Environ Monit Assess (2013) 185:10091–10100
DOI 10.1007/s10661-013-3315-z

Soil water, salt, and groundwater characteristics in shelterbelts with no irrigation for several years in an extremely arid area

**Xinfeng Zhao · Hailiang Xu · Peng Zhang ·
Jinyi Fu · Yuan Bai**

Received: 7 September 2012 / Accepted: 25 June 2013 / Published online: 13 August 2013

Abstract This paper is based on long-term monitoring data for soil water, salt content, and groundwater characteristics taken from shelterbelts where there has been no irrigation for at least 5 years. This study investigated the distribution characteristics of soil water and salt content in soils with different textures. The relationships between soil moisture, soil salinity, and groundwater level were analyzed using 3 years of monitoring data from a typical oasis located in an extremely arid area in northwest China. The results showed that (1) the variation trend in soil moisture with soil depth in the shelterbelts varied depending on soil texture. The soil moisture was lower in sandy and loamy shelterbelts and higher in clay shelterbelts. (2) Salinity was higher (about 3.0 mS cm^{-1}) in clay shelterbelts and lower (about 0.8 mS cm^{-1}) in sandy shelterbelts. (3) There was a negative correlation between soil moisture in the shelterbelts and groundwater level. Soil moisture decreased gradually as the depth of groundwater table declined. (4) There was a positive correlation between soil salinity in the shelterbelts and the depth of groundwater table. Salinity increased gradually as groundwater levels declined.

Keywords Shelterbelts · Soil moisture · Soil salinity · Groundwater level

Introduction

Oases are the main bodies of water in arid areas (Jia and Xu, 1998). Shelterbelts are the protection screens of agriculture and oases, and the economy is based on the local agriculture. However, a large number of shelterbelts have disappeared around Kalamiji Oasis since 2003 (Zhao et al. 2011), and wind erosion is a threat in arid and semiarid lands, many cultivated area gradually eroded by the desert, and woody vegetation decreased gradually.

In Sudan, the local people enhanced the local shelterbelt stability in the oasis by planting drip-irrigated shelterbelt in desert environment (Nasr Al-Amin et al. 2006); some studies research for the method of stimulating tree root growth to serve local shelter forest construction (Hendrick and Pregitzer 1992; Schroth 1995); in China, many ecologists studied the irrigation system of shelterbelt to maintain the sustainable development of the highway shelterbelt of Taklimakan Desert (Zhou et al. 2006); in Japan, Hiroyuki and Hajime (2007) studied the method of enhancing the wind-reducing efficiency to maintain the stability of the oasis by adjusting the structure of shelter forest.

X. Zhao · H. Xu · P. Zhang · J. Fu · Y. Bai
State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China

X. Zhao · H. Xu (✉) · P. Zhang · J. Fu · Y. Bai
Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China
e-mail: xuhl@ms.xjb.ac.cn

Kalamiji Oasis, which is the sink oasis for the Tarim River, is located in an extremely arid area with strong evaporation and low precipitation. Salt originating from mountains and upper and middle river areas result in high salinity levels in the groundwater and severe salt accumulation in low-lying areas (Fan et al. 2004). Due to the lack of irrigation, serious soil water loss occurs via soil evaporation leading to a salt accumulation in the upper soil layers. As a result, a large number of shelterbelts have died around the Kalamiji oasis. It is not clear whether this is a result of the low water levels or the effects of high salinity. If it is the combined effect of low water content and high salinity, then there is a need to find a way to ameliorate these effects. Therefore, this study was conducted in order to investigate the water and salt content in the soils found on oasis farmlands and their shelterbelts around the Kalamiji Oasis.

Methods and data collection

Study area

The Tarim River watershed lies in Xinjiang, China, in the interior of Eurasia. The study area was located at the Kalamiji Oasis, which is in the lower reaches of the Tarim River (87°925′E, 40°701′N) (Fig. 1). The average annual temperature is 10.5 °C. The average temperature for June, July, and August in the study area is 24.9–27.5 °C, and the average precipitation during this period is only 36 mm (Fig. 2). However, the annual potential evaporation ranges from 2,000 to 3,000 mm. All climate data above are based on observations by Tieganlike weather station.

The poor precipitation in the study area has little effect on the growth of natural vegetation. Because of that, there is no runoff produced by the Tarim River, and the runoff is mainly supplied by melting glacier and snow water in the headstreams along 1,321 km of the water channel. Following the growth of local population and arable land, this area experienced a substantial increase in water demand. Development and utilization of arable land and water resource in the upper and middle reaches of the Tarim River have led to a sharp decline of groundwater table in the lower reaches of the Tarim River. For example, the depth of groundwater table in desert areas of the lower reaches has declined to 8–12 m. As a result, the local environment has deteriorated seriously. Table 1 provided the details of salt content.

The surface water in the study area is supplied by the Tarim River. The river contains freshwater with an average conductivity of 1 mS cm^{-1}. The conductivity of groundwater in the entire salty water area is as high as 27 mS·cm^{-1}. Since the precipitation in the region is negligible, the groundwater exploitations are enormous. Although cotton fields and orchards generally receive irrigation water from the Tarim River, a variety of crops compete for water in an average/dry year. Consequently, the local farmers have to use salty underground water along with whatever amount of available freshwater for irrigation. Use of groundwater has resulted in an increase of salt accumulation in the study area to some extent.

