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Effects of straw mulch and buried straw on soil moisture and salinity in relation to sunflower growth and yield

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ABSTRACT

Salt accumulation in the root zone can be controlled by reducing the upward movement of salts and evaporation in arid areas of China. This paper aimed to examine the effects of the combined application of straw mulch and buried straw layer on soil moisture, soil salinity and growth of sunflower (*Helianthus annuus* L.) plants. A three-year field experiment was conducted in the Hetao Irrigation District, Inner Mongolia, China. Three field management practices were studied: deep tillage with no mulch (CK), deep tillage with straw mulch (SM) and combined application of straw mulch and burying of a maize straw layer (12 t ha^{-1}) at a depth of 40 cm (SM + SL). Except in the second half of the first growing season, soil moisture at the 0–40 cm depth was higher with SM + SL and SM than CK. Also the topsoil (0–20 cm) moisture during the early growth period under SM + SL was higher than that under SM by 1.6–9.9% in 2011 and 1.6–3.4% in 2013, but the value for SM + SL was 2.1–10.4% higher than that for SM during the whole growth period of 2012. Compared with SM, the topsoil salinity under SM + SL decreased by 5.4–23.0% in 2011, 0.7–19.8% in 2012 and 4.5–31.6% in 2013 but these two mulch treatments moderately increased the soil salinity in the subsoil (20–40 cm) layer compared with CK. Furthermore, SM + SL promoted sunflower growth, as indicated by taller plants and greater leaf area index. The highest sunflower shoot biomass was always obtained from the SM + SL treatment. Averaged across the three years, SM + SL increased the shoot biomass by 4.8% compared to SM and 20.8% compared to CK. The SM + SL may be an effective saline soil management practice in the Hetao Irrigation District and other similar ecological areas.

1. Introduction

Salinity has severely restricted global agriculture in arid and semiarid regions. At present, this stress is becoming even more prevalent as the intensity of land use increases throughout the world (Meloni et al., 2003; Dong et al., 2008, 2009). The Hetao Irrigation District, located in northwestern China, has an irrigated land area of 570,000 ha, and approximately half of the irrigated cropland is saline soil (Feng et al., 2005). Irrigation through Yellow River water plays an important role in crop production and agricultural development in this area. To reduce soil salinity and increase crop yields, flood irrigation has always been used. However, inappropriate irrigation and drainage systems have resulted in rising groundwater levels, which have the potential to trigger salt accumulation in the soil profile and have a negative effect on crop production (Sharma and Minhas, 2005; Qadir et al., 2009). In addition, limited precipitation, high evaporation and inadequate soil and water management have contributed to an increase in salinity. Therefore, effective techniques for controlling soil salinity and increasing water productivity should be developed to cope with these challenges (Dong et al., 2010a,b).

Sunflower (*Helianthus annuus* L.) is one of the most important economic crops in this area. Although sunflowers are classified as a salt-tolerant crop, they are also sensitive to salinity in the growth and development stages, especially during the emergence and early seedling stages. Reducing root zone salinity is one beneficial strategy to improve sunflower emergence and stand establishment in saline fields. Under conventional tillage regimes, several techniques, such as inorganic fertilisers, soil amendments, and mulching with different materials, have been used to increase sunflower yields (Qadir et al., 2000; Chen and Dong, 2008). However, these field practices have always followed abundant water input. Conversely, mismanagement of fertiliser and water applications results in salt accumulation (Darwish et al., 2005). The sunflower root system is dense in the upper 20 cm of the soil layer, with a trend toward rooting downward (Hu et al., 2013). Therefore, maintaining soil salinity levels within acceptable crop production limits in this

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layer should be the primary goals of soil and water management (Bezborodov et al., 2010).

Mulching with different materials has been demonstrated to reduce water evaporation (Li et al., 2013; Pabin et al., 2003), improve fallow efficiency and increase the amount of stored soil water available for plant use (Wang et al., 2001), and reduce salt build-up in the soil (Pang et al., 2010). Based on field experiments, Mulumba and Lal (2008) reported that crop residues placed on the soil surface shade the soil, reduce unproductive water evaporation, and enhance available water capacity, moisture retention and aggregate stability. Deng et al. (2006) reported that mulching with crop residues improved water-use efficiency by 10–20% as a result of reduced soil evaporation and increased plant transpiration. Carter (1998) observed that mulching results in higher soil moisture during the entire crop growth period and provides the best opportunity for increasing crop productivity. Havlin et al. (1990) and Lal and Stewart (1995) showed that returning crop residues to the soil has a beneficial effect on building soil organic carbon, which thereby improves soil quality and productivity.

A deeply buried straw layer in the soil serves as a water and salt transport barrier, inhibiting the movement of salts from the subsoil and shallow groundwater to the topsoil during the water evaporation process (Chi et al., 1994; Tumarbay et al., 2006). Based on field study results, Zhang et al. (2009) and Li et al. (2012) reported that straw layer burial enhanced salt leaching and controlled salt accumulation in the root zone. Other benefits of burying a straw layer deep in the soil have also been reported by other researchers, such as a reduction in soil pH, a decrease in particle density and improvement in plant earliness (Fan et al., 2012; Zhao et al., 2003). In addition, the straw layer burial promoted soil physical and chemical properties (Yang and Chen, 2000; Wang et al., 2012; Li et al., 2009).

Most previous works have concentrated on the beneficial effects of the individual use of straw mulch or buried straw layer on soil moisture, salinity and crop production. However, studies have rarely addressed the effects of combining straw mulch and straw layer burial on soil moisture and salinity dynamics and crop growth in saline soils. Currently, tillage machine for burying straw layer have been designed and are widely used in China (Wang et al., 2011; Zhao et al., 2013). Thus, the main objective of the study was to determine the effects of combining straw mulch and buried straw layer on soil moisture and salinity dynamics as well as sunflower growth and yield.

