Table 8: Change in relative crop yield which is calculated to result from a 15 % increase in the salinity of irrigation water, under low frequency irrigation (i.e. values in **Table 7** minus those in **Table 4**).

Crop	EC of Irrigation water (mS/m)														
	600			800			1000			1200			1400		
	Leaching Fraction			Leaching Fraction			Leaching Fraction			Leaching Fraction			Leaching Fraction		
	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1
Asparagus	-1	-2	-4	-2	-2	-5	-2	-3	-6	-3	-4	-7	-3	-4	-9
Beans	-13	-1	0	-3	0	0	0	0	0	0	0	0	0	0	0
Beetroot	-6	-8	-17	-8	-11	0	-10	-14	0	-12	-17	0	-14	-5	0
Broccoli	-6	-9	-12	-8	-11	0	-11	-14	0	-13	-11	0	-15	0	0
Cabbage	-7	-9	0	-9	-12	0	-11	-15	0	-13	0	0	-14	0	0
Carrots	-10	-13	0	-13	0	0	-7	0	0	0	0	0	0	0	0
Dates	-2	-3	-7	-3	-4	-9	-4	-6	-11	-5	-7	-13	-6	-8	-11
Lettuce	-9	-12	0	-12	-9	0	-15	0	0	0	0	0	0	0	0
Lucerne	-5	-7	-13	-7	-9	0	-8	-11	0	-10	-14	0	-12	-8	0
Maize	-8	-11	0	-11	-15	0	-14	0	0	-11	0	0	0	0	0
Onion	-11	-15	0	-15	0	0	0	0	0	0	0	0	0	0	0
Tomato	-7	-9	-3	-9	-12	0	-11	-15	0	-14	-1	0	-16	0	0
Zucchini	-5	-9	-17	-9	-12	0	-11	-15	0	-13	-18	0	-15	-7	0

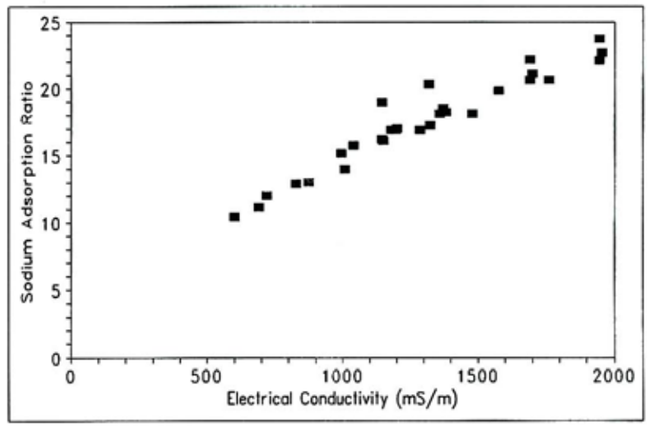

Figure 6: The relationship between SAR and EC for present water samples collected from extraction points in the Swakop River together with those for projected concentrations.

4.5.3 Sodium Adsorption Ratio (SAR)

The projected increase in irrigation water salinity will cause an increase in SAR (**Figure 5**). The SAR-EC combination for the projected future water qualities have been plotted together with those of the present water (**Figure 6**). It is clear that the SAR-EC relationship found for the present situation does not change when the projected future values are added. The effect of the projected water quality on soil physical conditions, should thus be similar to those experienced under present conditions. Since minimal problems are associated with the present situation, the projected increase in SAR is thus also expected to have practically no additional negative effects.

4.6 Possible measures to mitigate against the effect of an increase in salinity

Several options are available to mitigate against the negative effect of high salinity irrigation water. Those that are most commonly used are:

i. **An increase in the leaching fraction** to reduce the mean salinity in the soil profile to which crops are exposed. The impression is that over-irrigation is at present already the norm and that there is not much scope for further implementation of this mitigation measure.

ii. **A switch to more tolerant crops**. The impression is that this change has already largely taken place. No salt sensitive crops are being produced at present. However, there is still some potential to switch to more tolerant crops. One attractive option which remains is to switch to asparagus production, which is both a very salt tolerant and a very lucrative crop.

iii. **Increased planting density**. This strategy is used successfully where yield is being depressed because of a reduction in the size of the marketable product and size in itself is no disqualification of the produce. Tomatoes have, for example, been found to reduce in size with increasing salinity. This is, however, accompanied by an increase in solids content and improvement in taste.

iv. **Improved irrigation scheduling and fertilizer management**. It need to be assessed if there is room for improvement in this regard. Should improved irrigation scheduling and/or fertilizer management be feasible, their implementation should result in yield improvements.

v. **A switch from low frequency irrigation to high frequency micro-irrigation**. Since the soil is not allowed to dry to the same degree as with low frequency irrigation, the salt concentration within the soil is maintained at lower levels when irrigated at a high frequency. Because of the high salt content of the water in the lower Swakop River and the potential for leaf scorching, micro jets cannot be used - only drip irrigation would be acceptable.

