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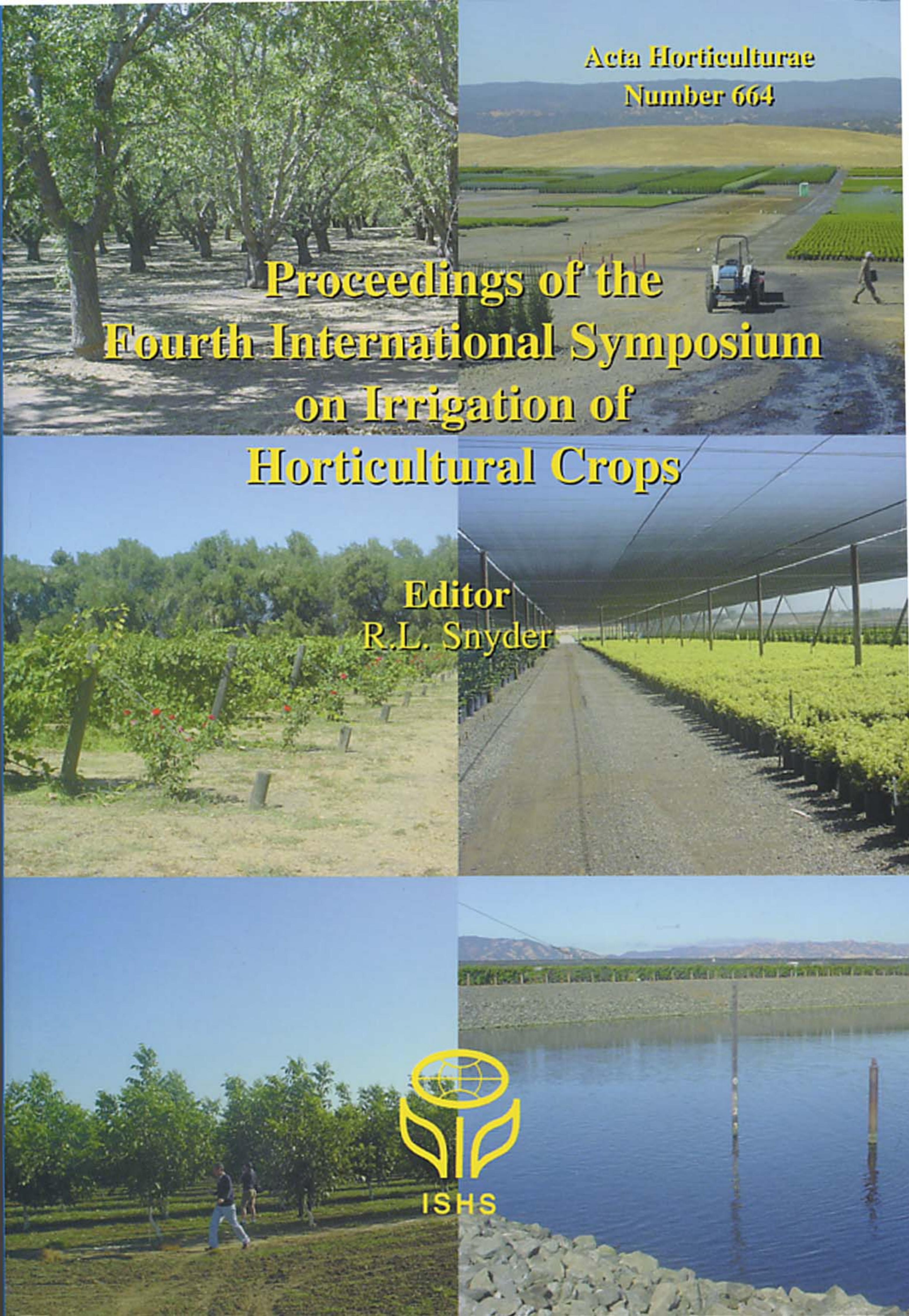

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Effects of Recycled Water on Soil Salinity Levels for Cool Season Vegetables