2. Materials and methods

2.1. Experimental area

Field experiments were conducted from October 2010 to September 2013 at the experimental station of the Management Department of Yichang Irrigation Sub-district (41°04′N, 108°00′E, 1022 m ASL) in the Hetao Irrigation District, Inner Mongolia, China. The study area has a typical arid continental climate that is very cold in the winter with little snowfall and very dry in the summer with little rainfall. The mean annual precipitation in the region is approximately 170 mm, occurring mainly between July and August. The mean annual evaporation is approximately 2068 mm, being 11 times the value of annual rainfall. The annual average temperature is 8.1 °C, with monthly averages ranging from 23.76 °C in July to 10.08 °C in January (Wu et al., 2008). The groundwater table at this site varied from 1.2 to 2.6 m, with a salt concentration ranging from 1.5 to 1.8 g L^{-1}. The soil texture is silt loam with severe salinization. The main physico-chemical properties of the pre-experiment soil are presented in Table 1.

Table 1
Soil properties of the pre-experimental soil in the study site collected at 0–40 cm depth.

Soil properties	Soil depth (cm)			
	0–10	10–20	20–30	30–40
Sand (%)	34.09	35.75	36.22	37.38
Silt (%)	51.92	53.76	53.46	55.38
Clay (%)	13.99	10.49	10.32	7.24
Bulk density (g cm^{-3})	1.45	1.47	1.49	1.47
Organic matter (g kg^{-1})	11.06	10.63	8.21	6.94
Available N (mg kg^{-1})	35.62	31.91	30.33	29.68
Available P (mg kg^{-1})	6.36	2.03	1.03	0.88
Available K (mg kg^{-1})	161.29	115.12	98.24	80.37
Salinity (g kg^{-1})	4.87	2.54	2.26	2.04
pH (H_2O, 1:5)	8.77	8.53	8.41	8.32
SAR	6.28	3.82	3.23	3.05

2.2. Experimental design and implementation

The experiment included three treatments: (i) deep tillage with no mulch (CK), (ii) deep tillage with straw mulch (SM), and (iii) combined application of straw mulch and burying of a straw layer at a depth of 40 cm at the beginning of the experiment (SM + SL). The treatments were arranged into a randomized complete block design with three replications. Each plot measured 4 m^2 (2 m × 2 m), and they were insulated by double-plastic sheets buried to a 100 cm depth relative to the soil surface to minimize the effects of lateral water and salt movement between plots. Each plot was surrounded by a concrete panel 40 cm wide and 60 cm high, and the exposed part of panel (approximately 20 cm) was hardened by cement.

After sunflowers were harvested in early October 2010, the upper 40 cm of soil in the SM + SL plot was removed at intervals of 20 cm depth by spade and placed in different positions, and then, the air-dried and chopped maize straw (10–15 cm) was uniformly placed on the bottom to a thickness of approximately 5 cm (equal to 12 t ha^{-1}). To guarantee the consistency of test conditions, the upper 40 cm of soil in the CK and SM plots was also dug out as performed in the SM + SL plot, but no straw layer was imposed. Based on the initial soil bulky density, the dug soil of each plot was refilled layer-by-layer and then flattened with a harrow. Afterward, the plots were flood irrigated with Yellow River water in later October (with a salt concentration approximately 0.58 g L^{-1}). For each plot, approximately 0.6 m^3 of water was applied. The straw layer burying operation was done once at the beginning of the experiment, and no straw layer was laid in the subsequent years.

To leach soluble salts for sunflower germination in each growing season, a second irrigation (0.6 m^3 $plot^{-1}$) was applied approximately 10 d before sowing. Considering the severely dry climate in 2011, the plots were covered completely with plastic film to reduce water loss by evaporation after spring irrigation until sowing. At sowing, the plots were ploughed to a depth of 15–20 cm and harrowed by hand when the mellowness of soil was physically acceptable. According to the local fertiliser practice, a compound fertiliser was applied at 180 kg ha^{-1} N (using urea (46% N) plus DAP (diammonium phosphate, 18% N and 46% P_2O_5)), 120 kg ha^{-1} P_2O_5 (using DAP) and 75 kg ha^{-1} K (using potassium sulphate, 50% K_2O). After fertiliser application, the soil surface was leveled.

Sunflower was planted with a row spacing of 60 cm at a density of 49,000 plants per hectare. The sunflower cultivar LD 5009 was manually sown on 28 May 2011, 8 June 2012 and 2 June 2013. For the SM and SM + SL plots, approximately 6 t ha^{-1} of air-dried and chopped maize straw (10–15 cm) was evenly applied to the inter-rows of sunflower after sowing. Neither irrigation nor fertilization was applied throughout the growing season. Sunflowers were harvested on 23 September 2011, 18 September 2012 and 16

September 2013, respectively. After harvest, the sunflower stalks were removed, and the remaining maize straw was ploughed into the soil to a depth of 15–20 cm. This was followed by flood irrigation using the same pre-sowing water volume per plot. Other management practices were conducted according to local agronomic practices.

2.3. Soil sampling and measurements

Weather data were obtained from the weather station at the experimental site. During the sunflower growing season, the soil water content was measured gravimetrically at 0–5, 5–10, 10–20, 20–30 and 30–40 cm depth at 15 day intervals, and to a depth of 100 cm at 20 cm increments below the 40 cm depth at sowing each year. Sampling was delayed 1–2 days if there was rainfall on sampling day. Soil sampling points were chosen from one of the two plant rows per plot. All the collected samples were ground fine enough to pass through a 2 mm sieve and were analyzed for salt contents. Soil salinity was measured by an extraction ratio of 1:5 ($EC_{1:5}$) method. Salt concentrations inferred from measured electrical conductivity values were converted to salt content on per cent basis using the method described in Pang et al. (2010).

2.4. Growth parameters

Plant growth parameters were recorded at different stages; three plants were randomly chosen to measure plant height and leaf area. The leaf area was assessed by multiplying leaf length by the greatest width and applying a correction factor (0.68) according to Girbhar (1989). The sum of the total green leaf area was used to determine leaf area index (LAI), based on the number of plants in the plot. After harvest, total above ground biomass was determined gravimetrically after oven drying, at 105 °C for 30 min initially and then at 65–75 °C for 48 h (Zhang et al., 2011).

2.5. Data analysis

All data within each individual year were analyzed using the analysis of variance (ANOVA) procedure to test the effects of the treatments on the measured parameters. Mean comparisons were performed using the Fisher's LSD (the least significant difference) test at $P < 0.05$. The analysis was conducted using the SPSS program.

