

The sufficiency range considered enabled us to see whether the nutrients were within, above or below the normal range but unable to rank which nutrient is most limiting in the crops irrigated with gypsiferous water. Thus, the Diagnosis Recommendation Integrated System (DRIS) was used to rank the most limiting nutrients. Examples of the results of the DRIS indices are shown in Tables 4.3 and 4.4. N, Mg, K and SO_4 were among the most negative, which indicated the most deficient nutrients in the maize leaf. N, K and Ca appeared to be the most deficient nutrients in wheat. Similar results were also obtained for maize and wheat grown in Pivot Four and TWF.

Table 4.3 DRIS indices of maize on site Major

	Seasons				
Nutrients	00/01	01/02	03/04	04/05	05/06
N	**-16**[c]	**-27**[c]	**-25**[a]	-3	**-57**[b]
P	-3	-11	-2	-4	6
K	29	26	**-17**[c]	**-27**[b]	**-61**[a]
Ca	-4	**-31**[b]	-4	-17	5
Mg	**-31**[a]	-16	-11	**-32**[a]	-2
SO_4	**-20**[b]	**-34**[a]	-10	16	5
Cu	-14	7	11	7	**-15**[c]
Fe	-3	3	-11	**-19**[c]	-10
Mn	0	-16	**-18**	7	58
Zn	3	51	15	-8	25

a, b and c indicate most limiting nutrients ranked a - as top limiting nutrient

Table 4.4 DRIS indices for wheat on site Major

	Seasons				
Nutrients	2001	2002	2003	2004	2005
N	**-10**[c]	0	**-37**[a]	**-34**[b]	**-23**[a]
P	7	2	**-18**[c]	4	**-7**[b]
K	6	**-18**[a]	**-29**[b]	**-53**[a]	-3
Ca	**-30**[a]	**-9**[c]	-7	-10	-1
Mg	**-15**[b]	1	13	15	6
SO_4	17	9	24	22	**-7**[b]
Cu	-9	**-12**[b]	5	**-11**[c]	7
Fe	-7	3	-6	8	-4
Mn	**-15**[b]	-3	23	39	4
Zn	8	**-9**[c]	4	6	11

a, b and c indicate most limiting nutrients ranked a - as top limiting nutrient

In the interpretation of the nutrient concentration ratios, more focus was given to K, N and S, because of their major physiological role in the plant. Potassium is known to have a key role in N uptake and translocation (Cushnahan *et al*., 1995), whereas S and N are vital co-constituents of proteins (Marschner, 1995). In all the crops irrigated with gypsiferous mine water, N, K and Mg were required in relatively higher quantities than the other nutrients. Hence, maintaining the correct ratios of these nutrients in crop production using gypsiferous mine water is obviously important. In the maize and wheat leaves, N and K were the most deficient nutrients, compared to the others, and would probably be the most limiting nutrients. Ca and Mg are unlikely to be yield limiting even though their indices are negative. Ca and Mg uptake by plants is a passive process driven by transpiration and mass flow (Marschner, 1995). Therefore, the negative indices could be related to the water uptake of the plants or osmotic potential of the soil that could lower the concentrations in the plant tissues than the other nutrients ratio. Zn, Mn, Cu and Fe showed irregular pattern during the growth period and were not identified as a limiting nutrient by DRIS or SR system.

No nutrient deficiencies on the leaves of potatoes were also observed at any stage during the growing season. All nutrient levels were within acceptable ranges for potatoes (Bennet, 1993) at both sampling times for both seasons. Generally, leaf nutrient levels declined from the first to the second sampling. This drop in nutrient content as the season progresses is a normal phenomenon, known for various annual crops (Lorenz & Tyler, 1983). The high calcium levels in irrigation water did not seem to suppress uptake of other essential nutrients. Good processing tuber quality was realized for both seasons, as reflected by high specific gravity and chip colour values. It can, therefore, be concluded that irrigating potatoes with gypsiferous mine water resulted in high tuber yields of good quality.