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Abstract

Agriculture in Monterey County, California is more than a $3 billion per year industry. Over-pumping of ground water has caused sea water to intrude into wells located near the coast. In an effort to reduce ground water extraction in the northern Salinas Valley, the Monterey Regional Water Pollution Control Agency in partnership with the Monterey County Water Resources Agency began providing recycled water to 4,900 hectares of prime farmland used to grow cool season vegetables in April 1998. The dominant soil types in this region are clay loam and heavy clay soils, both of which are susceptible to sodium accumulation and water penetration problems. Recycled water, blended with well water, is used to irrigate artichokes, broccoli, Brussels sprouts, celery, cauliflower, lettuce, and strawberries. Because of grower concerns that salts, particularly Na and Cl, in the recycled water would reduce yield and quality of their crops a long term study was developed to monitor salinity levels in commercial vegetable fields. Soil salinity levels were monitored at 4 control and test sites beginning in the spring of 2000. The control sites received well water and the adjacent test sites received an approximate 2:1 blend of recycled and well water. Control and test sites were paired so that they could be compared under the same soil, crop, drainage systems and farming practices. The soil was sampled three times per year from all sites: spring (before planting), mid-summer, and late fall. Composites of 4 cores were collected from the 0 to 90-cm depth at 30-cm intervals. Soil samples were analyzed for pH, electrical conductivity (EC_e), extractable cations (B, Ca, Mg, Na, and K) and extractable anions (Cl, NO_3, and SO_4). After 3 years of monitoring, the data showed that using recycled water for vegetable production increased EC_e (saturated paste extract) of the soil profile from 2.0 to 2.9 dS/m but decreased the sodium adsorption ratio (SAR) from 2.9 to 2.6. The SAR and EC of soil samples from all sites were in a range acceptable for vegetable production.

INTRODUCTION

The Monterey Regional Water Pollution Control Agency (MRWPCA) produces and supplies water to the Monterey County Water Recycling Projects (MCWRP) as part of Monterey County Water Resources Agency's (MCWRA's) Salinas Valley Water Project. This project started delivering recycled water for irrigation in 1998 and recycled water has been accepted and used by the majority of the growers. However, MRWPCA, MCWRA, and many growers are concerned with the possibility of intermediate or long-term deterioration of soil's physical and chemical properties with sustained use of recycled water. The prime irrigation water constituents of concern are sodium, chloride, bicarbonate, and pH. By agronomic standards, the average SAR of the recycled water at 4.7, in combination with an EC of around 1.6, are quite safe for long-term irrigation (Richards, 1969). However, some ESP (exchangeable sodium percentage) values collected by growers in 1999 (based on soil saturation extract data for SAR) indicated significant increases in the soil exchangeable sodium percentage[a]. While the average SAR and ESP values are generally within acceptable ranges, there was a significant concern that the data was indicative of a long-term trend of increasing ESP related to the use of recycled water. Increasing ESP would decrease soil permeability and water retention and these soil characteristics have been an ongoing challenge for farmers in the service area due to the soil types present. In addition, several of the cool season vegetable crops grown in the area are relatively salt sensitive and yields would be decreased by increasing soil salinity (Richards, 1969). These dual concerns initiated the soil salinity study described in this paper.

MATERIALS AND METHODS

A comprehensive soil sampling plan was developed with input from consultants, staff, and growers to monitor soil salinity over time in the same locations using the recycled water. In addition to the soil sampling, data was collected on the water quality for each site and the quality of the crops. This paper will summarize the water quality and resulting soil salinity levels at each site for the first three years of sampling: 2000, 2001, and 2002

Recycled Water Sampling and Analysis

The MRWPCA water recycling facility provides a relatively constant flow (around 76 million liters per day) of recycled water. This rate is inadequate to serve the MCWRP service area during peak demand periods. Therefore, supplemental wells, tapping groundwater from the 122-meter aquifer, are used to augment the recycled water supply, as necessary. During the periods when recycled water must be supplemented, incidental blending of recycled water with well water takes place within the pressurized distribution system.