The procedure to link crop yield to irrigation water EC for high frequency as proposed by Rhoades and Merril (1976) was used to calculate the relative yields in **Table 9**. It is clear that higher yields should be obtained for high compared to low frequency irrigation, when the same water is used. The differences in yield are calculated in **Table 10**. It is clear that the largest increase in yield can be expected at low LFs. Absolute yields will, however, be lower at low LFs.

Irrigators will have to decide whether the water saving achieved at low LFs (which could be used to irrigate additional land or effect a saving in pumping costs) will compensate sufficiently for the reduction in yield. A further benefit of drip irrigation is the possibility to apply fertilizer together with the irrigation water. This result in more effective utilisation of fertilizer and a reduction in the amount lost by leaching.

Table 9: Relative crop yield (%) which can be expected under high frequency irrigation with increasingly saline waters (EC) at three leaching fractions.

Crop	EC of Irrigation water														
	600			800			1000			1200			1400		
	Leaching Fraction			Leaching Fraction			Leaching Fraction			Leaching Fraction			Leaching Fraction		
	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1
Asparagus	100	98	92	97	94	87	94	91	81	91	87	76	89	84	70
Beans	40	19	0	13	0	0	0	0	0	0	0	0	0	0	0
Beetroot	98	89	63	86	73	38	73	57	14	61	42	0	48	26	0
Broccoli	87	78	51	74	61	26	62	45	1	49	29	0	36	13	0
Cabbage	77	67	39	63	50	12	50	33	0	36	16	0	23	0	0
Carrots	55	41	0	36	16	0	16	0	0	0	0	0	0	0	0
Dates	99	96	85	94	89	75	89	83	66	84	77	56	79	70	46
Lettuce	63	49	11	44	26	0	26	3	0	8	0	0	0	0	0
Lucerne	84	76	55	74	64	35	64	51	16	54	38	0	43	25	0
Maize	70	57	23	53	36	0	37	16	0	20	0	0	3	0	0
Onion	52	35	0	30	7	0	8	0	0	0	0	0	0	0	0
Tomato	83	73	44	70	56	17	56	38	0	42	21	0	28	4	0
Zucchini	100	95	68	92	78	42	79	62	17	66	46	0	52	29	0

Table 10: Change in relative crop yield which is calculated to result when a switch is made from the present low frequency irrigation to high frequency irrigation using the same water (i.e. the values in Table 9 minus those in Table 4).

Crop	EC of Irrigation water (mS/m)														
	600			800			1000			1200			1400		
	Leaching			Leaching			Leaching			Leaching			Leaching		
	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1
Asparagus	1	2	8	1	3	11	1	3	14	2	4	17	2	5	20
Beans	7	19	0	10	0	0	0	0	0	0	0	0	0	0	0
Beetroot	3	9	38	5	12	38	6	15	14	7	18	0	8	21	0
Broccoli	4	9	38	5	12	26	6	15	1	7	18	0	8	13	0
Cabbage	4	10	39	5	13	12	6	16	0	7	16	0	9	0	0
Carrots	5	14	0	7	16	0	9	0	0	0	0	0	0	0	0
Dates	1	4	15	2	5	20	2	6	25	3	7	30	3	8	35
Lettuce	5	13	11	7	17	0	8	3	0	8	0	0	0	0	0
Lucerne	3	7	31	4	10	35	5	12	16	6	14	0	7	17	0
Maize	5	12	23	6	16	0	8	16	0	9	0	0	3	0	0
Onion	6	16	0	8	7	0	8	0	0	0	0	0	0	0	0
Tomato	4	10	41	5	13	17	6	16	0	8	20	0	9	4	0
Zucchini	0	9	39	5	12	42	6	16	17	7	19	0	8	22	0

5. SUMMARY AND CONCLUSIONS

5.1 The water obtained from extraction points and used for irrigation in the lower Swakop River would normally not be considered for irrigation in most conventional farming operations. However, a number of factors combine to make irrigation possible. These are:

i. The irrigated soils of the farming area are of an alluvial nature and generally appear to be well drained. Well drained soils are a prerequisite for sustainable irrigation with high salinity waters. The reason being that significant over irrigation is required to leach excess salts and maintain salinities at levels which will allow for crop growth.

ii. Generally only salt tolerant crops are being cultivated.

iii. Water is applied in such a way that crop leaves are not wetted. Leaf scorch is expected should leaves be wetted with the water.

iv. The EC of the irrigation water is high enough to counteract the dispersive properties of the Sodium Adsorption Ratio. Soil physical properties are thus not expected to be negatively affected.