In general, the dominant ions in the irrigation water like Ca, Mg and SO_4 were found to be higher than normal in the crops at Kleinkopjé. Less K uptake was traced at Major, Pivot For and TWF, this could be as a result of low [K]/[Ca] ratio in the soil. The nutrient concentrations within plants were also not uniform and varied with time through the growing period. However, there was no any apparent nutrient disorder in the plants.

Micronutrients

The solubility of micronutrients (e.g. Cu, Fe, Mn, Mo and Zn) is usually low (Grattan & Grieve, 1998) however, plants grown in the mine water irrigated soils did not experience deficiencies. Cu was higher at 69 to 74 days after planting for all pivots. Rahman *et al.*, (1993) found that maize leaf Cu concentrations decreased when it is salt-stressed, which contrasts these results.

Mn, Fe and Zn were higher than the normal range throughout the growing period for maize in sites Major, TWF and Pivot Four. Similarly, Rahman *et al*. (1993) showed that salinity increased Zn concentration in maize tissues, whilst Hassan *et al*. (1970) point out that salinity decreased Fe concentration in the leaves of wheat and maize which is contrary to our results. High Fe test results normally indicate soil or dust contamination of the plant. The remaining analyses of maize plant material were normal.

4.3.2 New Vaal

At pivot New Vaal, plant samples were only taken from parts of the field that were not waterlogged, as analysis of plant tissue from drowning crops would be meaningless. In the plant analysis results of maize at pivot New Vaal, N was initially lower than the normal range, as the plant samples were taken before fertilizer application. K and Ca were higher than the normal ranges, but decreased at 81 DAP, and increased again 96 DAP. SO_4 was in the normal range throughout the growing period. Cu was high at 41 DAP, but decreased to 81 DAP and then increased again by 96 DAP. Fe also was high at 96 DAP. There were no observations of nutrient disorders during the trial period (Figure 4.12). Plant analyses results from soybeans at different stages during the growing period showed that nutrients were within the sufficiency range (Reuter, 1986). K in Maize leaves was found below the minimum range. Except for peas, no deficiency of macro or micronutrients was noted. Similarly, the plant analyses results of peas showed no nutritional imbalances for the growing period.