The selected shelterbelts were generally distributed evenly in the oasis as shown in Fig. 1. As far as the soil type was concerned, three of them were sandy, two of them were loamy, and four of them were clay. Most of the selected shelterbelts were planted in 1990s, and some were planted in 2000s, with the plant space of 3 m and without replacement. The shelterbelts use the same irrigation system (flood irrigation). After the drip irrigation is widely used in the fields (2003), the original channels were dismantled, and then the shelterbelts have rarely been irrigated.

Tree species of the shelterbelt in Kalamiji oasis is mainly *Populus euphratica*, their growth status is poor, and the depth of the root is 80–400 cm.

Groundwater monitoring

A total of 22 ecological monitoring wells were placed in the northeast area of the site between the oasis and the desert. There was farmland and farmland shelterbelt around each well. Depth of groundwater table was monitored twice a month to analyze the annual and interannual variations in groundwater table around the Kalamiji Oasis.

Plot layout

In 2007, eight shelterbelts were randomly selected from the 22 shelterbelts in the study area. Each of the shelterbelts selected was about 3,000 m^2 (100 m×30 m) in size. The selected shelterbelts were distributed evenly throughout the Kalamiji oasis area. To reduce the errors associated with geographic location and soil texture, the selected shelterbelts were subject to the following requirements: the protection of farmland shelterbelts was maintained and the same irrigation

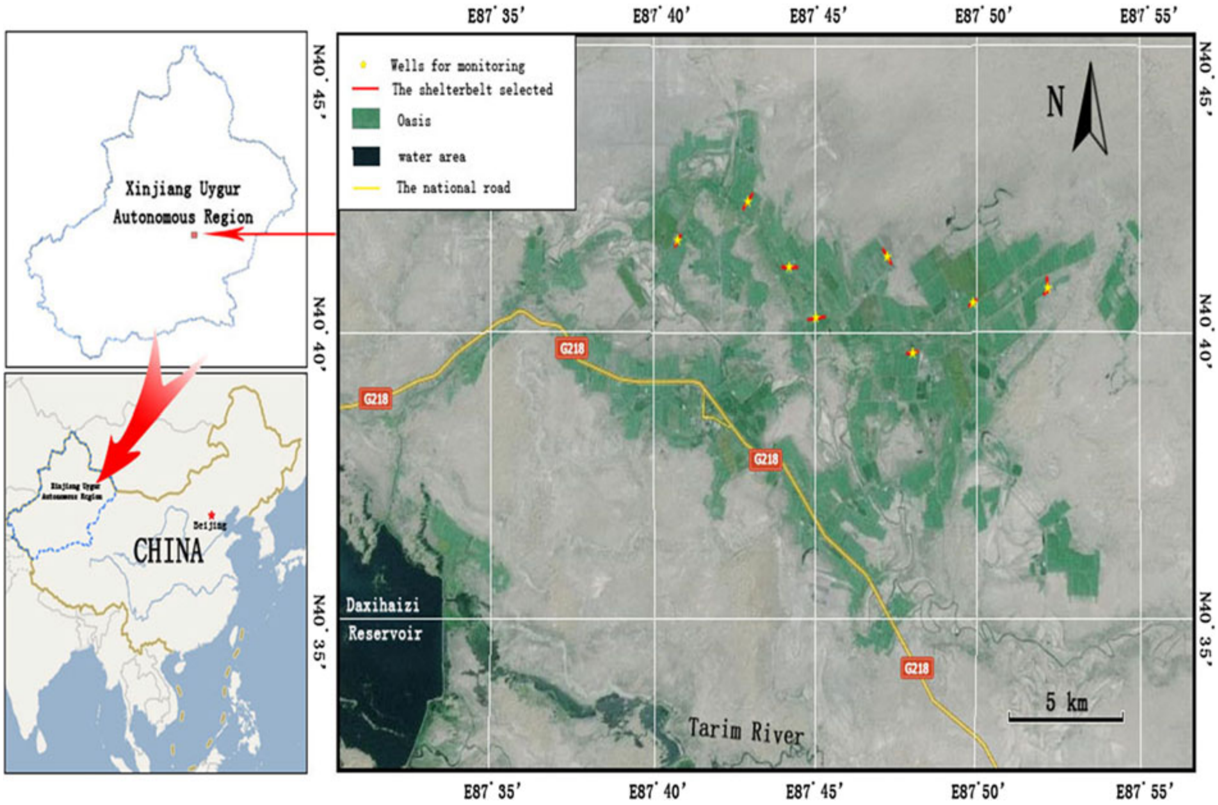

Fig. 1 Location map of the study area

system as used in the cotton fields was used in the shelterbelts and the growth of all selected shelterbelts was similar and there was a 2-m gap between the farmland shelterbelts and the adjacent cotton fields. Table 2 shows the geographic coordinates and other information for each of the eight shelterbelts.

One ecological monitoring well was placed in each woodland so that the underground water level data can be obtained.