5.2 The local climate is such that asparagus producers gain a competitive edge over other production areas in that they are the sole suppliers during the peak demand period. There is also a growing local market for high quality fresh produce.

5.3 Water quality shows significant variation in the farming area. However, there is a general increase in salinity from east to west. The ionic ratio of waters sampled from extraction points are fairly constant, which indicates that they have a similar or the same origin and that their increasing concentrations are a function of the degree of concentration which took place as a result of evapotranspiration.

5.4 Crop yield reductions as a result of a predicted 15 % increase in salinity following on the commissioning of the KARS project would result in yield reductions which will show considerable variation, but would mostly be less than 15 %. The yield decrease of crops with a high salt tolerance will be minimal. The increase in irrigation water salinity is expected to result in a continuation and acceleration of the trend to switch to salt tolerant crops as it becomes increasingly difficult to produce economically viable yields of less tolerant crops.

5.5 Although several options exist to mitigate against the present high salinity of water used for irrigation, and the potential salinity increase in future, these effects are expected to be incremental rather than once-off. One of the attractive options which needs to be further investigated is to make more use of drip irrigation.

6. RECOMMENDATIONS

6.1 This evaluation of present and expected water quality was largely based on the results of a desk study. Its assumptions and implications need to be further evaluated by conducting the necessary follow-up surveys.

6.2 Although farmers have through trial and error established practices which work, they could benefit from exposure to explanations of the theoretical reasons behind their experience in order to assist them in helping themselves even better.

6.3. The long term sustainability of the irrigation practice should be investigated and more specifically the effect that irrigation itself has on water quality degradation.

6.4 Tests should be conducted to ascertain that soil physical conditions are not negatively affected by the prevailing high SAR values.

6.5 The Rössing Foundation which displayed considerable courage and vision to initiate the asparagus project, should be encouraged to continue with their efforts. While their present initiatives have demonstrated the potential for asparagus production, their continued involvement to solve problems which are bound to occur, will not only benefit the local farming community, but probably also other potential asparagus production areas in Namibia and further afield.

7. ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to:

- Mr Lorenz Hesse, Project Director, Municipality of Swakopmund, who arranged for and accompanied Dr Ashton and myself on visits to farmers in the lower Swakop River. His considerable technical expertise and background information about the situation proved to be invaluable in assisting us to acquaint ourselves and gain a proper perspective of the situation. The local community is privileged to have someone with his background and experience concerning the irrigation with poor quality water in their midst.

- The following farmers who received us and shared their experience and insight about the irrigation situation in the lower Swakop River. They have learned to irrigate successfully with water which would in most cases be viewed as unsuitable for the purpose.

  Mr B.W.F.A. Fleishmann, Plot No. 178.
  Mr L.E.F. Pohle, Plot No. 185.
  Mr E.A. Putzier, Plot 181.
  Mr J. van Heerden, Plot No. 179.
  Mr C.B.N. Botha
  Mr B.H. Hoppe, Plot 171.
  Mr H.H. Schreiber, Three Sisters.

- Rössing Foundation who had the foresight to start the asparagus trials, thereby demonstrating to the local community the potential of a lucrative alternative crop, which is also very salt tolerant. The following individuals shared their knowledge, experience and expertise during our visit to the experimental site:

  Mr David Godfrey - Rössing Foundation
  Mr Stefanus van Niekerk - farm manager
  Ms Christine Lees - researcher from the Royal Agricultural College, Cirencester

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Appendix 1: Relative crop yield (%) for a selection of crops and a range of irrigation water ECs (mS/m) where water is irrigated at a low frequency to achieve a range of leaching fractions (present), and for the expected irrigation water EC (i.e. present plus 15%)