3. Results

3.1. Weather conditions

The daily precipitation figures during the sunflower growing seasons in the three years are given in Fig. 1. The precipitation patterns of the seasons were different. Precipitation during the sunflower growing periods amounted to 54.5 mm in 2011, 238.6 mm in 2012 and 64.8 mm in 2013. The second growing season was wetter than the other two seasons. In addition, the precipitation distribution was significantly different over the three growing seasons, e.g., much more rain fell during 20–70 days after sowing (DAS) in 2012 than in 2011 and 2013.

Air temperature also varied greatly among the three growing seasons (Fig. 1). In the first season, the mean daily air temperature was in the range 13.4–27.0 °C, averaging 20.6 °C. In the second season, it was 7.2–26.1 °C, averaging 19.8 °C and in the third season, it was 12.2–27.2 °C, averaging 20.3 °C. The average atmospheric temperature each season was higher during the early vegetative stage than the later ripening stage, especially in 2012. The differences in precipitation and air temperature between the three experimental seasons would be expected to affect sunflower growth.

3.2. Dynamics of soil moisture

Soil water content dynamics within the 0–40 cm depth showed substantially different patterns with large variations during the three growing seasons (Fig. 2). In 2011, the soil water content in the top 0–20 cm layer at sowing was 12.4% and 5.5% higher under SM + SL than under CK and SM. During the early growing season, both the SM and SM + SL treatments had significantly more soil water than CK, whereas the reverse occurred during the later period (Fig. 2a). Compared to SM, SM + SL increased the soil water content at the 0–20 cm soil layer by 1.6–9.9% before 66 DAS, but it decreased it by 0.8–5.8% thereafter. A similar trend was observed in the 20–40 cm soil layer (Fig. 2b).

In 2012, the patterns of soil water content in the 0–20 cm and 20–40 cm layers were similar throughout the growing season. The topsoil moisture of SM + SL at sowing was 4.8% and 3.6% higher than those of SM and CK. During the sunflower growing season, SM and SM + SL invariably retained more water than CK, but significant differences among the treatments were observed only in the 20–40 cm soil layer in the early periods of the season (Fig. 2d). SM + SL increased the soil water content at the 0–20 cm layer by 2.1–10.4% when compared with SM. At 61 DAS, the soil water content increased dramatically across treatments, particularly in the top 0–20 cm layer (Fig. 2c) because a large rainfall (79.4 mm) was received during those 15 d. Thereafter, the soil water content fell dramatically and then changed moderately during the later growth period.

In 2013, the soil water content before 31 DAS was 1.6–3.4% and 8.2–9.6% higher under SM + SL than under SM and CK and the differences were significant only between the SM + SL and CK treatments (Fig. 2e). At 44 and 62 DAS, the soil water content in the top 0–20 cm layer decreased across treatments because of little rain from 15 to 60 DAS (Fig. 1c). Consequently, soil moisture under SM + SL was lower than under SM but higher than under CK. Thereafter, SM + SL had 2.3–7.0% and 10.1–14.2% higher soil water content than SM and CK until harvest. In the 20–40 cm soil layer, the level of soil moisture was always higher under SM + SL than those under SM and CK, although there was a decrease in water content in the middle growth stage (Fig. 2f).

3.3. Dynamics of soil salinity

Changes in salt content within the 0–40 cm depth among treatments during the three growing seasons are shown in Fig. 3. In 2011, the topsoil salinity at sowing was 24.2% and 15.9% lower under SM + SL than under SM and CK. After that, the salt content in the top 0–20 cm layer generally increased up to harvest, especially under CK (Fig. 3a). In this layer, SM + SL decreased the salinity by 5.4–23.0% relative to SM and 12.1–56.4% relative to CK. SM also decreased the salt content by 1.1–43.4% when compared with CK, throughout the growing season. However, the subsoil (20–40 cm) salinity was higher under SM + SL and SM than that under CK, except for a slightly lower value recorded under SM + SL than under CK in the early growth stage (Fig. 3b). The highest level of salinity in the 20–40 cm soil layer was always obtained from the SM plots.

In 2012, the changes in salt content in the top 0–20 cm layer were small across treatments (Fig. 3c). During the growing season, SM + SL and SM invariably exhibited a lower soil salt content than CK, and the difference between SM + SL and CK treatments was significant. The SM + SL treatment decreased the top soil salt content by 0.7–19.8% compared to SM and 12.6–35.9% compared to CK. In the 20–40 cm soil layer, the levels of salinity at sowing also decreased remarkably under SM + SL but increased significantly relative to the levels in SM and CK plots (Fig. 3d) after sowing. However, SM consistently increased the salt content as compared with CK.