Soil sampling

Soil moisture changes depending on the season. In order to compare soil moisture in the eight shelterbelts at different groundwater levels, all of the shelterbelts should be sampled at the same time. However, it proved difficult to sample all the plots simultaneously. As a result, the sampling work was carried out between July 10 and July 13 in 2009 when the weather was sunny. The plots were

Fig. 2 Annual precipitation and average temperature of June–August in study area

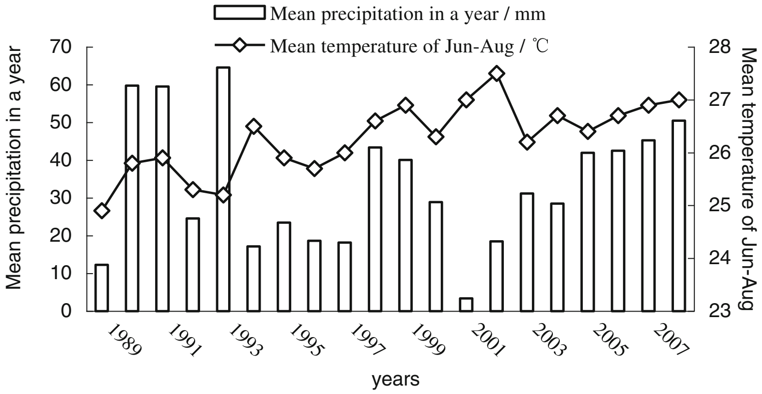

Table 1 Salt content in the soil layers of 0–100 cm in the study area

Conductivity (mS cm^{-1})	The salt content in the soil layers of 0–100 cm in the study area (g/kg)								
	pH	Total salt	Organic matter	Total N	Total P	Total K	Available N	Available P	Available K
2.43	7.8	12.93	13.7	0.85	0.61	16.8	111.1	5.4	308.5

sampled between 8:00 and 11:00 am, Beijing time. In order to reduce sampling differences, the sampling work in the eight shelterbelts began at the same time.

The soil sampling was carried out in the selected eight woodlands (respectively numbered loamy 1, loamy 2, sandy 1, sandy 2, clay 1, clay 2, clay 3, and clay 4). Soil samples were collected from the tree line in each shelterbelt at depths of 0–20, 20–40, 40–60, 60–80, 80–100, 100–120, and 120–150 cm. In each woodland, seven sampling plots were settled. So, sampling was repeated seven times in each woodland. Forty-nine soil cores (each 2.5 cm in diameter and 20 cm in length) were taken from each woodland. Therefore, 392 soil cores were sampled from the eight woodlands in the oasis.

When the soil samples were taken out with a drill, each soil sample was quickly placed into an aluminum box (with a cover). Because of the hot weather, we prepared the ice beforehand to reduce the moisture loss made by the high temperature.

Data processing

Soil moisture content and salinity were measured and estimated from the soil samples obtained from each shelterbelt.

The soil moisture content was obtained by gravimetric analysis using the following expression:

$$\frac{(W1-W2)}{W2} \times 100$$

where $W1$ is the fresh weight of soil and $W2$ is the soil dry weight.

The soil salinity was obtained by measuring its conductivity. Soil samples were brought back to the laboratory, sieved, and dried. The conductivity of the solution (soil-to-water ratio of 1:5) was then measured using a digital conductivity meter (DDS.307A, Light Ace Ltd., Taipei, Taiwan).

Table 2 Information of shelterbelts

Indexes	Loamy 1	Loamy 2	Sandy 1	Sandy 2	Clay 1	Clay 2	Clay 3	Clay 4
Coordinates	87°54′ 39.96″ E, 40°40′ 58.08″ N	87°51′ 51.12″ E, 40°40′ 36.84″ N	87°51′ 25.00″ E, 40°40′ 51.00″ N	87°46′ 27.00″ E, 40°39′ 15.00″ N	87°50′ 22.00″ E, 40°40′ 44.00″ N	87°48′ 37.00″ E, 40°40′ 0.00″ N	87°48′ 21.00″ E, 40°39′ 39.00″ N	87°48′ 55.00″ E, 40°39′ 20.00″ N
Monitoring wells	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8
Sampling repeated times	7	7	7	7	7	7	7	7
Soil texture	Loamy	Loamy	Sandy	Sandy	Clay	Clay	Clay	Clay
Groundwater level (m)	6.22	5.89	5.34	4.2	3.36	4.48	3.75	4.19
Total salt of groundwater (g/L)	2.03	1.77	2.18	3.49	2.09	3.27	2.97	2.95
Forest age	20	20	15	20	10	20	20	10
Irrigation	No irrigation for 6 years	No irrigation for 6 years	No irrigation for 6 years	No irrigation for 6 years	No irrigation for 6 years	No irrigation for 6 years	No irrigation for 6 years	No irrigation for 6 years

The data were analyzed using Origin 7.0 (Originlab, Guangzhou, China), SPSS 13.0 (SPSS, Chicago, IL, USA), and Microsoft Excel 2003 (Microsoft Corporation, USA).

Results and analysis

Groundwater characteristics

The data of depth of groundwater table in the eight shelterbelts was analyzed. The results of these analyses are presented in Fig. 3.