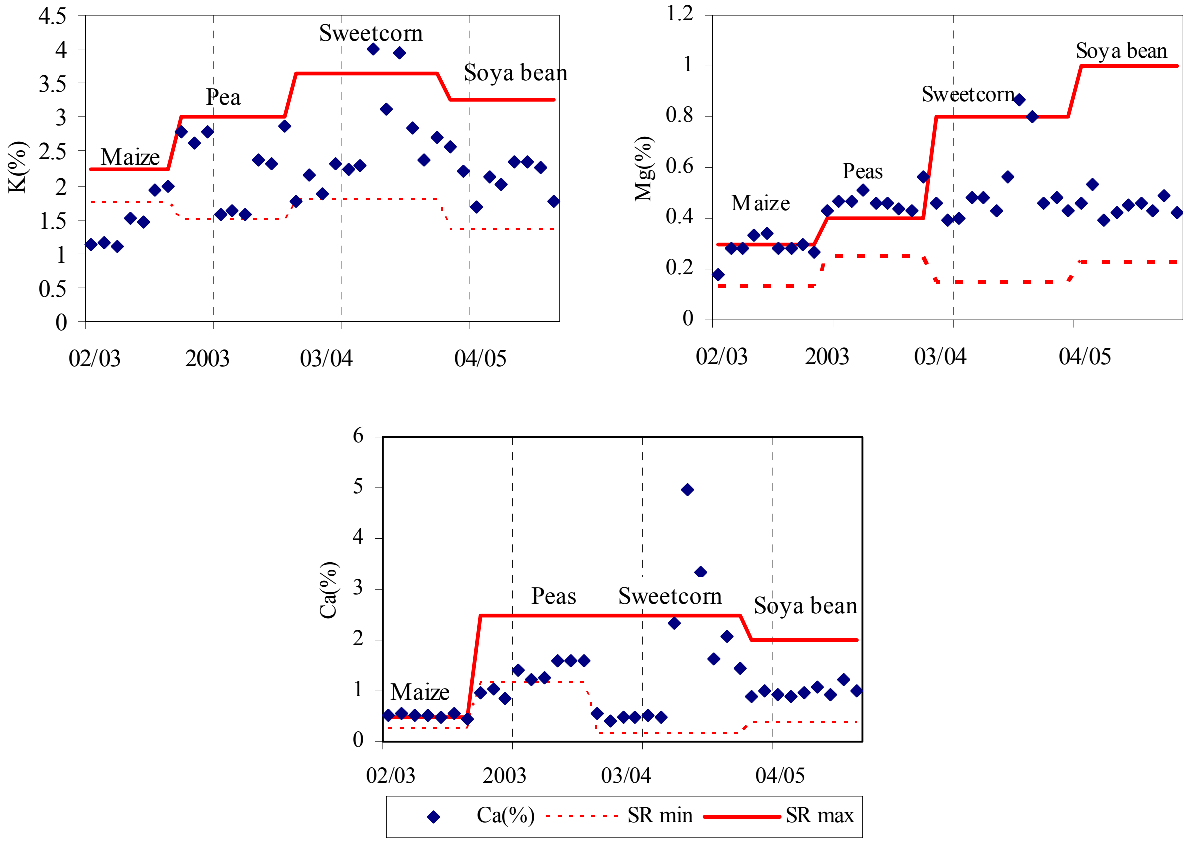


Figure 4.12 Leaf K(%), Mg(%) and Ca(%) content for site New Vaal

4.3.3 Syferfontein

The effect of the Na_2SO_4 rich irrigation water on forage quality (Nitrogen (N) and Crude Protein (CP) contents) of the planted pastures (Fescue and Lucerne) was negligible for the growing period. The N and CP contents of the pastures were also compared with typical values for these pastures found in literature (Appendix A). The N and CP for Fescue (N=19 g kg^{-1} and CP=12 %) and Lucerne (N= 27 g kg^{-1} and CP=17 %) were in the range that can be expected from dry land pasture production, but Eragrostis (N=17 g kg^{-1} and CP=10 %) and Kikuyu (N =12 g kg^{-1} and CP=5 %) showed lower quality than expected. This could possibly be due to natural behavior of Eragrostis to accumulate Na in the root that caused nutritional imbalances. Uptake of considerable Na by Kikuyu from the soil solution also disturbed enzymatic process of the plant and affected forage quality (Tainton, 2000).

4.3.4 Waterberg

Plants were not analysed in the winter experiment, as plants died due to waterlogging. In the summer experiment, plant samples were taken four times for Cotton and Bermuda grass. The sufficiency ranges for normal growth of cotton and the measured results are shown in Figures 4.13 and 4.14. In this study, deficiencies of N, Ca and Mg were observed throughout the growth period, probably due to the leaching of fertilizer and the presence of high Na in the soil. Only leaf K was sufficient in the latter part of the season.