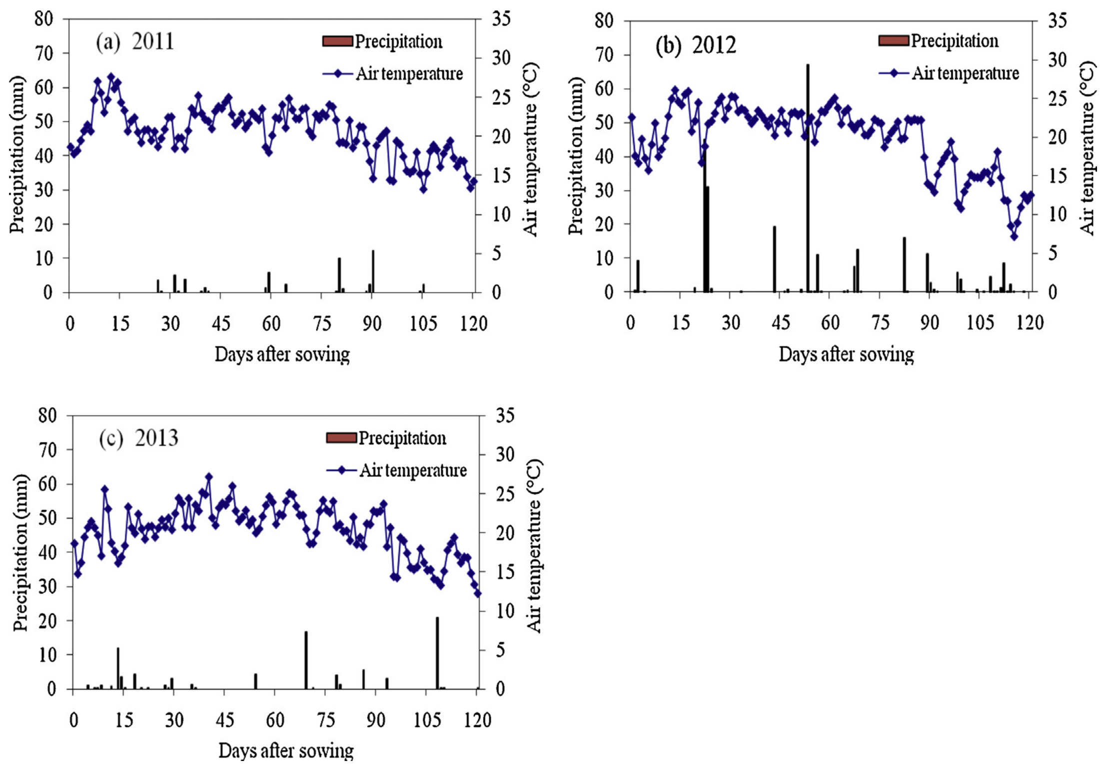

Fig. 1. Variations in daily precipitation and air temperature during the growing period of sunflower in 2011 (a), 2012 (b) and 2013 (c).

In 2013, the salt content in the top 0–20 cm layer increased gradually from sowing until it peaked at 62 DAS, and then decreased up to harvest (Fig. 3e). In this layer, SM + SL decreased the salt content by 4.5–31.6% relative to SM and 24.2–52.6% relative to CK. The salt content also effectively decreased (4.9–38.2%) under SM as compared with CK throughout the growing season. Likewise in 2012, SM + SL had a higher salt content in the subsoil layer (20–40 cm) than either SM or CK, except at sowing and 62 DAS (Fig. 3f). However, the trend was not consistent with the last two years in which the salt content in the 20–40 cm layer was remarkably lower under SM than under CK throughout the growing season.

3.4. Plant height and leaf area index

The changes in sunflower height during the three growing seasons are presented in Fig. 4. For each season, plants were much taller under mulched treatments (SM + SL and SM) than that under the non-mulched treatment (CK). Between the mulched treatments, plants under SM + SL remained consistently taller than those under SM throughout the growing season. The difference in plant height either between the mulched and non-mulched treatments or between the mulched treatments was significant in the later growth periods but not in the early growth stages.

The leaf area index (LAI) increased gradually with increasing plant height (Fig. 5) and the value was higher under mulched than under non-mulched plots throughout the growing season. Between the two mulched plots, the LAI was always higher under SM + SL than under SM. Generally, the difference in LAI among treatments was larger during the middle stages than the early and later stages of sunflower development.

3.5. Shoot biomass

The shoot biomass of sunflower varied significantly with the applied treatments (Table 2). The biomass under SM and SM + SL treatments was always higher than that under CK and the differences were significant only between the SM + SL and CK treatments. For each year, the highest biomass was obtained from the SM + SL treatment. Averaged for the three years, SM + SL increased the shoot biomass by 4.8% compared to SM and 20.8% compared to CK.

Table 2
Shoot biomass (kg ha^{-1}) as affected by CK, SM and SM + SL treatments during three sunflower growing seasons (2011, 2012 and 2013).

Treatment	2011	2012	2013	Mean
CK	6684b	10403b	13419b	10168b
SM	7761ab	11664ab	15753ab	11726ab
SM + SL	8103a	12229a	16532a	12288a

Values within a column followed by the same letter are not significantly different (LSD, $P < 0.05$).

4. Discussion

Proper field management practices can improve soil conditions, such as soil water and thermal status (Kouwenhoven et al., 2002; Mohler and Callaway, 1995), which play an important role in crop development and growth. With a lack of timely precipitation plus salinity stress under arid or semi-arid conditions, field management practices should attempt to increase soil water retention, reduce unproductive water losses from the soil surface, and maintain soil salinity levels in the root zone (Bezborodov et al., 2010; Dong et al., 2009, 2010b). Surface mulching shades the soil (Huang et al., 2005), preventing soil water loss by evaporation and thus helping to retain moisture (Sauer et al., 1996; Mulumba and Lal, 2008). As expected, the mulched treatments significantly and consistently increased soil water content at the 0–40 cm depth during the growing seasons of 2012 and 2013 (Fig. 2c–f). However, a lower soil water content was observed for the mulched treatments in the later growth period of 2011, particularly under the SM + SL plots (Fig. 2a and b). This was mainly because the mulched treatments promoted sunflower