The groundwater table in Kalamiji oasis showed a seasonal change that was characterized by deeper groundwater table in summer than winter, or deeper groundwater table during the irrigation season than the nonirrigation season (Fig. 3). In addition, the depth of groundwater table in irrigation season was deeper by 1 m than that in nonirrigation season, which was consistent with the results reported by Li and Yang (2002).

Drip irrigation reduces evaporation, decreases crop water consumption, and contributes to increasing groundwater levels (Lv et al. 2002). However, as shown in Fig. 3, the depth of groundwater table declined with the promotion of water-saving irrigation methods from 2008 to 2010. This decline is at a rate of 0.5 m per year. This phenomenon may be related to implementation of large-scale drip irrigation. Indeed, the water that was conserved was used for irrigation of newly reclaimed land; therefore, the water was still not enough.

Table 3 shows the groundwater quality characteristics. The quality of groundwater was tested by the Key Laboratory of Oasis Ecology and Desert Environment, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences. Groundwater quality in the different shelterbelts was compared using analysis of variance (Table 3).

There were almost no differences in the pH values, SO_4^{2-}, CO_3^{2-}, Ca^{2+}, and K^+ of groundwater between the eight shelterbelts. In shelterbelts of clay 1 and clay 2, many of the indicators, such as total hardness, degree of mineralization, total salt content, and HCO_3^-, Cl^-, Na^+, and Mg^{2+} content, were significantly larger than that in other shelterbelts. In shelterbelt of loamy 2, Na^+ content was significantly greater than the other seven shelterbelts.

Soil moisture characteristics in the shelterbelts

Soil sampling was conducted in eight selected shelterbelts, and the distribution of soil moisture and salinity in the shelterbelts were analyzed. Table 4 shows that there was less soil moisture in the zone closest to the surface in most of the shelterbelts. Soil moisture loss was mainly a result of external factors, such as dry climate.

It is apparent from Table 4 that soil moisture rose with increasing soil depth in loamy 1 and loamy 2, whereas soil moisture rose and then fell in sandy 1 and sandy 2. In clay 1, clay 2, and clay 3, the soil moisture rose as the soil depth increased in the 0–70-cm zone but it no long increased below 70 cm depth.

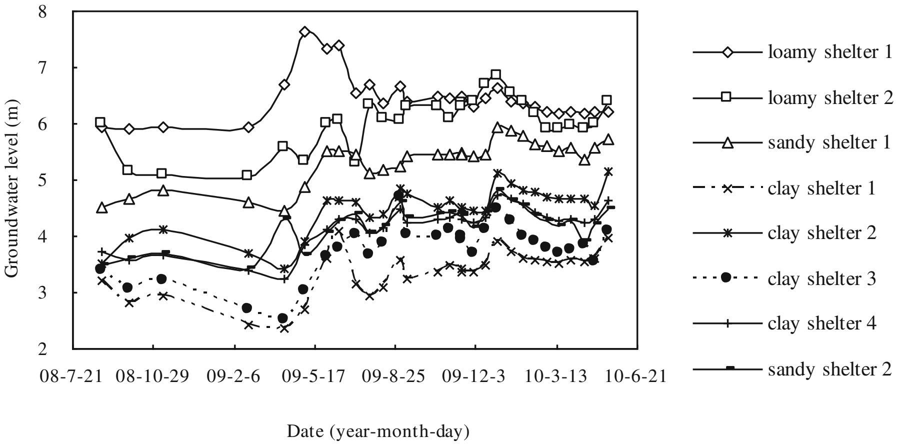

Fig. 3 Variation of groundwater table in shelterbelt of the irrigation zone

Table 3 Salt content of groundwater in shelterbelts

	Loamy 1	Loamy 2	Sandy 1	Sandy 2	Clay 1	Clay 2	Clay 3	Clay 4
Total alkalinity (mmol L^{-1})	16.02	7.16	5.00	7.19	4.43	4.66	5.76	5.71
Total hardness (mmol L^{-1})	25.59	21.79	8.69	8.84	8.92	14.78	10.88	7.47
pH	7.37	7.45	7.27	7.43	7.20	7.20	7.35	7.42
Mineralized degree (g L^{-1})	7.58	9.53	2.18	2.95	2.19	2.13	2.74	3.24
Total salt (g L^{-1})	7.36	2.14	2.65	9.36	2.83	3.15	2.07	2.10
CO_3^{2-} (g L^{-1})	0	0	0	0	0	0	0	0
HCO_3^- (g L^{-1})	0.98	0.44	0.31	0.44	0.27	0.28	0.35	0.35
Cl^- (g L^{-1})	2.4	4.16	0.70	1.02	0.53	0.58	0.72	0.86
SO_4^{2-} (g L^{-1})	1.14	1.21	0.29	0.36	0.52	0.39	0.56	0.56
Ca^{2+} (g L^{-1})	0.71	0.40	0.26	0.23	0.20	0.25	0.28	0.59
Mg^{2+} (g L^{-1})	0.19	0.19	0.07	0.11	0.08	0.06	0.07	0.08
K^+ (g L^{-1})	0.47	0.20	0.17	0.11	0.18	0.25	0.23	0.38
Na^+ (g L^{-1})	2.21	5.51	0.51	0.84	0.48	0.38	0.66	0.61

It is apparent from Table 4 that, in soil layers of 0–20 and 20–40, soil moisture content in sandy and loamy shelterbelts (sandy 1, sandy 2, loamy 1, and loamy 2) is significantly different from that in clay shelterbelts (clay 1, clay 2, clay 3, and clay 4) ($p<0.01$). Accordingly, soil moisture content of upper soil in sandy and loamy shelterbelt is lower than that in clay shelterbelt in Kalamiji Oasis.