Water sampling was conducted throughout the recycling project system as standard procedure in the MCWRP Monitoring Program. MRWPCA's tertiary effluent was sampled on a weekly basis to determine the levels of salt present. The delivery system sampling confirms the quality of the water received by the growers after supplemental well water is added to the recycled water. These data were used to generate the observed and calculated values of water delivered to each field sampling location. The water samples were analyzed for pH, ECw, Na, K, Mg, and Cl. The MRWPCA laboratory, an accredited laboratory run by the County, analyzed the water. Rainfall data were collected from California Irrigation Management Information System (CIMIS) for the Castroville site located within 3 miles of all field sites.

Site Selection and Soil Sampling Frequency

Four "Test" sites were selected for intensive monitoring. These "Test" sites have been irrigated with recycled water since 1998. These fields were chosen based on soil characteristics and stratification, drainage system, type of crops grown, irrigation method, and farming practices. The "Test" sites had both clay and clay-loam soils (see Table 1).

Four "Control" sites were selected and have used only well water. Two of these fields were within the MCWRP service area and two fields were outside the service area but adjacent to a "Test" site. The control sites were selected to assure as much similarity as possible to corresponding test sites, as listed above (see Table 1). The "Control" sites had both clay and clay-loam soils.

At each site, samples were collected from the same point within the field located via Global Positioning System (GPS) coordinates. This was done to reduce the effects of variability of salinity if different areas of the site were sampled on different dates. Therefore, the variability of salinity observed would be related to the quality of the water applied to the same physical locations each year. Samples were collected three times per

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[a] "Analysis of Soil Salinity on Dole Properties Utilizing CSIP Water", data sheets prepared by BEP, 12/8/99. These data calculate increases in ESP of up to 259 percent from the 1996/1997 season to the 1998/1999 season, with a maximum ESP of 10.3 on one field (unpublished data).

year at each site as follows: 1) after the winter rains prior to the first crop, 2) mid-growing season and after harvest of the first crop, and 3) at the end of the season after the second crop and before the winter rains. The average of the three sampling dates was used to summarize the salinity level for each site for each year.

Sampling Methodology and Statistics

At each site, sub samples were taken at three different soil depths and at four different locations within 100 cm of the designated GPS point. The three soil depths were: 1) 0 to 30 cm with the top 2.5 cm of soil discarded, 30 to 60 cm, and 60 to 90 cm. Composite samples for each soil depth were made by combining the samples of the four locations at each site. Sample analysis was done by an independent accredited lab (Valley Tech, Tulare, CA) and included pH from saturated soil paste, electrical conductivity (EC_e), extractable cations (B, Ca, Mg, Na, and K) and extractable anions (Cl, NO_3, and SO_4). The main effects of water treatment, location, depth, year and their interactions were statistically analyzed using SAS 8.1 general linear means procedure (SAS, 1999). Fisher's protected LSD multiple means comparison test was performed for significant main effects ($p< 0.05$).

RESULTS AND DISCUSSION

Annual average percentage of recycled water used system-wide was 59.9 % in 2000, 65.3 % in 2001, and 66.2 % in 2002. The estimated SAR and ECw values of the average blend delivered to each location are summarized in Table 2. During the study, the SAR of the recycled blend (test) was higher than the well water (control). While the average ECw values were not substantially different, the amounts of applied sodium (Na) for each treatment were different. The average amount of Na in the recycled water was 175 ppm, which applied 210 kg of Na per acre-foot of water (AF). The average amount of Na in the well water was 120 ppm, which applied 144 kg of Na per AF. In addition, Table 2 includes the annual rainfall and reference ETo for the project area.

The variability of soil salinity levels was evaluated by location, depth, year, and treatment. Each of these main effects was statistically significant and the mean separations are reported in Tables 3 – 6. The interaction between location and treatment was significant for EC at all locations, but only statistically significant at location 1 for SAR and ESP. The interactions between depth and treatment and treatment and year were not statistically significant.

