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YIELD RESPONSES OF WINTER (RABI) FORAGE CROPS TO IRRIGATION WITH SALINE DRAINAGE WATER

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SUMMARY

A field experiment in an alluvial sandy loam saline soil was conducted during the winter (*rabi*) season from 1997–98 to 1999–2000 at the Central Institute for Research on Buffaloes, Hisar, to study the effect of saline drainage water (EC = 3.6 –7.4) on five (*rabi*) forage crops: oat (*Avena sativa*), rye grass (*Lolium rigidum*), senji (*Indian clover*) (*Melilotus indica*) berseem (Egyptian clover) (*Trifolium alexandrinum*) and shaftal (Persian clover) (*Trifolium resupinatum*). All the crops were established using canal water as pre-sowing irrigation and the various irrigation strategies were imposed subsequently. Irrigation with canal water resulted in a 115 % increase in forage yield compared with the saline drainage water. The results suggested that alternate irrigation with saline drainage water increased the yields of all the forage crops compared with using saline drainage water only. Further, alternate irrigation, starting with canal water, was superior to alternate irrigation starting with saline drainage water because less salt was added in total. Oat produced the largest green-forage yield (32.3 t ha^{-1}) in the first year while rye grass gave its maximum in the second (34.6 t ha^{-1}) and third years (37.0 t ha^{-1}). Persian clover performed better than did Egyptian clover in all the three years. Interaction between species and irrigation treatments was significant. In comparison with canal irrigation water, there was a 36 %, 42 %, 54 %, 68 %, and 85 % yield reduction in rye grass, oat, Persian clover, Egyptian clover and senji, respectively when only saline drainage water was used for irrigation reflecting their relative tolerances of salinity. Yields declined linearly for all crops with increases in the quantity of salt applied.

INTRODUCTION

Saline soils are widespread in the arid to semi-arid parts of the world, including in the Indian states of Haryana, Punjab and Rajasthan, where the mean annual rainfall is generally less than 550 mm. It has been estimated that 17 % of the total irrigated area in India is affected by salt (Ghassemi *et al*., 1995). These soils generally have a shallow saline water table and often remain waterlogged or submerged for quite a long time. As a result, crop production on these soils becomes extremely difficult, yields are very low and cultivation becomes uneconomical. The Hisar district of Haryana, (29°10′N; 75°46′E, 215 m asl) represents such a situation with an annual precipitation of 425 mm.

For successful crop production on such soils, leaching, together with sub-surface drainage, is required to flush out the salts from the root zone. Disposal of the saline

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Table 1. Initial soil physical parameters of the experiment site.

Soil depth (m)	Sand (%)	Silt (%)	Clay (%)	Bulk density (g cm^{-3})	Texture
0–0.15	75.0	16.5	8.5	1.72	Loamy sand
0.15–0.30	65.5	21.5	13.0	1.68	Loamy sand
0.30–0.45	65.0	22.0	13.0	1.61	Loamy sand
0.45–0.60	62.0	22.5	15.5	1.56	Loamy sand
0.60–0.90	58.0	26.0	16.0	1.52	Loam
0.90–1.20	50.5	26.0	23.5	1.50	Silt

drainage effluent is a major problem, however, because of saline ground water and unfavourable hydrological conditions due to the lack of a suitable outlet. Under such situations *in-situ* re-use of saline drainage water for irrigation is one of the options proposed (Sharma *et al.*, 1994). Also, canal irrigation facilities are inadequate in this part of the country. This field study was conducted to find out how best to use saline drainage water to irrigate the commonly grown *rabi* forage crops, which otherwise are grown in normal soils with good quality water irrigation in northern India.