Roots grown in different direction and spacing mainly depend upon the forest age and location (Hillel et al. 1976). Owing to the impact of hydraulic lift and water use by plants, the soil moisture in deeper layers is absorbed by deep-rooted plants and then is released into the drier, less deep zones for use by shallower rooted plants (Congbin 2003; Alamusa et al. 2002; Dawson 1993). Soil layers with lower moisture contents may have been subject to hydraulic lift impact in this study. The soil layer with the lowest soil moisture is always found around the roots. It is apparent from Table 4 that the soil layer with the lowest soil moisture started from the 80–100-cm zone in clay 4, the soil layer with lowest moisture started from 100–120 cm in clay 1, and from the 120–150 cm zone in loamy 1, loamy 2, clay 2, and clay 3.

Table 2 indicates that the forest age order for the shelterbelts was as follows: clay 4<clay 1<loamy 1, loamy 2, clay 2, and clay 3. Therefore, in the shelterbelt containing the oldest forest, the zone with the lowest minimum moisture (caused by hydraulic lift) was found at the deepest soil depths, whereas in the shelterbelt containing the youngest forest, the zone with the minimum moisture (caused by hydraulic lift) was found at the shallowest depth.

Shelterbelts of loamy 1, loamy 2, clay 2, and clay 3 were all about 20 years old. The trees in these shelterbelts depend on groundwater, and water is taken up through their deep roots. Although shelterbelt of clay 1

Table 4 Soil moisture in shelterbelts (in percent)

Depth	Loamy 1	Loamy 2	Sandy 1	Sandy 2	Clay 1	Clay 2	Clay 3	Clay 4
0-20 cm	1.53±0.61	3.43±0.65	1.67±0.98	2.30±0.82	10.55±0.49	8.95±2.24	4.65±1.85	14.75±1.50
20-40 cm	3.38±2.09	5.62±0.42	3.21±0.30	4.08±3.14	12.47±1.81	12.13±0.60	7.70±0.30	14.16±0.25
40-60 cm	5.83±1.17	5.02±1.28	11.22±1.86	4.14±2.06	17.86±0.69	15.70±3.30	9.77±1.56	17.68±1.02
60-80 cm	8.04±1.68	6.93±1.09	4.10±1.46	10.08±3.09	18.96±0.91	18.95±1.58	13.56±1.74	17.20±0.73
80-100 cm	9.76±1.37	10.20±2.37	9.84±1.10	14.08±1.75	19.19±1.47	15.50±2.31	15.90±0.74	15.39±2.82
100-120 cm	12.93±1.53	13.02±1.39	10.31±3.92	9.15±2.04	17.18±1.16	17.92±1.24	16.14±1.11	7.97±1.72
120-150 cm	13.46±0.67	14.11±1.25	20.90±1.11	17.20±3.65	16.19±0.55	17.21±0.48	16.51±1.62	6.03±0.30
Means	7.85±4.56	8.33±4.15	8.75±6.58	8.72±5.57	16.06±3.32	15.19±3.52	12.03±4.70	13.31±4.53

was only 10 years old, and therefore has relatively shallow roots, it was still able to survive because it had the shallowest groundwater level (3.1 m). Shelterbelt of clay 4 was also 10 years old but its groundwater level was deeper (5 m), so it would be difficult for shelterbelt 7 to take up water through its roots. Therefore, mature shelterbelt has a strong vitality based on its huge root system and thus has a higher survival rate in arid environments. In the study area, where there had been no irrigation for 5 years, the young shelterbelt could only survive when it was located in areas with shallow groundwater levels.

Transpiration creates a pull or suction that draws water up through the roots. Although the mature tree can increase its ability to withstand drought, the plant will eventually wilt after several years of nonirrigation, unless the roots have a continuous supply of water (Cerny et al. 2001). Therefore, a serious water shortage phenomenon would occur in shelterbelts.

Soil salt characteristics in the shelterbelts

Table 5 shows that salinity declined as the soil depth increased between depths of 0–150 cm in the eight shelterbelts. It is apparent from Table 5 that the salinity distribution in the eight shelterbelts could be classified into three types. Firstly, there was a lower salinity level of 0.5–0.8 mS cm^{-1} between 0 and 150 cm depth, as seen in shelterbelts of sandy 1 and sandy 2. Secondly, there was an intermediate salinity level of 1.5–1.9 mS cm^{-1}, as seen in shelterbelts of loamy 1 and loamy 2, and thirdly, there was a higher salinity level of 2.7–3.0 mS cm^{-1}, as seen in shelterbelts of clay 1, clay 2, and clay 3. Generally, the clay shelterbelts (such as shelterbelts of clay 1, clay 2, and clay 3) had higher salinity levels whereas sandy shelterbelts (such as shelterbelts of sandy 1 and sandy 2) had lower salinity levels. The loamy shelterbelts (such as shelterbelts of loamy 1 and loamy 2) had salinity levels midway between the clay and sandy shelterbelts.