Table 3 summarizes the variability of salinity among different paired locations including both test and control sites. The range of values is rather narrow indicating a small amount of variability between the four paired locations. Only one pair has a significantly higher ESP and SAR (location 3). Table 4 analyzes the variability of salinity at different depths. There is a significant increase in SAR and ESP with depth for all locations. The significant increase in salinity at the deepest part of the profile (60-90 cm) demonstrates that salts are being leached by irrigation practices. These significant differences in location and depth are normal given the variation in soil types between locations and the unimpeded movement of salts through the soil profile in this area.

Table 5 analyzes the variation of salinity among years at all sites. The significant difference in average soil salinity between years was not expected. The recycled and well water have shown very small variation during the study (see Table 2). The significantly lower values for SAR and ESP occurring in 2001 correlate with the larger amount of rainfall during the winter of 2000-2001 (see Table 1) which appeared to reduce salts in the 90 cm sampling zone regardless of treatment. A comparison of this leaching effect is shown in Figure 1. Specifically, the average SAR of the test treatments using recycled water decreased from 2.9 to 2.6. The amount of the winter rainfall may affect the accumulation of Na significantly since all locations regardless of treatment had reductions in salinity in 2001.

The comparison of values for control and test treatments for all locations is in Table 6. Both SAR and ESP are significantly higher at the test sites using recycled water and this result was expected with the differences in Na levels in the water applied to each treatment. However, the higher values have been acceptable to date for cool season vegetable production with no yield losses reported by the growers. While there is no significant difference in the EC among treatments, Figure 2 indicates an upward trend in EC in both treatments with the test treatment EC values increasing from 2.0 to 2.9 dS/m.

CONCLUSIONS

Comprehensive soil monitoring of soils receiving recycled water with a higher salt content has shown significantly increased levels of soil salinity in comparison to soils receiving a lower salt well water. However, the difference in soil salinities does not appear to be increasing over the three year period of the study. In fact, both the test and control sites had reductions in SAR values from the start of the study that appear to be correlated with a larger amount of rainfall during 2000. It is important to note that the increases in EC values are indicators of the potential for the overall soil salinity to increase in the near future. These sites will continue to be monitored in the future in order to track the effects of the use of recycled water.

Literature Cited

Richards, L.A. (ed.), 1969. Diagnosis and improvement of saline and alkali soils. Agriculture Handbook No. 60. U.S.D.A., U.S. Govt. Printing Office, Washington, D.C.
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Tables

Table 1. Summary of soils, crops, and drainage at all locations.

Location	Soil Type	Average Sat. %	Crops Grown	Tile Drain Present
Control 1	Clear Lake Clay	59	Celery, Lettuce	Yes
Test 1	Clear Lake Clay	66	Cauliflower, Lettuce	Yes
Control 2	Clear Lake Clay	56	Lettuce, Broccoli	Yes
Test 2	Clear Lake Clay	61	Cauliflower, Lettuce	Yes
Control 3	Pacheco Clay Loam	55	Lettuce	Yes
Test 3	Pacheco Clay Loam	63	Lettuce	Yes
Control 4	Antioch Sandy Loam	45	Artichoke	No
Test 4	Antioch Sandy Loam	52	Artichoke	No

Table 2. Estimated SAR and EC of water applied to test and control sites, annual rainfall and annual reference ETo.

Year	SAR - Test	SAR - Control	EC -Test	EC- Control	Rainfall (cm.) July 1 – June 30	Ref. ETo (cm.) Jan. 1 – Dec.31
2000	4.71	3.10	1.04	1.05	41.64	88.78
2001	4.74	3.99	1.30	0.73	29.55	89.08
2002	4.70	3.40	1.27	1.06	29.84	93.12

Table 3. Average soil salinity levels at different locations from all depths during the study (2000-2002).

Location	N	SAR	ESP	EC
1	54	2.17 a	1.88 a	2.94 a
2	54	2.02 a	1.66 a	1.50 b
3	57	2.85 b	2.84 b	2.00 b
4	54	2.12 a	1.82 a	1.83 b
P>F Value		0.001	0.001	0.001

Table 4. Average soil salinity levels at different depths from all locations during the study (2000-2002).