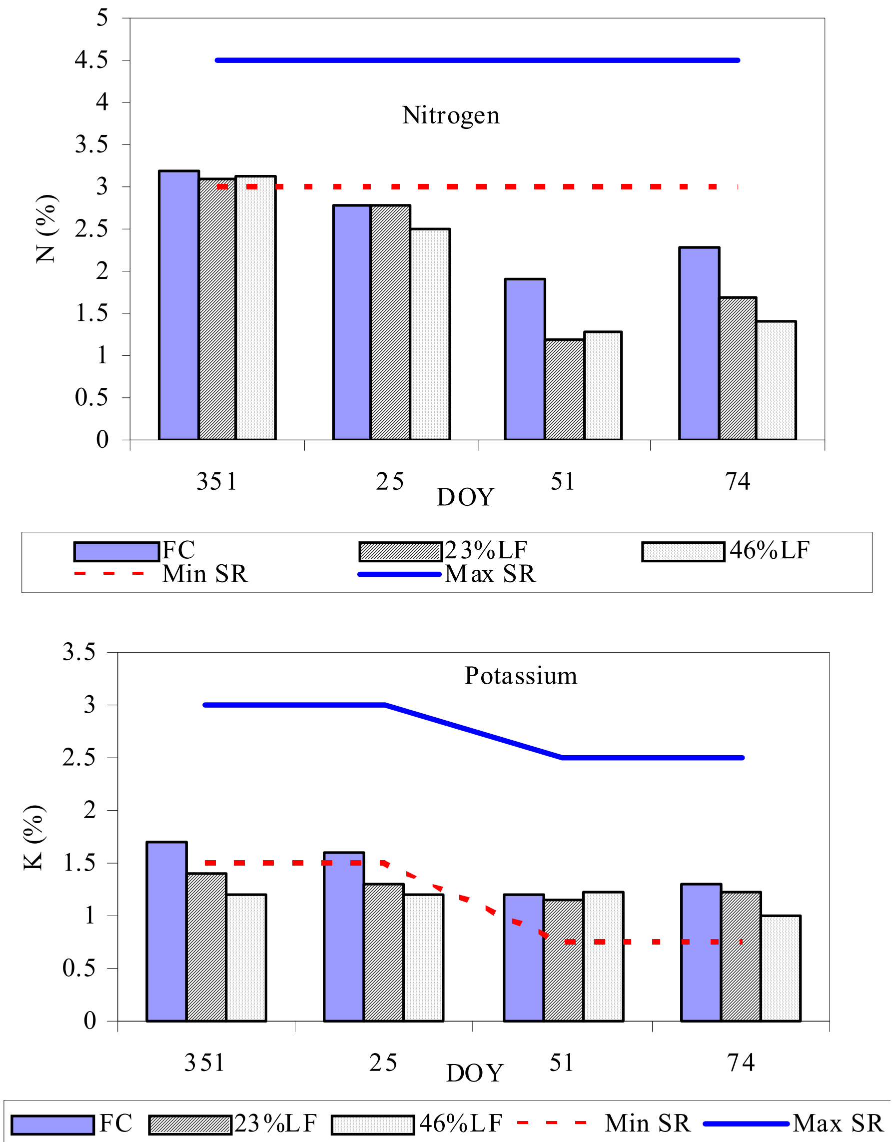


Figure 4.13 N and K concentrations in the leaves of cotton drip irrigated with CBM water, following different irrigation management strategies