MATERIALS AND METHODS

A field experiment on an alluvial sandy loam, saline soil at the Central Institute for Research on Buffaloes, Hisar, was conducted for three years in the winter (*rabi*) season from 1997–1998 to 1999–2000. The experiment was laid out in a split plot design with four replications. It comprised of four post-sowing irrigation treatments: canal water (CW); saline drainage water ($EC = 3.6 - 7.4$) (DW); alternate use of canal water and saline drainage water (CW-DW); and alternate use of saline drainage water and canal water (DW-CW) in the main plots. The five *rabi* forage crops were oat (*Avena sativa*), rye grass (*Lolium rigidum*), berseem (Egyptian clover) (*Trifolium alexandrinum*), senji (Indian clover) (*Melilotus indica*) and shaftal (Persian clover) (*Trifolium resupinatum*) in the sub-plots. The sub-plots measured 20 m^2. Initial soil samples from six soil depths viz. 0–0.15, 0.15–0.30, 0.30–0.45, 0.45–0.60, 0.60–0.90 and 0.90–0.12 m were taken at the beginning of the experiment in winter 1997. Initial soil physical parameters are given in Table 1 and soil chemical characteristics in Table 2. The bulk density of soil decreased with depth. Soil samples were also collected every year before sowing (October) and during the final harvest (May) using a 50 mm diameter auger. The samples were air-dried, ground, passed through a 2 mm sieve and their physico-chemical properties analyzed using standard methods as described by Page *et al*. (1982).

On average, the canal water had an electrical conductivity (EC) of 0.4 dS m^{-1}, pH 7.4 and sodium adsorption ratio (SAR) 0.4 $(mmol^{-1})^{1/2}$. The EC, pH and SAR of the drainage water which was used for irrigation, changed with time, with low values during the winter months and high values in the summer. Since, there was very little variation from year to year, the average temporal changes of EC, pH and SAR for the months of irrigation during crop growth are shown in Figure 1. The EC and

Table 2. Initial soil chemical characteristics of the experiment site.

	Soil depth (m)	
	0–0.15	0.15–0.30
EC_e (dS m^{-1})	4.8	5.2
pH	7.8	7.4
SAR (mmol l^{-1})$^{1\backslash 2}$	14	13
Organic carbon (%)	0.45	0.35
Available nitrogen (kg ha^{-1})	68.3	44.7
Total nitrogen (kg ha^{-1})	1833	1268
NH_4–N (μg^{-g})	6.7	6.3
NO_3–N (μg^{-g})	18.8	10.1
Available phosphorus (kg ha^{-1})	23.6	19.1
Available potassium (kg ha^{-1})	247	229

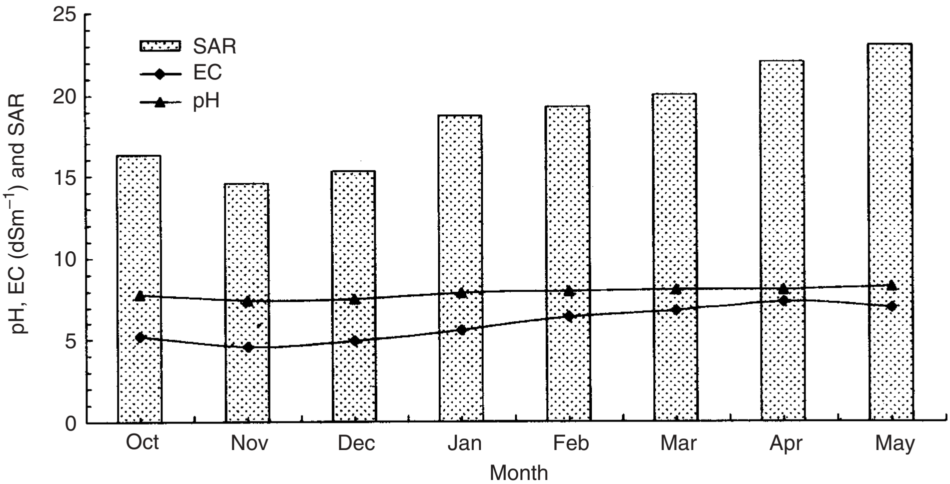

Figure 1. Average changes in electrical conductivity EC (–■–), pH (–▲–) and sodium adsorption ratio SAR (□) of drainage effluents over the season.

pH of the water were determined by the procedures described by Richards (1954) and SAR by the method given by APHA (1992). The total quantity of salts added (load) was calculated on the basis of the number of saline/canal irrigations applied to a particular crop. For this, the EC value was multiplied by a common factor of 640 (Richards, 1954), which gives the salt applied in mg l^{-1} and was subsequently converted to t irrigation^{-1}. The total salt load applied to the different crops was calculated on the basis of the amount of water and the salinity of the water used for each irrigation.