Relative Crop Yield with Low Frequency Irrigation Application and a Leaching Fraction of 0.05										
Crop	EC of Irrigation water									
	600		800		1000		1200		1400	
	Present	Expected	Present	Expected	Present	Expected	Present	Expected	Present	Expected
Asparagus	69	63	56	48	43	33	30	19	17	4
Beans	0	0	0	0	0	0	0	0	0	0
Beetroot	0	0	0	0	0	0	0	0	0	0
Broccoli	0	0	0	0	0	0	0	0	0	0
Cabbage	0	0	0	0	0	0	0	0	0	0
Carrots	0	0	0	0	0	0	0	0	0	0
Dates	44	34	21	7	0	0	0	0	0	0
Lettuce	0	0	0	0	0	0	0	0	0	0
Lucerne	0	0	0	0	0	0	0	0	0	0
Maize	0	0	0	0	0	0	0	0	0	0
Onion	0	0	0	0	0	0	0	0	0	0
Tomato	0	0	0	0	0	0	0	0	0	0
Zucchini	0	0	0	0	0	0	0	0	0	0

Relative Crop Yield with Low Frequency Irrigation Application and a Leaching Fraction of 0.10										
Crop	EC of Irrigation water									
	600		800		1000		1200		1400	
	Present	Expected	Present	Expected	Present	Expected	Present	Expected	Present	Expected
Asparagus	84	80	75	70	67	61	59	52	51	42
Beans	0	0	0	0	0	0	0	0	0	0
Beetroot	25	9	0	0	0	0	0	0	0	0
Broccoli	12	0	0	0	0	0	0	0	0	0
Cabbage	0	0	0	0	0	0	0	0	0	0
Carrots	0	0	0	0	0	0	0	0	0	0
Dates	70	63	55	46	40	29	26	12	11	0
Lettuce	0	0	0	0	0	0	0	0	0	0
Lucerne	25	11	0	0	0	0	0	0	0	0
Maize	0	0	0	0	0	0	0	0	0	0
Onion	0	0	0	0	0	0	0	0	0	0
Tomato	3	0	0	0	0	0	0	0	0	0
Zucchini	28	11	0	0	0	0	0	0	0	0

Appendix 1 (Continued).

Relative Crop Yield with Low Frequency Irrigation Application and a Leaching Fraction of 0.20										
Crop	EC of Irrigation water									
	600		800		1000		1200		1400	
	Present	Expected	Present	Expected	Present	Expected	Present	Expected	Present	Expected
Asparagus	92	90	87	84	82	78	76	71	71	65
Beans	0	0	0	0	0	0	0	0	0	0
Beetroot	64	53	40	26	16	0	0	0	0	0
Broccoli	52	41	28	13	3	0	0	0	0	0
Cabbage	40	28	14	0	0	0	0	0	0	0
Carrots	2	0	0	0	0	0	0	0	0	0
Dates	86	81	76	70	66	59	57	48	47	37
Lettuce	13	0	0	0	0	0	0	0	0	0
Lucerne	56	48	37	25	17	3	0	0	0	0
Maize	25	10	0	0	0	3	0	0	0	0
Onion	0	0	0	0	0	0	0	0	0	0
Tomato	46	34	19	4	0	0	0	0	0	0
Zucchini	69	58	44	29	19	0	0	0	0	0

Relative Crop Yield with Low Frequency Irrigation Application and a Leaching Fraction of 0.30										
Crop	EC of Irrigation water									
	600		800		1000		1200		1400	
	Present	Expected	Present	Expected	Present	Expected	Present	Expected	Present	Expected
Asparagus	96	94	92	89	87	84	83	80	79	75
Beans	1	0	0	0	0	0	0	0	0	0
Beetroot	80	71	61	50	42	28	24	7	5	0
Broccoli	68	60	49	38	30	16	11	0	0	0
Cabbage	57	48	37	25	17	2	0	0	0	0
Carrots	27	14	0	0	0	0	0	0	0	0
Dates	92	89	84	80	77	71	70	63	62	54
Lettuce	36	24	9	0	0	0	0	0	0	0
Lucerne	69	62	54	45	39	27	24	10	8	0
Maize	46	34	21	6	0	0	0	0	0	0
Onion	19	4	0	0	0	0	0	0	0	0
Tomato	63	54	42	30	22	6	1	0	0	0
Zucchini	86	77	66	54	47	32	27	9	7	0

Appendix 1 (Continued).