Soil moisture content was lowest in shelterbelts of loamy 1, loamy 2, sandy 1, and sandy 2, which also recorded the lowest soil salinity values. Conversely, soil moisture content was highest in shelterbelts of clay 1, clay 2, clay 3, and clay 4, where the highest salinity was recorded.

In soil layers of 0–20, 20–40, 40–100, and 100–150 cm, soil salinity in sandy and loamy shelterbelts (sandy 1, sandy 2, loamy 1, and loamy 2) is significantly different from that in clay shelterbelts (clay 1, clay 2, clay 3, and clay 4) ($p<0.01$). Accordingly, soil salinity in sandy and loamy shelterbelt is lower than that in clay shelterbelt in Kalamiji Oasis. The soil salinity in sandy shelterbelts is relatively lower than that in the loamy shelterbelt (loamy 1 and loamy 2)

In the extremely arid areas investigated in the study, where there had been no irrigation for at least 6 years, the salt was accumulating on the surface in each shelterbelt. The salts dissolved in the phreatic aquifer may be continuously lifted up by plant transpiration and evaporation, eventually gathering at the soil surface (Guan et al. 2003). The sandy and loamy shelterbelts had the lowest soil moisture and salinity, and the clay shelterbelts had the highest soil moisture and salinity.

Relationship between depth of groundwater table and soil moisture

The soil moisture in the shelterbelts correlated with the depth of groundwater table. The soil moisture values shown were the average value of soil moisture at each of the seven depths (0–20, 20–40, 40–60, 60–80, 80–

Table 5 Soil salinity in shelterbelts (in millisiemens per centimeter)

Depth	Loamy 1	Loamy 2	Sandy 1	Sandy 2	Clay 1	Clay 2	Clay 3	Clay 4
0–20 cm	2.98±0.05	1.97±0.14	1.02±0.19	0.94±0.44	4.20±0.22	4.51±0.34	4.50±0.53	3.96±0.71
20–40 cm	2.31±0.40	1.17±0.18	0.69±0.18	0.76±0.33	2.53±0.62	2.43±0.15	2.61±0.54	3.07±1.13
40–60 cm	1.99±0.40	1.26±0.23	0.80±0.12	0.55±0.26	2.52±0.30	2.35±0.27	2.42±0.35	2.69±0.46
60–80 cm	1.79±0.43	1.04±0.18	0.45±0.05	0.37±0.19	2.37±0.21	2.43±0.12	2.14±0.06	1.65±0.19
80–100 cm	1.78±0.33	1.22±0.21	0.77±0.24	0.30±0.08	2.43±0.39	2.08±0.38	2.10±0.36	1.52±0.39
100–120 cm	1.60+0.42	1.72±0.13	0.73±0.15	0.33±0.09	2.60±0.47	2.18±0.24	2.21±0.52	0.81±0.13
120–150 cm	1.46±0.11	1.52±0.21	1.34±0.35	0.38±0.08	2.44±0.39	2.07±0.19	1.84±0.14	0.72±0.13
Means	1.99±0.52	1.41±0.34	0.83±0.28	0.52±0.25	2.73±0.65	2.58±0.87	2.55±0.90	2.06±1.21

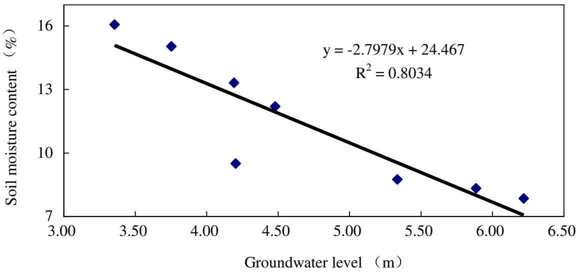

Fig. 4 Variation of soil moisture with the depth of groundwater table

100, 100–120, and 120–150 cm). The soil moisture in the shelterbelts decreased gradually as the depth of groundwater table declined (Fig. 4). The line of best fit showed that the soil moisture in shelterbelts was negatively correlated with the depth of groundwater table. A paired samples *t* test showed that the correlation coefficient was 0.8034 and the linear equation was significant at the 0.01 level (α=0.01, *P*=0.000). From the regression models, the linear equation was calculated as y=−2.7979x+24.467 (*R*=0.8034, *P*=0.000). Therefore, most of the shelterbelts with shallower groundwater depths have higher soil moisture contents whereas the shelterbelts with deeper groundwater depths have lower soil moisture contents.