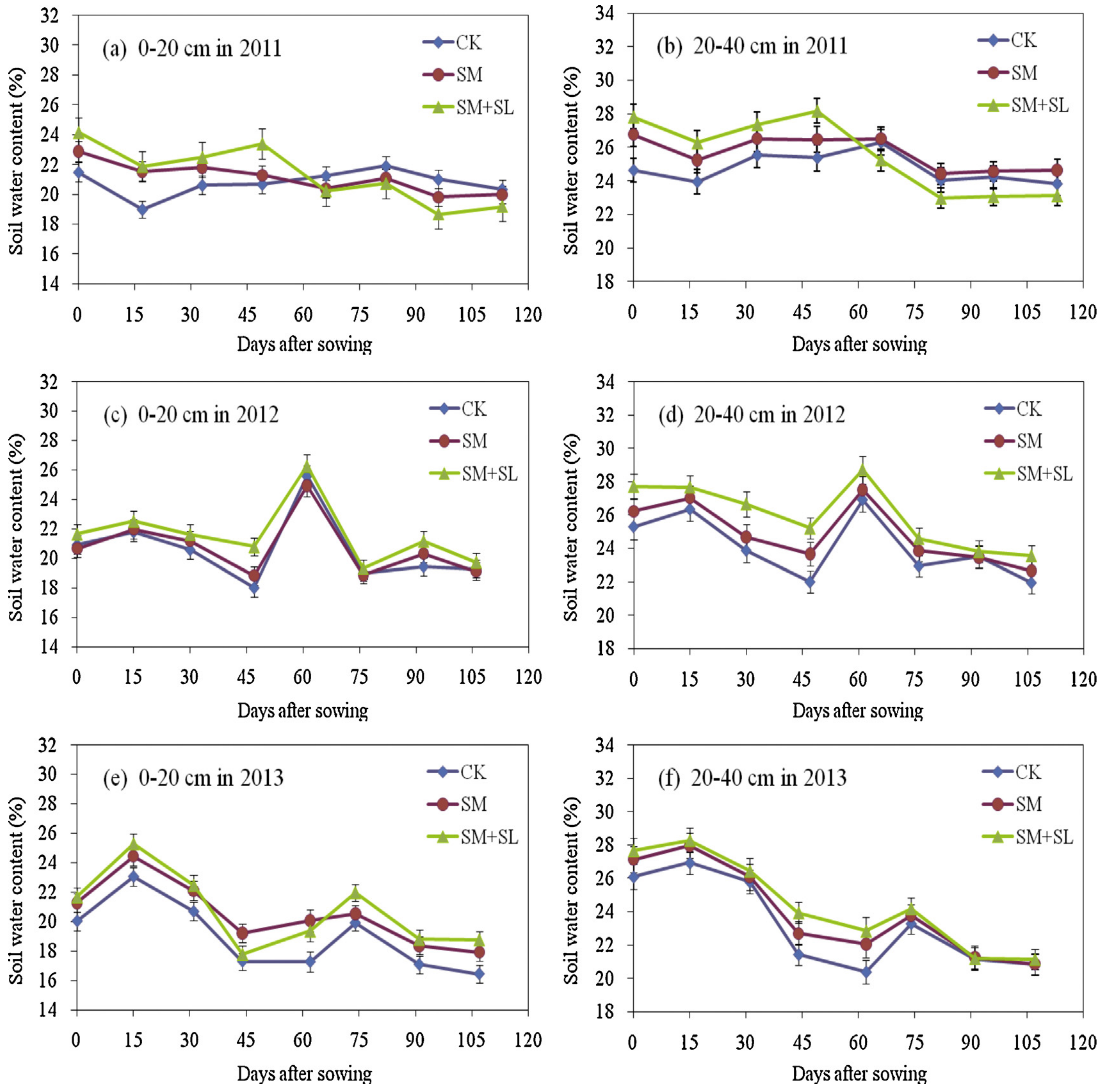

Fig. 2. Soil water content in the soil layers of 0–20 cm and 20–40 cm under CK, SM and SM + SL treatments during three sunflower growing seasons: 2011, 2012 and 2013. CK: deep tillage with no mulch; SM: deep tillage with straw mulch; SM + SL: combined application of straw mulch and straw layer burial. Values are means of three replicates ± standard deviation.

development and thus the greater consumption of soil water led to lower soil water storage (Zhang et al., 2011). On the other hand, the effectiveness of straw mulch in reducing evaporation weakens with natural decomposition. In addition, there was little rainfall, and increased plant growth led to higher transpiration rates, further accounting for the reduced soil water content in the later growth period of the first season.

Between the mulched treatments, the SM + SL treatment had substantially more soil water than SM at the 0–40 cm depth during the sunflower growing season, except for a slight low in the later period of the first season and the middle period of the third season (Fig. 2). The increase in soil moisture can be attributed to better water retention as burying a straw layer in the soil retards the infiltration speed of surface water after irrigation (Qiao et al., 2006a; Cao et al., 2012). In our experiment, the distribution of soil water in the soil profiles at sowing showed that straw layer burial increased soil moisture in the upper 40 cm depth (Fig. 6). This finding indicates that straw layer burial enhanced the water storage capacity in the root zone. Ji and Unger (2001) also showed that straw mulching could increase soil moisture storage. The integrative effect of straw mulching and straw layer burial on soil water retention was better than the single use of straw mulch. However, it should be noted that the water supply from deep soil layers was limited under the SM + SL treatment as the soil capillary was cut off by the straw layer (Chi et al., 1994; Qiao et al., 2006b). Consequently, a lower soil water content was observed for SM + SL in the later growing period of 2011 (Fig. 2a and b). Fortunately, the buried straw layers can conserve more rainwater because of lower water infiltration, which thus helped to alleviate insufficient soil water after rainfall events. Particularly in 2012, the abundant rainfall helped to increase soil moisture and thus a higher water content was recorded under SM + SL than under SM throughout the sunflower growing season. However, in light of the depletion in soil water during the late growth period of an exceptionally dry cropping year, further studies are needed to investigate the effects of supplemental irrigation on growth stages as well as water regimes for crop growth.

In saline fields, the control of root zone salinity is considered beneficial to seed emergence and stand establishment (Meiri and Plaut, 1985; Dong et al., 2010a,b). Previous studies have shown that straw mulching is a promising technique for salinity control in agriculture (Bezborodov et al., 2010; Deng et al., 2003; Pang et al., 2010). In our experiment, a consistently lower salt content in the 0–20 cm soil layer was recorded for the mulched treatments

