



Ecological effects of salinization on soil physico-chemical characteristics and dry matter partitioning in arid region of Northwestern China

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ABSTRACT

The research aimed to quantify the change processes of soil physico-chemical characteristics and partitioning of dry matter in alfalfa and barley in farm salinization in saline area of Northwestern China. The experiment was carried out by taking different salinization stage plots under *Hordeum vulgare* L. and *Medicago sativa* L. grown fields as the study objects, and by using the method of replacing time with space. Results were as follows: 1) Compared to non-saline plot, soil bulk density was increased by 3.00%, 4.54%, 8.62% and 9.96%, respectively in slightly, moderately, severely and very severely salinized plot in alfalfa grown field, whereas for barley grown field, the change of soil bulk density had no obvious trend in corresponding salinized gradient plots. Soil temperature of different salinized gradient plots in alfalfa grown field showed a low-high-low fluctuation, while that of barley grown field was increased. In the two farmlands, soil organic matter and alkali-hydrolyzable nitrogen were all significantly decreased, and the rate of decrease were faster in soil depth of 0-10 cm than that in soil depth of 10-20 cm, but soil organic matter and alkali-hydrolyzable nitrogen in alfalfa grown field was in the following order: slightly salinized plot (S1)>non-saline plot (CK)>moderately salinized plot (S2)>severely salinized plot (S3)>very severely salinized plot (S4); for barley, it was in the following order: CK>S1>S2>S3>S4, and there had different significant difference between different salinized plots under the two farmlands; 2) In growing seasons, different salinization gradient plots had different soil depths of salt accumulation and appearing the peak of average soil EC_p under the two crops farmlands. In the composition of soil soluble salt ions and ratio, the same salinized gradient plots between the two crops farmlands were similar; but in alfalfa grown field, the ratios of Cl⁻ and Na⁺+K⁺ in CK and S1 were significantly lower than that of CK and S1 in barley grown field, and the change ranges of different ions from CK to S4 were higher than that of barley; 3) In dry matter accumulation and distribution traits, at any given growth stage, along salinization gradient increased, plant total dry matter was more distributed to leaves and roots and center of accumulation and distribution of dry matter in the plant in different salinization gradients was gradually slowly than CK plant. And salt stress made the dry matter partitioning ratio of total shoot of the two crops be gradually reduced and root/shoot ratio increased.

Key words: Dry matter partitioning, Ecological effect, Field conditions, Method of replacing time with space, Salinization process

Soil salinization is a serious problem in arid and semiarid zones of the world (Shi and Wang 2005, Yang *et al.* 2011). Salt tend to accumulate in the upper soil profile, especially when an intense evapotranspiration is associated to an insufficient leaching (De Pascale and Barbieri 1997). The addition of salt to the soil alters its physico-chemical properties, including soil structure and hydraulic conductivity. Excessive exchangeable sodium and high pH reduced soil permeability and infiltration capacity through swelling and dispersion of clays as well as slaking of aggregates (Pisinaras *et al.* 2010) and further compromised the productivity of salinized cropland. The analysis of soil

salinization has long played a crucial role in environmental sciences (Jodán *et al.* 2003). The mitigation and control of soil salinity is one of the main challenges in the agriculture of the 21st century (Amezketta 2006).

Productivity of crops under marginal environments, which are often characterized by drought, low temperature and salinity (Maas and Hoffman 1997, Baum *et al.* 2004), is strongly related to the processes of dry matter in the plant and the spatial and temporal root partitioning. The processes of partitioning of dry matter in the plant had impact on plant growth rate and growth way and the capacity of getting environment resources as well as shaped construction (Bidel *et al.* 2000). Salinity stress remains one of the world's oldest and the most serious environmental problems, which substantially hampers crop productivity in many arid and semi arid regions (Clark and Duncan 1993). The plant

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growth and development and the allocated pattern and dynamic of the amount of assimilates under salt stress condition, and adaptational mechanism in crop physiology and ecology to salt stress had become important research area in agriculture and ecology science (Hichem *et al.* 2010, Aye *et al.* 2013). At present, the study on the processes of partitioning of dry matter in the plant under marginal environmental condition was mostly concentrated on the drought, low temperature and so on (H. Kage *et al.* 2004, Gorka Erice *et al.* 2006, Peter Malcolm *et al.* 2007), particularly in crop cultivations. However, the study on partitioning of dry matter in the plant under salt stress condition was relatively little, and which was mostly conducted in pot experiment and a salinity concentration-dependent manner. Only few studies have analysed the change processes of accumulation and partitioning dynamic of dry matter in the plant in a successive salinization gradients under field context.