The variations in water table depth and consequent salinity of the ground water are given in Table 3. Winter forage crops were sown in the second week of October in all the three years using canal water to ensure good germination and early establishment. In each year, nine irrigations of about 70 mm depths were given to Persian clover,

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Table 3. Variations in the water table and ground water salinity in different months of the growing season in each year.

	Water table depth (m)			Ground water salinity (dS m^{-1})		
Month	1997–1998	1998–1999	1999–2000	1997–1998	1998–1999	1999–2000
October	1.10	1.00	1.43	3.6	3.7	4.3
November	1.22	0.95	1.52	3.9	4.0	4.9
December	1.28	1.18	1.63	4.1	4.3	5.1
January	1.34	1.30	1.58	4.5	4.7	5.4
February	1.32	1.36	1.62	4.6	5.1	6.1
March	1.46	1.42	1.71	5.6	6.3	6.6
April	1.52	1.66	1.76	6.3	7.1	7.4
May	1.53	1.72	1.82	6.7	7.3	7.4

Egyptian clover and rye grass and seven irrigations to the oat and senji crops. The oat and senji were only harvested once every year whereas four harvests were taken from the Persian clover, Egyptian clover and rye grass. The recommended fertilizer rates of N, P and K were applied at sowing to Egyptian clover, Persian clover and senji, whereas 1/3 N and a full dose of P and K were given to oat and rye grass at sowing and the remaining 2/3 N as two equal splits at 60 and 90 d after sowing.

Rainfall received during the growth period was 123, 158 and 26 mm in 1997–98, 1998–99 and 1999–2000, respectively. Plant samples for calculation of dry matter yield were collected at harvest (in the case of Persian clover, Egyptian clover and rye grass during the third cut) and dried in an oven at 70 °C ± 2 for 48 h.

RESULTS

Green forage yield

Irrigation with CW continuously through the crop season resulted in higher yields, and irrigation with saline drainage water (DW) significantly lower yield compared to other two treatments of alternate irrigation during all the three years (Table 4). During 1997–98, using canal water as post-sowing irrigation first then saline drainage water (CW-DW) was slightly better over applying drainage water first then canal water (DW-CW). However, during 1998–99 and 1999–2000, alternate irrigation starting with canal water produced 50 % and 53 % more yield, respectively compared with starting with saline drainage water. On average over the three years, there were 15 %, 39 % and 53 % reductions in the green forage yield in the CW-DW, DW-CW and DW treatments respectively compared with the CW treatment. When comparing different forage crops (Table 4) for 1997–98, oat produced the largest yield (32.3 t ha^{-1}) and senji the smallest (12.1 t ha^{-1}). Persian clover performed better than Egyptian clover in all three years. Rye grass, which gave a low yield (19.8 t ha^{-1}) during 1997–98, produced the largest green-forage yield in the following two years (34.6 and 37.0 t ha^{-1} respectively). In 1998–99, Persian clover and oat yields were similar. Senji gave the lowest yield in 1998–99 and 1999–2000. The interaction between species and irrigation treatments was significant. Averaged over all species, the green-forage yields

Table 4. Effect of saline drainage irrigation on the green forage yield (t ha^{-1}) of *rabi* crops in each year.