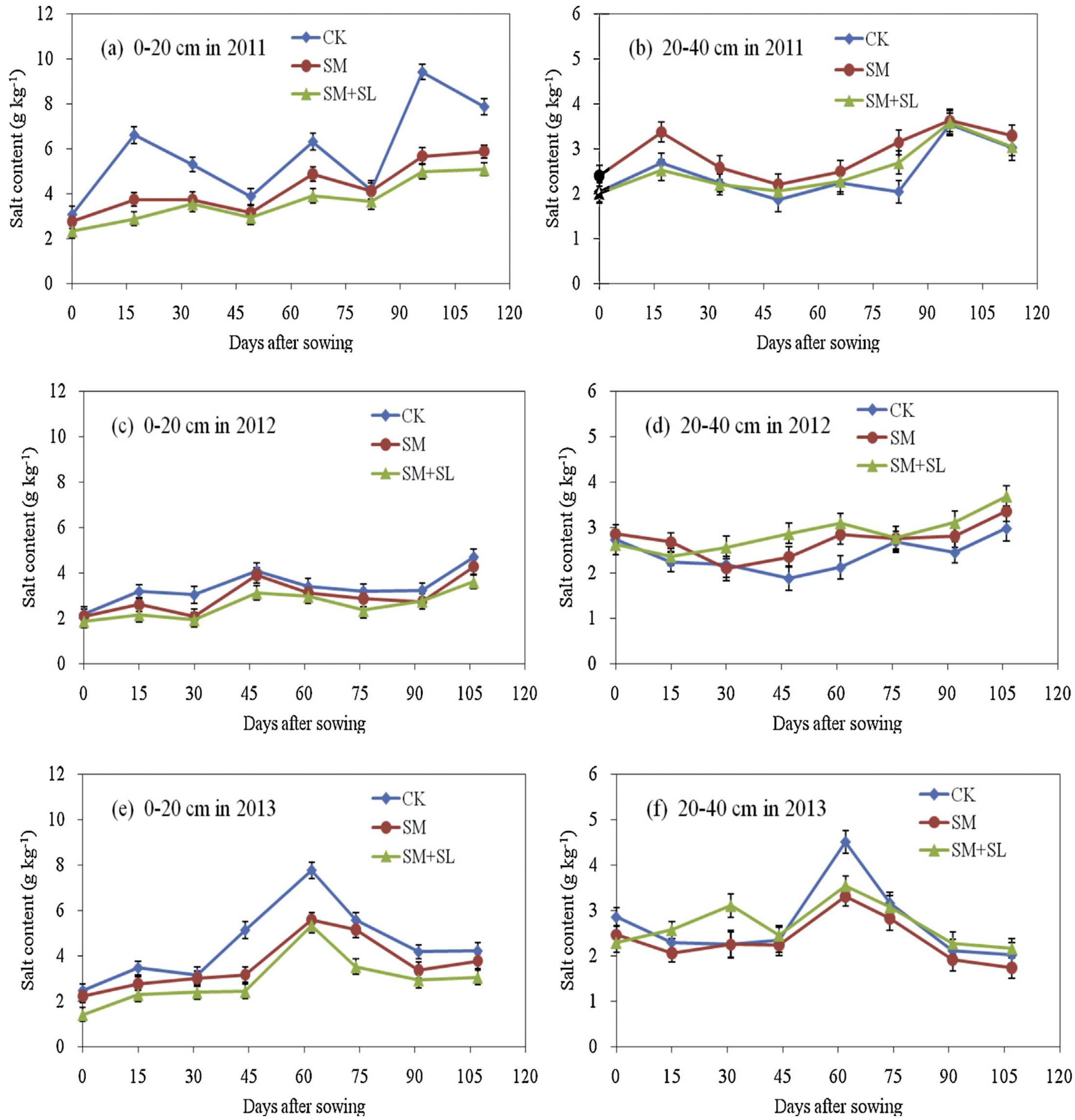

Fig. 3. Salt content in the soil layers of 0–20 cm and 20–40 cm under CK, SM and SM + SL treatments in three sunflower growing seasons: 2011, 2012 and 2013. CK: deep tillage with no mulch; SM: deep tillage with straw mulch; SM + SL: combined application of straw mulch and straw layer burial. Values are the means of three replicates ± standard deviation.

than non-mulched treatment, whereas the reverse occurred in the 20–40 cm layer except in 2013 (Fig. 3). This might be attributed, in part, to the fact that straw mulch can efficiently conserve water that has hindered run off and infiltrated into the soil profile (Deng et al., 2003; Li et al., 2013), and thus, the salts accumulated in the topsoil would be washed to deeper soil layers.

In this experiment, the topsoil salinity was invariably lower under SM + SL than under SM (Fig. 3) because straw burial improved the salt leaching efficiency during the water infiltration process (Zhang et al., 2009). Since soil moisture storage capacity helped to promote ion exchange and absorption and increased the total dissolved salts (Feng et al., 2000), the straw layer burial treatment resulted in lower salt content than the control in the upper 40 cm depth at sowing (Fig. 7). In addition, the straw layer served as a barrier against salt accumulation in topsoil during the evaporation process (Qiao et al., 2006b). As the soil capillarity was broken in the straw layer burial plots, the evaporation from phreatic water may be reduced, and thus the rise to the topsoil of salts dissolved in the groundwater and/or in deep soil layer was prevented (Tumarbay et al., 2006; Guo et al., 2006). Our recent study further confirmed that the straw layer burial treatment reduced the salt content of the topsoil by 9.87% under continuous infiltration and decreased the cumulative evaporation by 75.07–95.42% during successive evaporation for 30 days (Zhao et al., 2013). In addition, a combination of straw mulch could significantly reduce soil water loss by evaporation from the soil surface (Li et al., 2013), augmenting available soil water (Anikwe et al., 2007; Liu et al., 2010) and thus decreasing salt accumulation. The present results also indicated that the combined application of straw layer burial and straw mulch better reduced salt accumulation in the root zone than the individual use of straw mulch.

In our experiment, a higher soil moisture and lower soil salinity stimulated sunflower growth, as indicated by taller plants with higher leaf area index under the mulched treatments than under the non-mulched treatment (Figs. 4 and 5). The SM + SL treatment was better than the SM treatment in improving sunflower growth and biomass accumulation because it created a more conducive edaphic environment for plants. Rainfall is one of the most important supplemental sources for soil water; the salts that accumulate in the topsoil can be washed out by rainwater (leaching) during the