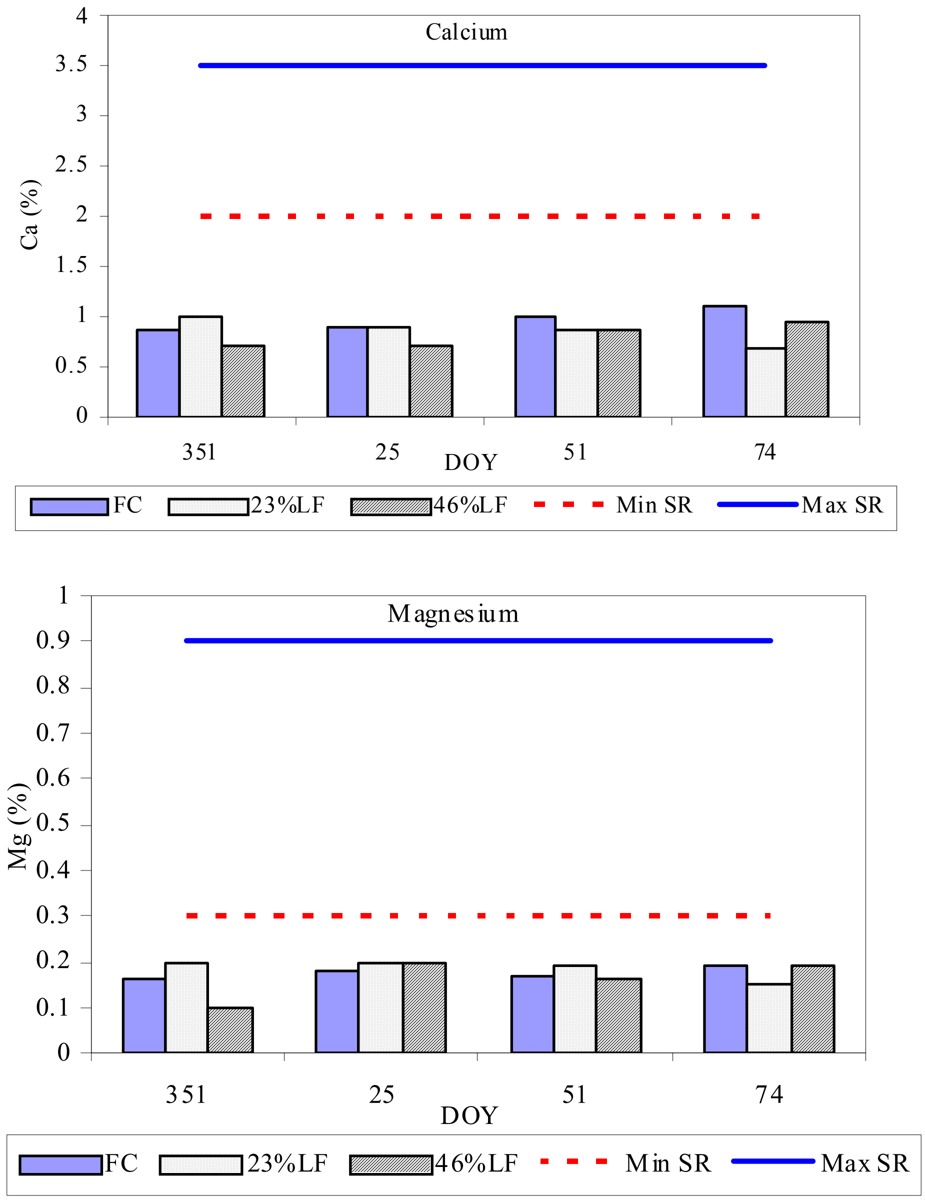
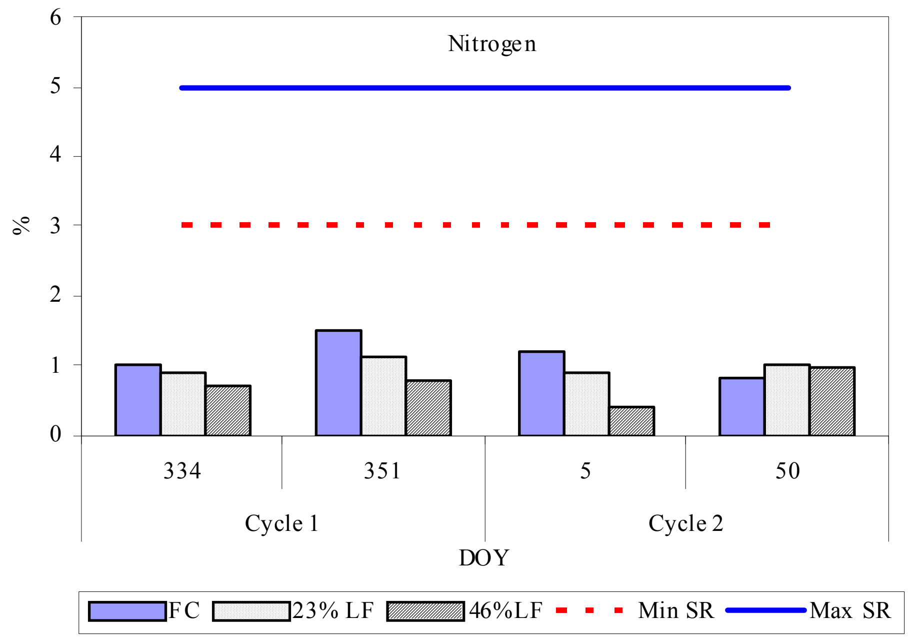