Relative Crop Yield with Low Frequency Irrigation Application and a Leaching Fraction of 0.40										
Crop	EC of Irrigation water									
	600		800		1000		1200		1400	
	Present	Expected	Present	Expected	Present	Expected	Present	Expected	Present	Expected
Asparagus	98	96	94	92	91	88	87	84	84	80
Beans	20	5	0	0	0	0	0	0	0	0
Beetroot	89	82	73	64	58	46	42	28	26	10
Broccoli	78	70	62	52	46	34	30	15	14	0
Cabbage	67	59	50	40	33	20	16	1	0	0
Carrots	41	30	16	2	0	0	0	0	0	0
Dates	96	93	89	86	83	78	77	71	71	64
Lettuce	49	39	26	13	4	0	0	0	0	0
Lucerne	76	71	64	56	51	41	38	27	26	12
Maize	58	48	37	24	16	0	0	0	0	0
Onion	36	23	8	0	0	0	0	0	0	0
Tomato	73	65	56	45	39	26	21	6	4	0
Zucchini	95	88	79	69	62	50	46	31	30	12

Relative Crop Yield with Low Frequency Irrigation Application and a Leaching Fraction of 0.50										
Crop	EC of Irrigation water									
	600		800		1000		1200		1400	
	Present	Expected	Present	Expected	Present	Expected	Present	Expected	Present	Expected
Asparagus	99	98	96	94	93	91	90	87	87	84
Beans	32	19	3	0	0	0	0	0	0	0
Beetroot	95	89	81	73	68	57	54	41	40	26
Broccoli	84	77	70	61	56	45	42	29	28	13
Cabbage	73	67	58	50	44	33	29	16	14	0
Carrots	50	40	29	16	7	0	0	0	0	0
Dates	98	95	92	89	87	83	82	77	76	70
Lettuce	58	49	38	26	18	3	0	0	0	0
Lucerne	81	76	70	63	59	51	48	38	37	25
Maize	66	57	47	36	29	15	11	0	0	0
Onion	46	35	22	7	0	0	0	0	0	0
Tomato	80	73	64	55	49	38	34	21	19	3
Zucchini	100	95	87	78	73	62	58	45	44	29

Appendix 2: Relative crop yield (%) for a selection of crops and a range of irrigation water ECs (mS/m) where water is irrigated at a high frequency to achieve a range of leaching fractions (present), and for the expected irrigation water EC (i.e. present plus 15 %).

Relative Crop Yield with High Frequency Irrigation Application and a Leaching Fraction of 0.05										
Crop	EC of Irrigation water									
	600		800		1000		1200		1400	
	Present	Expected	Present	Expected	Present	Expected	Present	Expected	Present	Expected
Asparagus	87	84	80	76	73	67	66	59	59	51
Beans	0	0	0	0	0	0	0	0	0	0
Beetroot	40	26	8	0	0	0	0	0	0	0
Broccoli	28	13	0	0	0	0	0	0	0	0
Cabbage	14	0	0	0	0	0	0	0	0	0
Carrots	0	0	0	0	0	0	0	0	0	0
Dates	76	70	63	56	51	41	38	26	25	12
Lettuce	0	0	0	0	0	0	0	0	0	0
Lucerne	37	25	11	0	0	0	0	0	0	0
Maize	0	0	0	0	0	0	0	0	0	0
Onion	0	0	0	0	0	0	0	0	0	0
Tomato	19	4	0	0	0	0	0	0	0	0
Zucchini	44	29	11	0	0	0	0	0	0	0

Relative Crop Yield with High Frequency Irrigation Application and a Leaching Fraction of 0.10										
Crop	EC of Irrigation water									
	600		800		1000		1200		1400	
	Present	Expected	Present	Expected	Present	Expected	Present	Expected	Present	Expected
Asparagus	92	89	87	83	81	77	76	71	70	65
Beans	0	0	0	0	0	0	0	0	0	0
Beetroot	63	52	38	24	14	0	0	0	0	0
Broccoli	51	40	26	11	1	0	0	0	0	0
Cabbage	39	27	12	0	0	0	0	0	0	0
Carrots	0	0	0	0	0	0	0	0	0	0
Dates	85	81	75	69	66	58	56	47	46	36
Lettuce	11	0	0	0	0	0	0	0	0	0
Lucerne	55	46	35	24	16	1	0	0	0	0
Maize	23	8	0	0	0	0	0	0	0	0
Onion	0	0	0	0	0	0	0	0	0	0
Tomato	44	32	17	1	0	0	0	0	0	0
Zucchini	68	56	42	27	17	0	0	0	0	0

Appendix 2 (Continued).