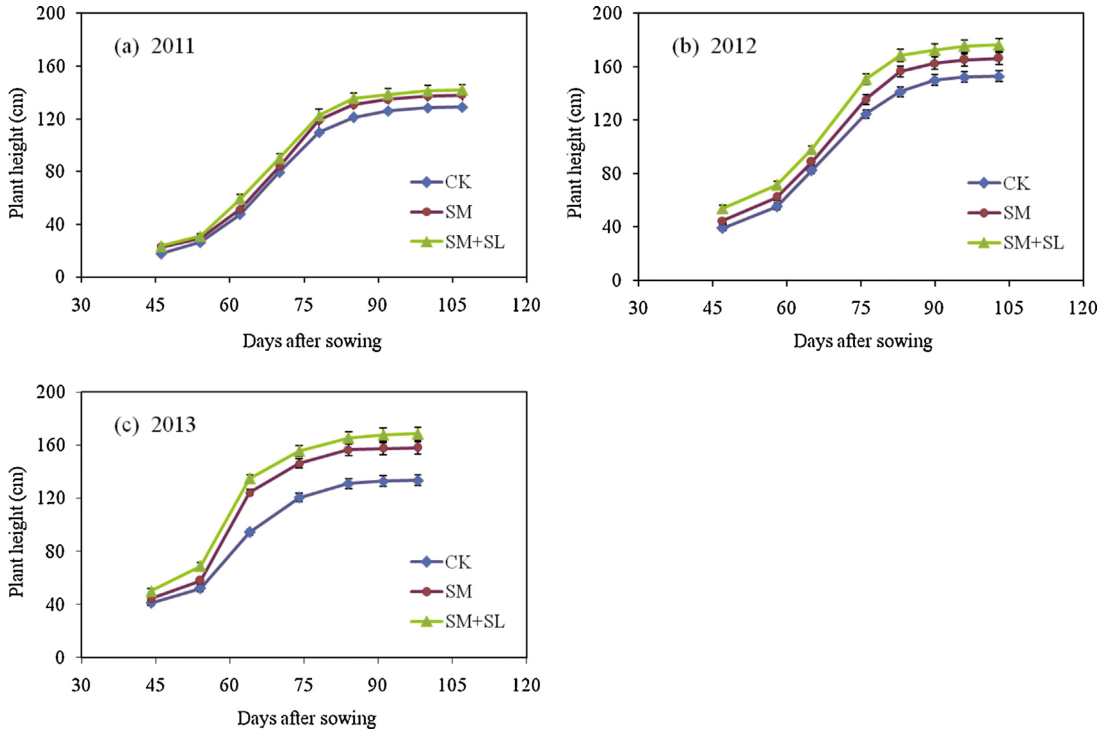

Fig. 4. Changes in plant height under CK, SM and SM + SL treatments during three sunflower growing seasons (2011, 2012 and 2013). CK: deep tillage with no mulch; SM: deep tillage with straw mulch; SM + SL: combined application of straw mulch and straw layer burial. Values are the means of three replicates ± standard deviation.

growing season (Jia et al., 2006). We observed that both the plant height and leaf area index of sunflower were higher in 2012 than in 2011 (Figs. 4 and 5), possibly due to the considerably lower rainfall in 2011 which led to severe drought stress for plants. In contrast, the abundant rainfall for the entire 2012 growing season allowed normal growth. In addition, returning straw to soil increased the soil organic matter and reduced soil bulky density, thereby improving soil porosity and aeration (Lal and Stewart, 1995; Duiker and Lal, 1999; Tejada et al., 2008), which supported the formation of larger water stable aggregates, and then increased biopores spaces

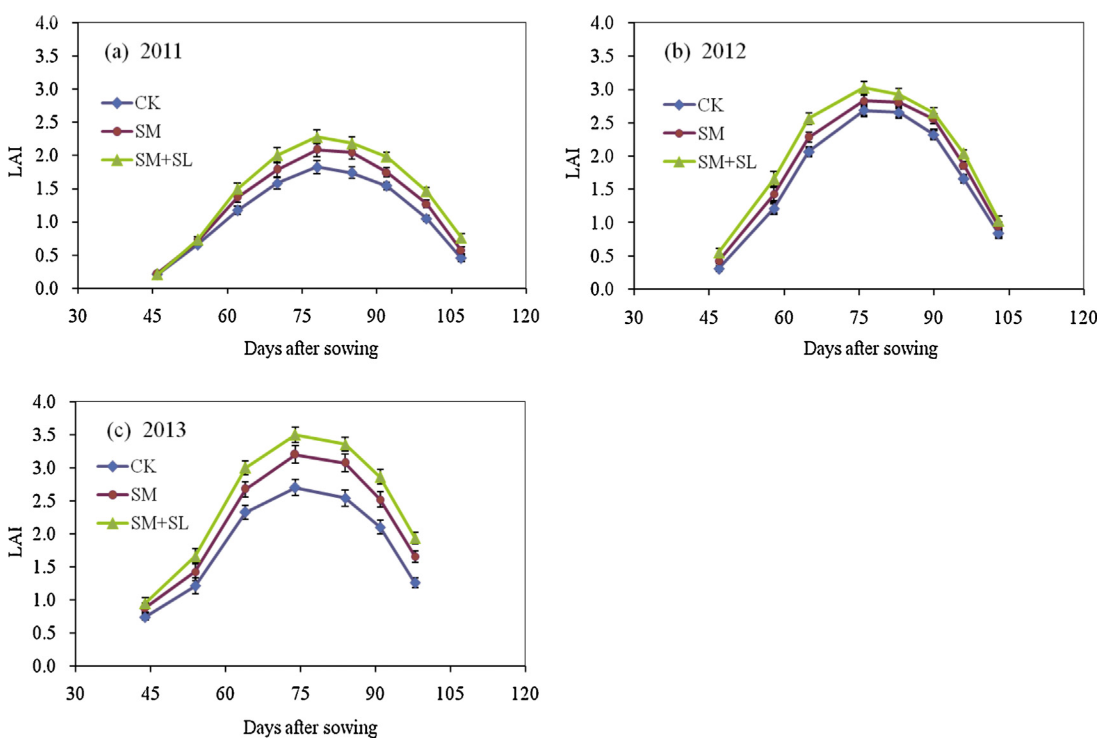

Fig. 5. Changes in leaf area index (LAI) under CK, SM and SM + SL treatments during three sunflower growing seasons (2011, 2012 and 2013). CK: deep tillage with no mulch; SM: deep tillage with straw mulch; SM + SL: combined application of straw mulch and straw layer burial. Values are the means of three replicates ± standard deviation.