Figure 4.14 Ca and Mg concentration in the leaves of cotton drip irrigated with CBM water following different irrigation management strategies

The sufficiency range of N, K, Ca and Mg for the normal growth and leaf analysis of Bermuda grass of two cycles is shown in Figures 4.15 and 4.16. Sufficient levels of nitrogen in Bermuda grass are considered to be between 3.0 to 5.0% (Jones *et al*., 1991), signifying that the grass in this irrigation trial was not adequately supplied with nitrogen. Potassium levels in the 46%LF were also lower than the FC and 23%LF treatments. This could be due to the high leaching fraction applied. In the grasses irrigated with 23%LF, relatively higher in nutrient level than the other treatment was observed, nevertheless, they were below the sufficiency range for the rest of the growing period.



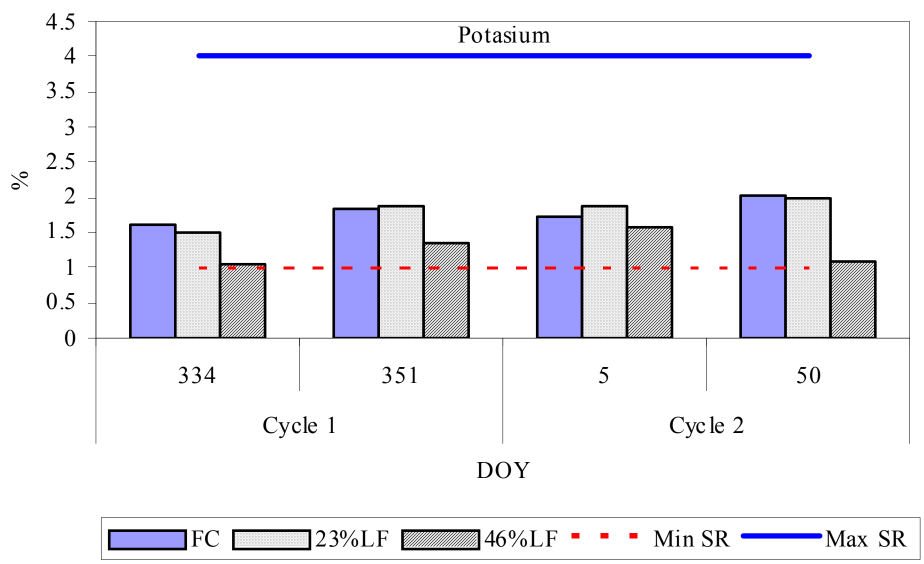


Figure 4.15 Concentrations of N and K of two growth cycles of Bermuda grass drip irrigated with CBM water following different irrigation management strategies