Alfalfa (*Medicago sativa* L.) is an important leguminous forage crop worldwide. Salt stress at 50–200 mM NaCl significantly limits the productivity of alfalfa, via its adverse effects on growth, formation of nodules and symbiotic nitrogen-fixation capacity (Johnson *et al.* 1992). Barley (*Hordeum vulgare*) is an important crop used as feed for animals, malt, and human food. Its importance derives from the ability to grow and produce in marginal environments. In all salt tolerance classifications barley is listed at the top of the annual crops (Maas and Hoffman 1997, Maas and Grattan 1999) and this is thought to be due to a more vigorous root growth (Jaradat *et al.* 2004), which could exclude salt. A better understanding and quantifying of the response of partitioning of dry matter of alfalfa and barley to salinity stress, thereby, is a prerequisite to maximizing productivity of the two dominant crops grown in saline soils.

Therefore, in this work, taking different salinization stage field under alfalfa and barley grown fields as the study object, by using the method of replacing time with space, effects of farmland salinization on change processes of soil physico-chemical characteristics and dry matter partitioning in alfalfa and barley were studied in saline area of Northwestern China.

The objective of this research was to quantify changes processes in soil physico-chemical characteristics and the dynamic of dry matter partitioning of alfalfa and barley in soil salinization, which may be of crucial importance to formulate effective farm management and to understand mechanism of crop salt tolerance and maximizing productivity of crops in saline agriculture. Furthermore, this study would form the basis for increasing crop yield in moderate and severely salinized farmland in arid region especially in China.

MATERIALS AND METHODS

Study area is located in Linze county of the Gansu Hexi Corridor, China (100°02' E, 39°15' N), a typical oasis farming irrigation zone of the middle reach of the Heihe

River. The elevation was 1 390 m. Semidesert conditions prevail in the farm with a warm continental climate. The annual average temperature was 7.6°C, the maximum and minimum temperatures being 38°C and –28°C, respectively. The mean annual precipitation reached 121.5 mm, nearly 61% received in summer and autumn. The annual sunshine duration was about 3042 hours and the evaporation was 2337.6 mm. Relative humidity of atmosphere was about 47%. The underground water level was about 1.55–2.04 m from the surface. Mineralization of underground water of shallow layer (2m) and deep layer (100m) was 2.684 8 g/L and 0.367 0 g/L, respectively. Soils are mostly salinization meadow soil and saline soil. Ion concentrations of salinization soil was dominated by sulfate. In the total mass of soil salt ions, the content of SO_4^{2-} , Mg^{2+} and Na^+ was about 33%, 25% and 16%, respectively, besides, there had little of CO_3^{2-} and HCO_3^- .

In 2011, investigations were performed in the experimental farm of Linze Grassland Ecological Research Institute of Lanzhou University, with an area of 280 hm², in which saline area was 200 hm². Due to effect of land used types and other factors, there had obvious salinization gradients in farmland. Because alfalfa and barley were the dominant crops in salinized farmland of the Hexi Corridor, different salinization stage fields under the two farmlands were taken as the study objects. In the two farmlands, three locations of having obvious salinization gradients were taken as the study sites, respectively. According to Soil Survey Division Staff (1993), each site was divided to five salt gradient plots, including a salinization negligible plot, slightly (S1), moderately (S2), severely salinized (S3) and very strongly salinized plots (S4), with the electrical conductivity of the water within the soil pores (EC_p) of 0–2, 2–4, 4–8, 8–16 and >16 dS/m, respectively, in which very strongly salinized plot had to be abandoned by the reason of serious salinization. And salinization negligible plot was treated as the control (CK). The spatial distribution of the experimental plots followed a randomized block design with three replications. The total number of plots was twenty-seven and the size of per plot was 10×50 m².