Relationship between depth of groundwater table and soil salinity

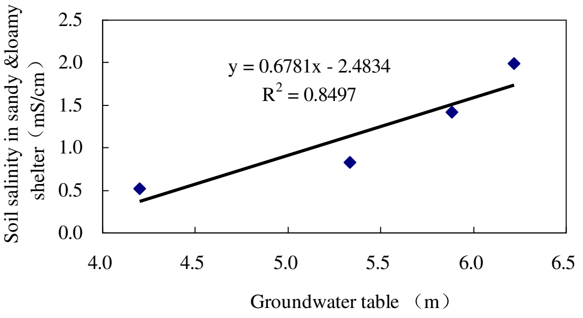

Fig. 5 Relationship between soil salinity and depth of groundwater table in sandy and loamy shelterbelt

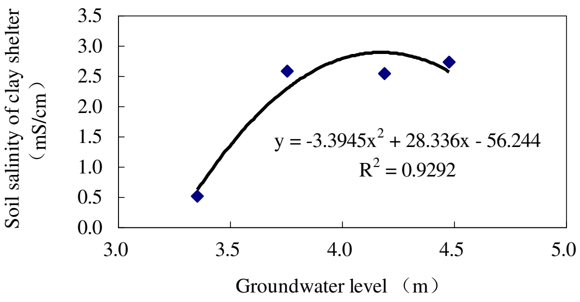

Fig. 6 Relationship between soil salinity and the depth of groundwater table in clay shelterbelt

Figures 5 and 6 show the variation in soil salinity as the depth of groundwater table changes. The soil salinity quoted is the average value for the soil moisture at each of the seven sampling depths (0–20, 20–40, 40–60, 60–80, 80–100, 100–120, and 120–150 cm). The histogram shows the variation in soil salinity with changes in the depth of the groundwater table. There was no good relationship between soil salinity and groundwater table in the shelterbelts around the oasis. However, if sandy and loamy shelterbelts are classified as one class and clay shelterbelts as a separate class, then the correlation between soil salinity and groundwater table becomes clearer.

The soil salinity in the shelterbelts increased gradually in the sandy and loamy shelterbelts as the depth of groundwater table dropped. The line of best fit shows that soil salinity in the shelterbelts was positively correlated with the depth of groundwater table. Using a paired samples *t* test, the correlation coefficient was shown to be 0.8497 and the linear equation was significant at the 0.01 level (α=0.01, *p*=0.000). From the regression model, the linear equation was shown to be y=0.6781x−2.4834 (*R*=0.8497, *P*=0.000).

Salinity in the shelterbelts increased gradually in the clay shelterbelt as the depth of groundwater table dropped. The curve of best fit shows that the soil salinity in the shelterbelts was positively correlated with the depth of groundwater table. A paired samples *t* test showed that the correlation coefficient was 0.8252 and the fitted equation was significant at the 0.01 level (α=0.01, *p*=0.000). From the regression model, the fitted equation was shown to be y=−3.3945x^2+28.336x−56.244 (*R*=0.9292, *P*=0.000).

Discussions

The soil moisture and salinity distribution characteristics in farmland shelterbelts with different groundwater levels were analyzed, and the influence of large-scale drip irrigation on farmland shelterbelt in a typically extreme arid area, the Kalamiji Oasis, was investigated.

1. The most direct meteorological factor affecting soil water storage capacity has been found to be precipitation, which also largely controls soil moisture levels (Wendroth et al. 1999; Qiu et al. 2001; Liu et al. 2000). However, in the Kalamiji Oasis area, the annual regional rainfall is only 36 mm. Therefore, it is difficult to link rainfall with the sustainable development of shelterbelts around the Kalamiji oasis. Additionally, local irrigation cannot satisfy the water requirements of the plants in the shelterbelts. The roots of farmland shelterbelts have to go deep into the soil to absorb water, leading to a lower soil moisture zone occurring in each of the shelterbelts ($p<0.01$). The current method of not supplying water to farmland shelterbelts for many years will likely result in a lack of soil moisture in shelterbelts, causing the groundwater levels to decline. It has been speculated that, with the decline of the groundwater level in the oasis, capillary force will become too weak to meet the root uptake water demand.
2. In Kalamiji oasis, the accumulation of soil salinity was the result of the changes in groundwater movement, which is very closely to the conclusion made by Sang (1996). Salt accumulation on the soil surface has been found to stop when the groundwater reaches a critical level (Thomas et al. 2001). When the groundwater level exceeds the critical level, the groundwater will no longer be lifted by evapotranspiration (Fan and Ma 2002); therefore, it is very necessary to control underground water levels continue to decline.
3. Under the impact of hydraulic lift and nonirrigated conditions, a zone of minimum moisture occurred in each shelterbelt. Shelterbelt of clay 4 was the youngest of the eight shelterbelts studied. Its minimum moisture zone was at a shallower (80–100 cm) depth, compared to shelterbelts of loamy 1 and sandy 2, which were older, and had a deeper minimum moisture zone (20–150 cm or more).