	Irrigation				
Crop	CW	CW-DW	DW-CW	DW	Mean
		1997–1998			
Oat	35.9	32.8	31.3	29.2	32.3
Egyptian clover	33.6	25.2	20.7	12.6	23.0
Persian clover	36.0	29.6	26.8	20.6	28.2
Senji	20.7	13.3	9.8	4.6	12.1
Rye grass	23.2	19.6	18.7	17.6	19.8
Mean	29.8	24.1	21.5	16.9	
s.e.		Irrigation-1.1; Crops-0.6; Interaction 1.2			
		1998–1999			
Oat	33.8	33.4	23.9	18.3	27.3
Egyptian clover	40.9	33.8	16.0	11.6	25.8
Persian clover	39.4	35.7	24.8	15.9	28.9
Senji	27.0	12.3	7.9	2.4	12.4
Rye grass	42.1	40.5	30.2	25.4	34.6
Mean	36.6	31.1	20.7	14.7	
s.e.		Irrigation-1.4; Crops-0.8; Interaction 1.6			
		1999–2000			
Oat	34.3	31.2	19.4	18.7	25.9
Egyptian clover	38.9	33.1	14.6	12.6	24.8
Persian clover	39.4	35.5	25.1	16.8	29.2
Senji	17.7	12.8	8.6	2.8	10.5
Rye grass	45.2	42.8	33.0	27.1	37.0
Mean	35.1	31.1	20.2	15.6	
s.e.		Irrigation-1.3; Crops-0.8; Interaction 1.7			

were in the order CW > CW-DW > DW-CW > DW. Where the alternate irrigation treatment CW-DW was applied, rye grass and oat showed the least yield reduction and senji the highest compared with CW (Figure 2). The yield reductions compared with CW in rye grass, oat, Persian clover, Egyptian clover and senji due to irrigation with saline drainage water were 36 %, 42 %, 54 %, 68 % and 85% respectively; and with alternate use starting with drainage saline water and followed by CW were 26 %, 28 %, 33 %, 54 % and 60 % respectively.

Dry-matter yield

During 1997–98, irrigation with saline drainage water, on average, decreased the dry-matter yield of the forage crops by 30 % compared with CW irrigation (Table 5). However, there were no noticeable yield differences between CW irrigation and the two alternate irrigation treatments. In the ensuing two years, the difference in dry-matter yield due to saline drainage water irrigation and that of CW widened further, showing a 50 % decline. The dry-matter yields in the irrigation treatments with CW and the alternate irrigation starting with canal water (CW-DW) were similar. Alternate irrigation starting with CW, however (CW-DW) resulted in a 30 % greater yield compared with alternate use starting with drainage saline water (DW-CW). During

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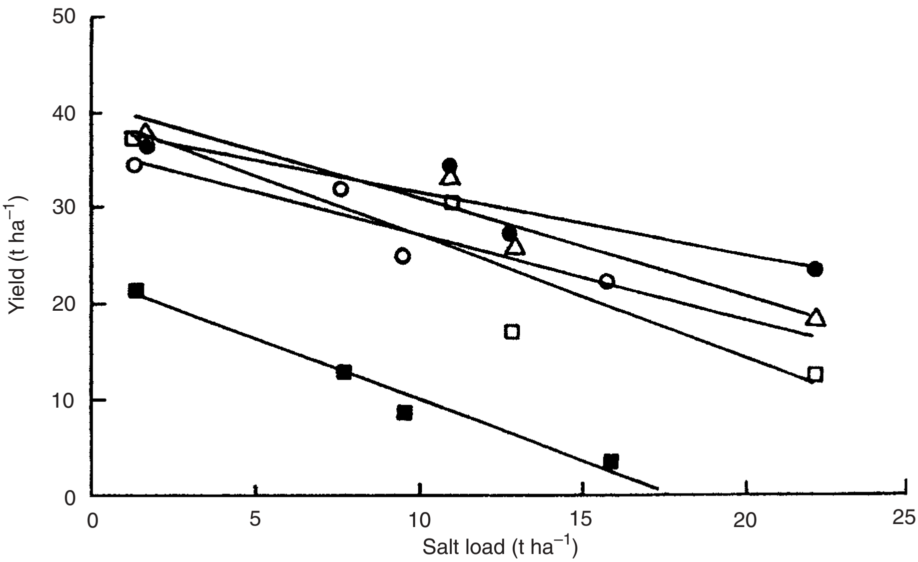

Figure 2. Effect of average annual salt load on the corresponding green forage yield of Oat (○), Egyptian clover (□), Persian clover (△), Senji (■) and Rye grass (●).