Relative Crop Yield with High Frequency Irrigation Application and a Leaching Fraction of 0.20										
Crop	EC of Irrigation water									
	600		800		1000		1200		1400	
	Present	Expected	Present	Expected	Present	Expected	Present	Expected	Present	Expected
Asparagus	96	94	92	89	88	84	83	80	79	75
Beans	1	0	0	0	0	0	0	0	0	0
Beetroot	80	72	62	50	43	29	24	8	6	0
Broccoli	69	60	50	38	31	16	12	0	0	0
Cabbage	57	48	37	25	17	2	0	0	0	0
Carrots	27	14	0	0	0	0	0	0	0	0
Dates	92	89	85	80	77	72	70	63	62	54
Lettuce	36	24	9	0	0	0	0	0	0	0
Lucerne	69	63	54	45	39	28	24	10	9	0
Maize	46	35	21	6	0	0	0	0	0	0
Onion	20	5	0	0	0	0	0	0	0	0
Tomato	63	54	43	31	22	7	2	0	0	0
Zucchini	86	77	66	55	47	32	28	10	8	0

Relative Crop Yield with High Frequency Irrigation Application and a Leaching Fraction of 0.30										
Crop	EC of Irrigation water									
	600		800		1000		1200		1400	
	Present	Expected	Present	Expected	Present	Expected	Present	Expected	Present	Expected
Asparagus	98	96	94	92	91	88	87	84	84	80
Beans	19	4	0	0	0	0	0	0	0	0
Beetroot	89	82	73	64	57	46	42	27	26	9
Broccoli	78	70	61	52	45	33	29	15	13	0
Cabbage	67	59	50	39	33	20	16	0	0	0
Carrots	41	30	16	1	0	0	0	0	0	0
Dates	96	93	89	85	83	78	77	71	70	64
Lettuce	49	39	26	12	3	0	0	0	0	0
Lucerne	76	71	64	56	51	41	38	27	25	12
Maize	57	48	36	24	16	0	0	0	0	0
Onion	35	23	7	0	0	0	0	0	0	0
Tomato	73	65	56	45	38	25	21	5	4	0
Zucchini	95	87	78	69	62	50	46	31	29	12

Appendix 2 (Continued).

Relative Crop Yield with High Frequency Irrigation Application and a Leaching Fraction of 0.40										
Crop	EC of Irrigation water									
	600		800		1000		1200		1400	
	Present	Expected	Present	Expected	Present	Expected	Present	Expected	Present	Expected
Asparagus	99	98	96	94	93	90	90	87	87	83
Beans	31	18	2	0	0	0	0	0	0	0
Beetroot	94	88	80	72	67	56	53	40	39	24
Broccoli	83	77	69	61	55	44	41	28	26	12
Cabbage	73	66	58	49	43	31	28	14	13	0
Carrots	49	40	28	15	6	0	0	0	0	0
Dates	98	95	92	89	87	82	81	76	76	70
Lettuce	57	48	37	25	17	2	0	0	0	0
Lucerne	81	76	70	63	58	50	47	37	36	24
Maize	65	57	46	35	28	14	9	0	0	0
Onion	45	34	21	6	0	0	0	0	0	0
Tomato	79	72	64	55	48	37	33	19	18	2
Zucchini	100	94	86	78	72	61	57	44	43	27

Relative Crop Yield with High Frequency Irrigation Application and a Leaching Fraction of 0.50										
Crop	EC of Irrigation water									
	600		800		1000		1200		1400	
	Present	Expected	Present	Expected	Present	Expected	Present	Expected	Present	Expected
Asparagus	100	99	97	95	94	92	91	89	89	86
Beans	40	28	13	0	0	0	0	0	0	0
Beetroot	98	93	86	78	73	64	61	49	48	35
Broccoli	87	82	74	67	62	52	49	37	36	23
Cabbage	77	71	63	55	50	40	36	24	23	9
Carrots	55	47	36	24	16	2	0	0	0	0
Dates	99	97	94	91	89	86	84	80	79	74
Lettuce	63	54	44	34	26	13	8	0	0	0
Lucerne	84	79	74	68	64	56	54	44	43	33
Maize	70	63	53	43	37	24	20	5	3	0
Onion	52	42	30	17	8	0	0	0	0	0
Tomato	83	77	70	61	56	45	42	30	28	14
Zucchini	100	99	92	84	79	69	66	54	52	39