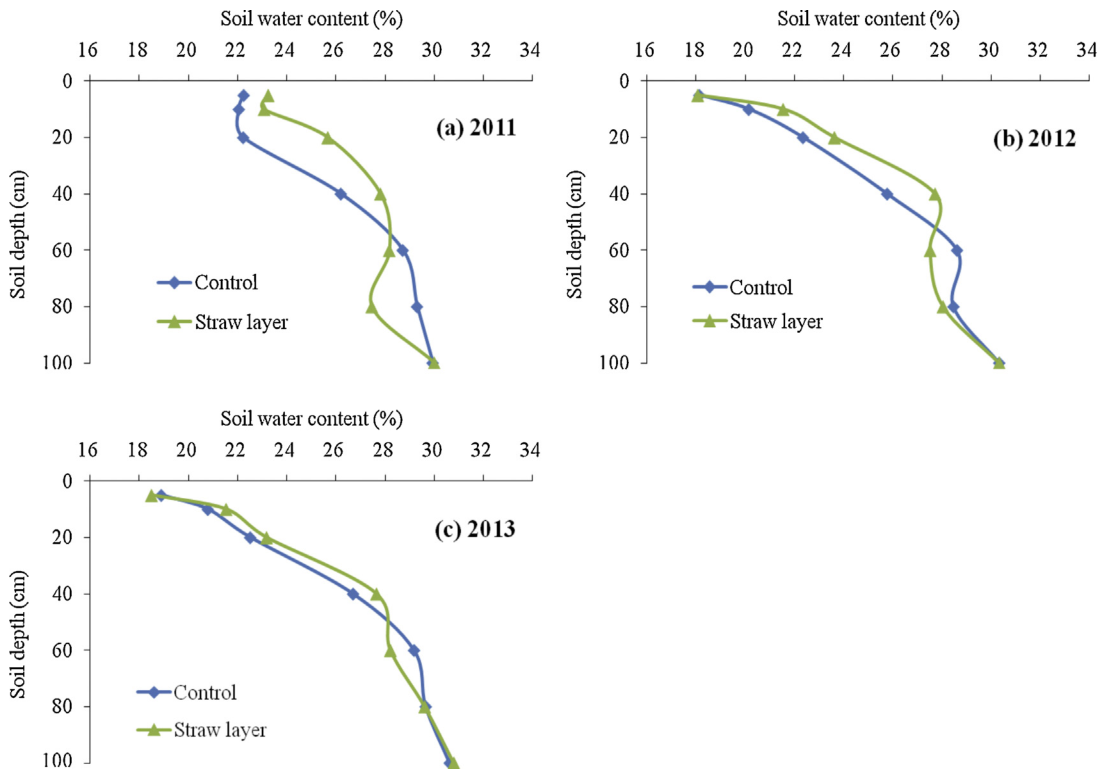

Fig. 6. Dynamics of soil water at sowing in 2011(a), 2012(b) and 2013(c).

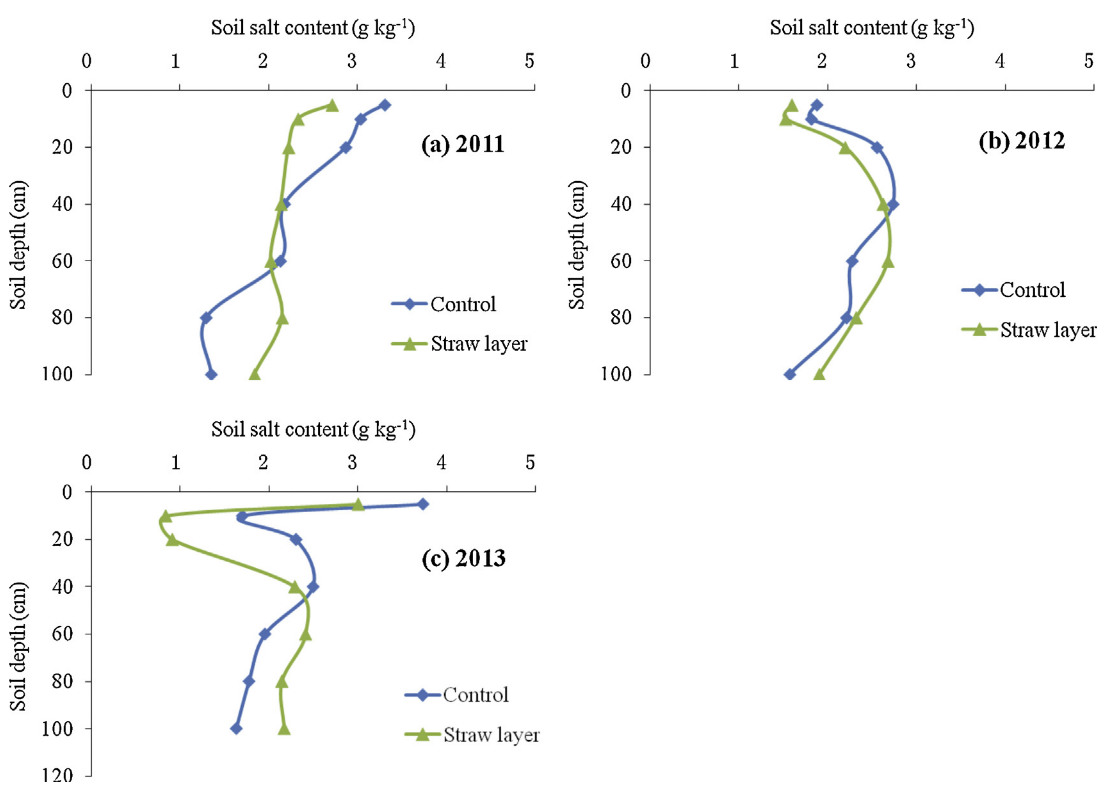

Fig. 7. Dynamics of salt content in the soil profile at sowing in 2011(a), 2012(b) and 2013(c).

that improve the growth of plants (McConnell et al., 1993; Rasool et al., 2008). Therefore, the sunflower growth parameters and shoot biomass in 2013 were greater than in 2012, regardless of the lower rainwater received.

5. Conclusions

Based on this three-year field experiment conducted in the saline soils of Hetao Irrigation District, Inner Mongolia, China, it can be concluded that the combined application of straw mulch and buried straw layers had significant effects on soil moisture and salinity dynamics and sunflower growth. Throughout the three growing seasons, the combination of straw mulch with buried straw layer considerably increased the soil moisture at the 0–40 cm depth, except in the later growing period of the first season and significantly decreased the salinity of the topsoil layer (0–20 cm). Higher soil moisture and lower salinity in the root zone promoted sunflower growth. Over the three years, the highest sunflower shoot biomass was always obtained from the plot with straw mulch and straw layer burial. Accordingly, the combined application of straw mulch and buried straw layer may be a better field-management option for sunflower production in saline soils. It should be noted that the conclusions of this study were based on three years of investigation. To maximize the beneficial effects of straw mulching and straw layer burial, further studies should be conducted.

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