Table 5. Effect of saline drainage irrigation on the dry matter yield (t ha^{-1}) of *rabi* crops in each year.

	Irrigation				
Crop	CW	CW-DW	DW-CW	DW	Mean
		1997–1998			
Oat	7.2	7.1	7.3	7.0	7.2
Egyptian clover	4.8	4.0	3.6	2.3	3.7
Persian clover	4.4	3.9	3.8	3.1	3.8
Senji	3.4	2.6	1.8	0.9	2.1
Rye grass	5.1	4.7	4.4	4.2	4.6
Mean	5.0	4.6	4.2	3.5	
s.e.	Irrigation-0.34; Crops-0.12; Interaction 0.30				
		1998–1999			
Oat	6.8	7.3	5.5	4.3	6.0
Egyptian clover	5.9	5.3	2.7	2.0	4.0
Persian clover	5.1	4.9	3.7	2.5	4.1
Senji	4.3	2.1	1.4	0.4	2.0
Rye grass	9.3	9.3	7.3	6.4	8.1
Mean	6.3	5.8	4.1	3.1	
s.e.	Irrigation-0.41; Crops-0.28; Interaction 0.37				
		1999–2000			
Oat	6.9	6.8	4.5	4.2	5.6
Egyptian clover	5.8	5.3	2.4	2.1	3.9
Persian clover	5.5	5.2	3.7	2.7	4.3
Senji	3.2	2.3	1.5	0.5	1.9
Rye grass	10.0	9.9	7.6	6.7	8.6
Mean	6.3	5.9	3.9	3.2	
s.e.	Irrigation-0.34; Crops-0.12; Interaction 0.31				

1997–98, oat followed by rye grass produced considerably more dry matter than all the other crops. In the next two years, however, rye grass produced more dry matter than did oat,which, in turn, gave 32 % and 23 % higher yield than Persian clover and 33 % and 30 % more than Egyptian clover during 1998–1999 and 1999–2000 respectively. Senji yielded least. Interaction between the forage crops and irrigation treatments was significant. Whereas oat and rye grass gave similar yields under the irrigation treatments with CW and alternate irrigation starting with canal water (CW-DW), the yield of other forage crops decreased under the CW-DW treatment. Oat, rye grass, Persian clover, Egyptian clover and senji yields were reduced by 25 %, 29 %, 46 %, 62 % and 83 % respectively when drainage saline water was used for irrigation compared with CW.

Relative yield

For each crop there were negative linear relationships (Figure 2) between the average annual fresh yield (Y, t ha^{-1}) and the corresponding total amount of salt applied (x, t ha^{-1}):

Rye grass: $Y = -0.68x + 38.5$, $r^2 = 0.86$
Persian clover: $Y = -1.03x + 41.0$, $r^2 = 0.92$
Oat: $Y = -0.92x + 36.3$, $r^2 = 0.83$
Egyptian clover: $Y = -1.30x + 39.8$, $r^2 = 0.85$
Senji: $Y = -1.29x + 22.6$, $r^2 = 0.97$

The yield decrease was for rye grass, followed by oat, and greatest for Senji and Egyptian clover.

Electrical conductivity of soil

The salinity build up was noticed in all irrigation treatments including the CW in which EC_e increased from the original 4.8 to 8.9 dS m^{-1} in the 0 – 0.15 m layer and from 5.2 to 7.9 dS m^{-1} in the 0.15–0.30 m layer (Table 6). However, the salinity build up was highest (EC_e 14.0 dS m^{-1}) in the treatment where saline drainage water alone was used for irrigation. Between forage crops, salinity build up was greatest in senji and oat in all the irrigation treatments including CW irrigation.

DISCUSSION

The use of saline drainage water for irrigation creates soil salinity due to the accumulation of soluble salts in the absence of adequate leaching. When the soil salinity exceeds the critical level (threshold) crop yields decrease. The yield decrease depends upon several factors such as the inherent tolerance of a crop for soil salinity, soil type, climate, crop water requirements, and stage of growth of the crop. Most crops are sensitive at germination and early establishment. If good quality water (canal or tube well) is available, this can be used for pre-sowing irrigation. Considering this

Table 6. Effect of saline drainage irrigation on the electrical conductivity (dS m^{-1}) of soil at 0–0.15 and 0.15–0.30 m soil depths at the end of experiment (May 2000).