Depth (cm.)	N	SAR	ESP	EC
0-30	73	2.12 a	1.82 a	2.33 a
30-60	73	2.22 a	1.96 a	2.02 b
60-90	73	2.55 b	2.40 b	1.84 b
P> F value		0.001	0.001	0.001

Table 5. Average soil salinity levels in different years from all depths and locations.

Year	N	SAR	ESP	EC
2000	72	2.49 a	2.31 a	1.72 a
2001	75	2.13 b	1.84 b	1.91 a
2002	72	2.28 ab	2.05 ab	2.55 a
P>F value		0.035	0.046	0.056

Table 6. Average soil salinity levels in the test and control treatments for all depths and locations during the study (2000-2002).

Treatment	N	SAR	ESP	EC
Control	108	1.93 a	1.55 a	1.69 a
Test	111	2.66 b	2.56 b	2.43 a
P>F value		0.021	0.024	0.108

Figures

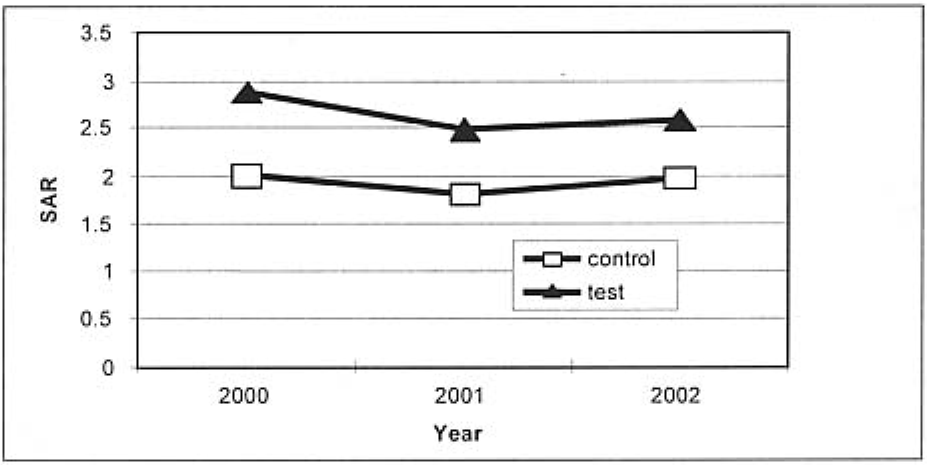

Fig. 1. Average soil SAR values for test and control sites in different years.

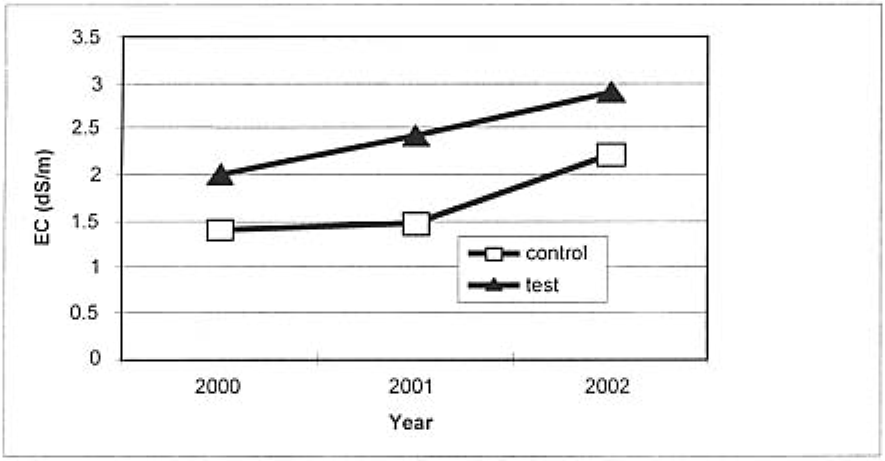

Fig. 2. Average soil EC values for test and control sites in different years.