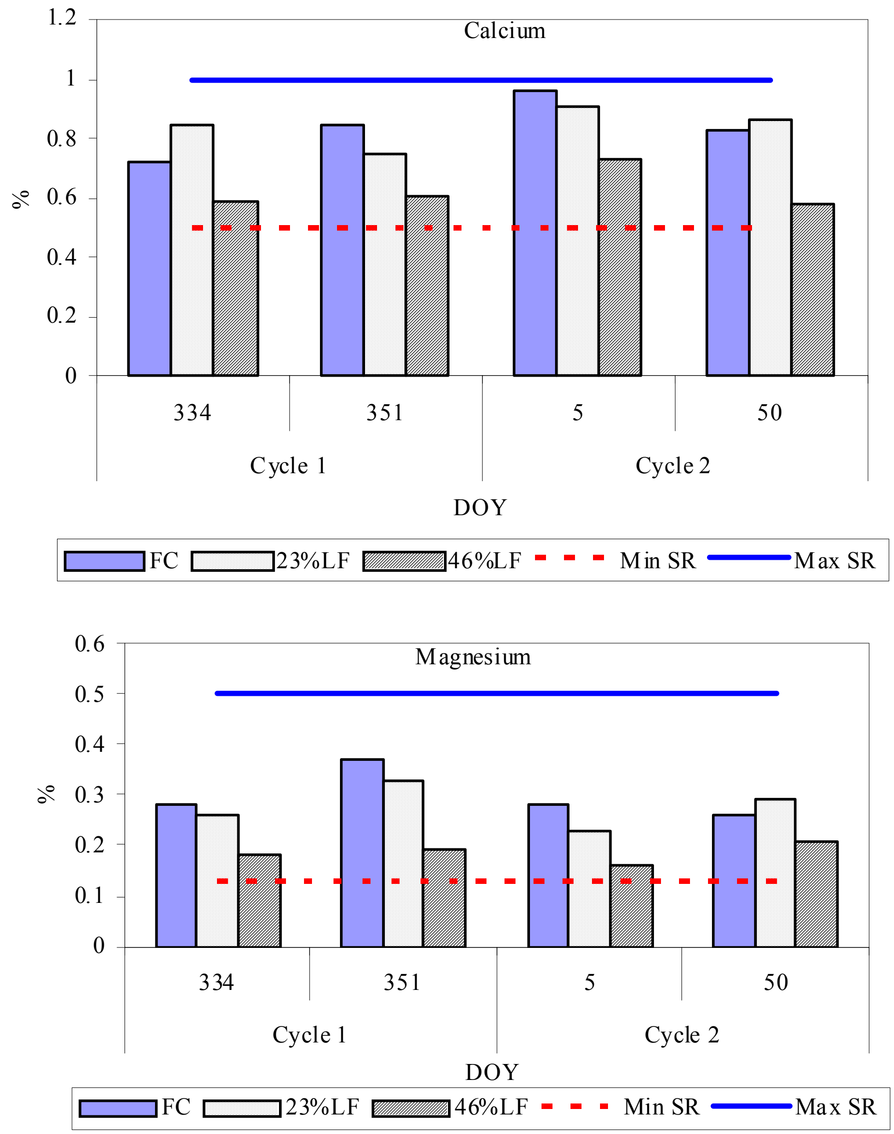


Figure 4.16 Concentration of Ca and Mg of two growth cycles of Bermuda grass drip irrigated with CBM water following different irrigation management strategies

Conclusions

In conclusion, results of plant analysis were useful to diagnose nutrient deficiencies and to reveal imbalances between nutrients that can cause unfavourable nutrient interactions. Visual symptoms are also an important part of diagnosing nutrient deficiencies and toxicities in the field. We attempted to distinguish symptoms from non-nutritional causes like disease or pesticide toxicity. Clearly recognizable leaf symptoms associated with specific nutritional disorders were not observed. It, therefore, seems that one can produce crops using gypsiferous mine water without experiencing major plant nutritional problems, but it is essential to take into account what ions are being added to the soil in the irrigation water. Particular attention should be given to K fertilization as it may become unavailable due to high Ca and Mg in the soil.

In general, the dominant ionic species in the irrigation water like Ca, Mg and SO_4 were found to be higher than normal in the crops at Kleinkopjé. Less K uptake in particular was also observed under all the pivots and, this could be as a result of the low [K]/([Ca] + [Mg]) ratio that had developed over time. At New Vaal, the results indicated that the nutrient concentrations were found to be within the SR norms. The possibility of incurring deficiency and toxicity symptoms with the New Vaal Colliery water is unlikely. However, the ability to identify deficiencies and toxicities of plant nutrients before they limit crop yield is of major importance for successful gypsiferous mine water irrigation of crops.

At Syferfontein, the effect of the Na_2SO_4 rich irrigation water on forage quality of the planted pastures (Fescue and Lucerne) was negligible for the growing period. Eragrostis and Kikuyu showed low quality as compared to typical fresh water irrigated pastures. This could possibly be due to the uptake of considerable amounts of Na from the soil solution that may have inhibited the enzymatic processes of the plant.

In the CBM irrigation trial, crops irrigated with a high leaching fraction needed higher K and N amounts, as the high leaching fraction leached the nutrients from the soil. Special attention should be given to K and NO_3 fertilization management, as the high irrigation frequency and leaching fraction can leach the nutrients below the root zone.

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