Crop	Irrigation				
	CW	CW-DW	DW-CW	DW	Mean
		0–0.15 m			
Oat	9.6	9.5	13.5	14.3	11.7
Egyptian clover	7.9	8.8	12.8	13.9	10.9
Persian clover	8.3	8.7	11.3	13.7	10.5
Senji	10.3	9.3	14.2	14.6	12.1
Rye grass	8.2	8.6	11.4	13.5	10.4
Mean	8.9	9.0	12.6	14.0	
		0.15–0.30 m			
Oat	8.1	8.2	10.8	11.7	9.7
Egyptian clover	7.6	8.0	10.3	9.8	8.9
Persian clover	8.1	8.4	10.5	10.4	9.4
Senji	7.9	8.5	11.1	10.8	9.6
Rye grass	7.6	7.6	9.8	9.8	8.7
Mean	7.9	8.1	10.5	10.5	

Notes:
Initial EC of soil at 0–0.15 m depth was 4.8 dS m^{-1} and at 0.15–0.30 m depth 5.2 dS m^{-1}, respectively.
For Rye grass, Persian clover and Egyptian clover, number of applied irrigations for different treatments were: CW = 9; CW-DW = 5 + 4; DW-CW = 5 + 4; DW = 9 respectively.
For oat and senji, number of applied irrigations for different treatments were: CW = 7; CW-DW = 4 + 3; DW-CW = 4 + 3; DW = 7 respectively.
CW = canal water.
DW = drainage water.

important feature, all the crops were sown with CW, and other modes of irrigation treatments were imposed thereafter. The results showed that in the second and third years of experimentation, CW-DW alternate irrigation produced 50 % and 53 % larger yields respectively compared with DW-CW. Higher yields in such cases could be because, with the former treatment, the crops were exposed to salt stress at a relatively older age and may perhaps have developed the capacity to withstand greater stress. Also, the salt load applied through irrigation was lower (10.9 t ha^{-1}) in CW-DW treatment compared with DW-CW treatment (12.8 t ha^{-1}). Minhas *et al*. (1989; 1990) reported that forage sorghum and mungbean were comparatively more tolerant at later stages compared with the seedling and early establishment stages. Kumar *et al*. (1997) concluded that a pre-sowing irrigation with good quality water to sunflower (*Helianthus annuus*) can help in the subsequent utilization of water of much higher salinity which, otherwise when used alone, could cause a substantial reduction in yield. Both these alternate irrigation treatments proved much better than irrigation with saline drainage water. On average over the three years, the substitution of saline drainage water with CW irrigation resulted in an 83 % increase in the green forage yield if CW was used first, while starting with saline drainage water gave a 32 % increase. Also, Sharma *et al*. (1994) found that using saline drainage water in conjunction with non-saline canal water in various treatments, 88–94 % of wheat yield could be obtained without any serious soil degradation. Rhoades *et al*. (1989) and Bradford and Letey

(1992) reported advantages of cyclic over the blending strategy in most of the cases. The results suggest, therefore, that alternate use of CW-DW and DW-CW helps in minimizing yield reductions in all forage crops.