Conclusions

1. In Kalamiji oasis, the depth of groundwater declined was at a rate of 0.5 m per year.
2. Under the nonirrigation conditions, soil moisture was lowest in the sandy shelterbelts and highest in the clay shelterbelts. The EC values were all below than 1.9 mS cm^{-1} in the loamy shelterbelts, about 0.8 mS-cm^{-1} in the sandy shelterbelts, and about 3.0 mS cm^{-1} in the clay shelterbelts.
3. Under nonirrigation conditions, the shelterbelts with the highest soil moisture contents also had the highest salinity levels, while the shelterbelts with lower soil moisture contents had the lowest salinity levels.
4. Around an oasis in an extremely arid area, under nonirrigation conditions, the shelterbelt with the shallowest groundwater depth had highest soil moisture level and the shelterbelt with the deepest groundwater level had the lowest soil moisture content. In sandy and loamy shelterbelts, the shelterbelts with the shallowest groundwater depths had the lower salinity levels and the shelterbelts with the deepest groundwater depths had the highest salinity levels. In clay shelterbelts, the shelterbelts with the shallowest groundwater depths had the highest salinity levels and the shelterbelts with the deepest groundwater depths had the lowest salinity levels.

Acknowledgments This work was supported by the National Natural Science Foundation of China (grant numbers 30970549, 41101534, and 40971284) and the Ministry of Water Resources Public-spirited Special Research (grant number 201101049).

References

Alamusa, Jiang, D. M., Fan, S. X., & Luo, Y. M. (2002). Soil moisture dynamics under artificial Caragana microphylla shrub. *Chinese Journal of Applied Ecology, 13*, 1537–1540.

Cerny, T.A., Kuhns, M., Kopp. KL., et al. (2001). Efficient irrigation of trees and shrubs, All Archived Publications, 2002, Paper 742.

Congbin, F. (2003). Potential impacts of human-induced land cover change on East Asia monsoon. *Global and Planetary Change, 37*, 219–229.

Dawson, T. E. (1993). Hydraulic lift and water use by plants: implications for water balance, performance and plant-interactions. *Oecologia, 95*, 565–574.

Fan, Z. L., Ma, Y. J., Zhang, H. R., et al. (2004). Research of eco-water table and rational depth of groundwater of Tarim River drainage basin. *Arid Land Geography, 27*, 8–13.

Fan, Z. L., & Ma, Y. J. (2002). Assessment and prediction of developing trend of soil salinization of the cultivated land in west China. *Arid Land Geography, 25*, 97–102.

Guan, X., Li, Q. Y., Zhang, F. R., et al. (2003). Soil-forming conditions and gypsum accumulation in aridosols in the south of Xinjiang. *The Soil, 35*, 148–151.

Hendrick, R. L., & Pregitzer, K. S. (1992). Spatial variation in tree root distribution and growth associated with minirhizotrons. *Plant and Soil, 143*, 283–288.

Hiroyuki, T., & Hajime, S. (2007). Relationship between shelterbelt structure and mean wind reduction. *Agricultural and Forest Meteorology, 145*(3), 186–194.

Hillel, D., Van Beek, C. G. E. M., & Talpaz, H. (1976). A microscopic-scale model of soil water uptake and salt movement to plant roots. *Soil Science, 120*, 385–399.

Jia, B. Q., & Xu, Y. Q. (1998). The conception of the eco-environmental water demand and its classification in arid land—taking Xinjiang as an example. *Arid Land Geography, 21*, 8–12.

Li, X., & Yang, D. G. (2002). Analysis on the utilization efficiency of water resources in the upper reaches of Tarim River, Xinjiang. *Arid Area Research, 19*(1), 23–26.

Liu, S. C., Lv, J. L., Zhang, Y. P., et al. (2000). Study on relationship of water movement and thermodynamic function in unsaturated soil. *Acta Pedolggica Sinica, 37*(3), 388–395.

Lv, D. Q., Wang, J. Q., Wang, W. Y., et al. (2002). Evaluation of the soil salt distribution characteristics. *Acta Pedologica Sinica, 39*(5), 720–725.

Nasr Al-Amin, N. K., Stigter, C. J., & Mohammed El-Tayeb, A. (2006). Establishment of trees for sand settlement in a completely desertified environment. *Arid Land Research and Management, 20*, 309–327.

Qiu, Y., Fu, B. J., & Wang, J. (2001). Soil moisture in relation topography and land use in a hillslope catchment of the Loess Plateau, China. *Journal of Hydrology, 10*(3–4), 243–263.

Sang, Y. L. (1996). Formation properties and characteristics of alkalized soil in the Hetao irrigation district of Nei Mongol. *Acta Pedologica Sinica, 33*(4), 398–404.

Schroth, G. (1995). Tree root characteristics as criteria for species selection and systems design in agroforestry. *Agroforestry Systems, 30*, 125–143.

Thomas, R. R., Johnston, Kromm, D. E., et al. (2001). On-farm water conservation practices in southern Alberta. *Journal of the American Water Resources Association, 37*(3), 737–750.

Wendroth, O., Pohl, W., Koszinski, S., et al. (1999). Spatial temporal patterns and covariance structures of soil water status in two Northeast German field sites. *Journal of Hydrology, 215*(1–4), 38–58.

Zhao, X. F., Xu, H. L., Yan, J. P., et al. (2011). Impact of changes of irrigation pattern on salt-water dynamics of soils in farmland and its shelterbelt in the irrigated zone in the lower reaches of Tarim River. *Acta Pedologica Sinca, 48*(6), 1116–1124.

Zhou, Z. B., Xu, X. W., Lei, J. Q., et al. (2006). Ecological stability of Tarim Desert Highway shelterbelt. *Chinese Science Bulletin, 51*(supp.1), 153–160.