Of the crops tested, oat and rye grass yielded much more, on average, than the other crops. Persian clover yielded more than Egyptian clover. The differences in production of different crops with various modes of irrigation could be due to their yield potential and tolerance of saline environment (Maas and Hoffman, 1977). Although oat and senji received the same amount of salt load (8.5 t ha^{-1}) the yield of oat was marginally decreased while that of senji was adversely affected. Similarly, rye grass, Egyptian clover and Persian clover received an equal amount of salt (11.9 t ha^{-1}) yet rye grass out-performed the other two species. In a sand culture greenhouse study, Kumar and Sharma (1995) reported that the yields of Egyptian clover, Persian clover and Chinese cabbage were significantly reduced at 7.5 dS m^{-1} over their respective controls. However, the yield of lucerne (alfalfa) was reduced significantly only where saline water of EC 10 dS m^{-1} was used while that of oat was not affected even at this level. Under field conditions at Hisar where there were soil patches of different salinity, Yadav and Kumar (1997) observed that germination of Egyptian clover, pearl millet and maize was reduced at soil salinity (EC_2 1: 2 soil and water ratio) levels greater than 1.5 dS m^{-1} while the germination of barley, oat and sorghum was reduced when the EC_2 exceeded 3.0 dS m^{-1}. These results suggest further that in soils where the EC_2 exceeds 4.5 dS m^{-1}, only barley and oat can give satisfactory yields. Rogers (2001) concluded that despite of intraspecific variation for salt tolerance, it is detrimental to irrigate lucerne with water at electrical conductivities greater than 2.5 dS m^{-1} on red-brown earth in southern Australia. Maas and Hoffman (1977), while assessing the salt tolerance of various crops, reported that barley (*Hordeum vulgare)* for forage and perennial rye grass (*Lolium perenne*) were moderately tolerant, and clover berseem (*Trifolium alexandrinum*) was moderately sensitive to salinity. The findings of this study are in agreement with the results and assessments made by other authors such as Kumar and Sharma (1995), Yadav and Kumar (1997) and Maas and Hoffman (1977).

There was a build up in the EC_e of the soil, more particularly in the 0–0.15 and 0.15–0.30 m soil layers compared with the lower surface layers. On average, the build up was more in the first year (May 1998) than in subsequent years. This could be due primarily to the high water table and no rainfall during April and May of that year. The salinity build up was noticed in all irrigation treatments including the CW. This could be attributed to redistribution of salts in the profile because of high evaporative demands during the summer months, and leaching of salts to lower layers following the monsoon in September/October. However, the salinity build up was highest (EC_e 14.0 dS m^{-1}) in the treatment in which saline drainage water was used for irrigation. The treatments of CW, CW-DW, DW-CW and DW, especially in Egyptian clover, Persian clover and rye grass, received 0, 280, 350 and 630 mm saline water respectively, which caused differences in the EC of the soil and were in proportion to the amount of saline water given. Incidentally, the last irrigation in the treatment DW-CW coincided with saline drainage water, resulting in a higher salinity build up than in the CW-DW treatment. Rogers (2001) found that after four seasons of irrigating with saline water, soil EC had risen to 4.2 dS m^{-1} at the end of the season for the highest salinity treatment (7.6 dS m^{-1}). When alternate irrigation treatments were compared, it was found that where the saline drainage irrigation was applied first there was a comparatively higher build up of EC than where CW was applied first. Among forage crops, salinity build up was greater in senji and oat than in Egyptian clover, Persian clover or rye grass in all the irrigation treatments, including CW irrigation. The lower build up of soil salinity in Egyptian clover, Persian clover and rye grass could be because these are densely grown crops with thick canopies covering larger soil surface areas than other crops, thereby permitting comparatively less evaporation from the surface and, hence, less salt accumulation. In the case of oat and senji only one cut was taken about a month before the last cut from Egyptian clover, Persian clover and rye grass. This increased the exposure of the soil surface to the sun and resulted in the relocation of salts within the soil profile. These factors might have contributed to the higher build up of salinity in oat and senji and concomitant higher EC values although these crops received less water (0.21, 0.28 and 0.49 m in CW-DW, DW-CW and DW treatments respectively).

CONCLUSIONS

Continuous use of saline drainage water for irrigation results in the build up of soil salinity and causes a reduction in the yields of forage crops. The results presented here reveal that, if the crops are sown with good quality water (canal irrigation), and thereafter given alternate irrigations of canal water and saline drainage water, the yields of forage crops are enhanced particularly so if the first alternate irrigation is with canal water. Rye grass, oat and Persian clover are comparatively more tolerant to salinity build up than are Egyptian clover and senji and, therefore, should be given preference in saline conditions.

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