On September 20, 2010, alfalfa (*Medicago sativa* cv. Golden Empress) were sown by line sowing, with a density of 5.25 kg/ha. Prior to sowing, $(\text{NH}_4)_2\text{HPO}_4$ at a rate corresponding with 200 kg N/ha and 225 kg P/ha, and $\text{CO}(\text{NH}_2)_2$ at a rate of 75 kg N/ha were applied uniformly in single dose and were mixed well by plowing. On March 12, 2011, barley (*Hordeum vulgare* L. cv. Ganpi No. 4) were sown by line sowing, with a density of 3.75 kg/ha. Prior to sowing, $(\text{NH}_4)_2\text{HPO}_4$ at a rate corresponding with 375 kg N/ha and 375 kg P/ha, and $\text{CO}(\text{NH}_2)_2$ at a rate of 75 kg N/ha were applied uniformly in single dose as base fertilizers and were mixed well by plowing. Four and eight weeks after sowing, $\text{CO}(\text{NH}_2)_2$ at a rate of 300 kg N/ha was applied in single dose.

Study area has been irrigated from pumped ground water from eight power-operated wells (102 m) with EC of 1–3 mS/cm, which is used in a limited area; and good-

quality irrigation water with EC of 0.38 mS/cm from the Heihe river. The water supply of the farm is sufficient. A drainage system with the depth of drainage channels of about 2–3 m had been built. Irrigation water is delivered to fields via a system of chutes. In November 2010, 100 m³/ha underground water were applied on different salinized gradients plots in the two farmlands to obtain a sufficient emergence. In 2011, in the whole growing seasons, alfalfa crop was irrigated three times from mid-May till mid-September and barley was irrigated only once at mid-May.

During April to September, 2011, effect of farmland salinization on dry matter accumulation and distribution traits of alfalfa was measured at successive phenological stages. At different growing stage, ten plants in each plot of different salinized gradients were sampled, and fresh and dry weight (after drying at 60 °) of leaves, stem and roots were determined. In each plot of different salinized gradients, plants were harvested at the soil surface in a 1×1m² plot at 275, 297, 361 days after sowing.

During April to July, 2011, response of barley dry matter accumulation and distribution traits to soil salinization were investigated. Fresh and dry weight (after drying at 60°C) of leaves, stem, ear and roots were determined at successive phenological stages of ten plants in each plot of different salinized gradients. In each plot of different salinized gradients, plants were harvested at the soil surface in a 1×1m² plot at 123 days after sowing.

Soil sampling was performed in each plot on May 12-May 19 (before irrigation), June 5-June 12 (after irrigation), July 20-July 26 (after irrigation), August 11-August 20 (before irrigation), September 14-September 19 (after irrigation) and October 13-October 15, respectively in 2011. In each plot, nine sampling points were randomly set up. In each sampling point, soil samples were collected at depths

of 0-5, 5-10, 10-20, 20-40, 40-60, 60-80, 80-100 and 100-120 cm. The soil samples were taken to the laboratory for measuring soil physico-chemical characteristics, at the same time, soil volumetric water content was determined by auger and the gravimetric method, after drying in a forced-draft oven at 105°C to constant weight, and soil salinity was determined by measuring the soil EC_p with WET Sensor (HH2 Delta-T Devices Moisture Meter, England). Soil bulk density was determined by cutting ring; soil temperature of the growing seasons were measured by WET sensor.

The soil samples were taken to the laboratory for measuring soil organic matter, soil nutrients content and the concentrations of Cl⁻, SO₄²⁻, HCO₃⁻, Na⁺, K⁺, Mg²⁺ and Ca²⁺ by traditional approaches.

Analysis of variance was performed by SPSS 15.0 program. Means were grouped by using the least significant difference (LSD) test at 5% level.

RESULTS AND DISCUSSION

Soil bulk density and soil porosity

As can be seen in Fig 1, for alfalfa, in soil depth of 0-20 cm, soil bulk density was increased by 3.00%, 4.54%, 8.62% and 9.96% along salinization gradients while soil porosity decreased by 2.62%, 4.03%, 7.70% and 8.85%; in soil depth of 20-60 cm, soil bulk density between different gradient fields and CK were in the following order: S3>S1>CK>S2>S4. For barley, at the 0-20cm horizon, soil bulk density was increased by -1.00%, 10.92%, 6.19%, 10.90%; and the porosity decreased by -0.49%, 9.54%, 5.40%, 9.53%; in soil depth of 20-60 cm, soil bulk density between different gradient plots and CK were in the following order: S3>S2>CK>S1>S4.

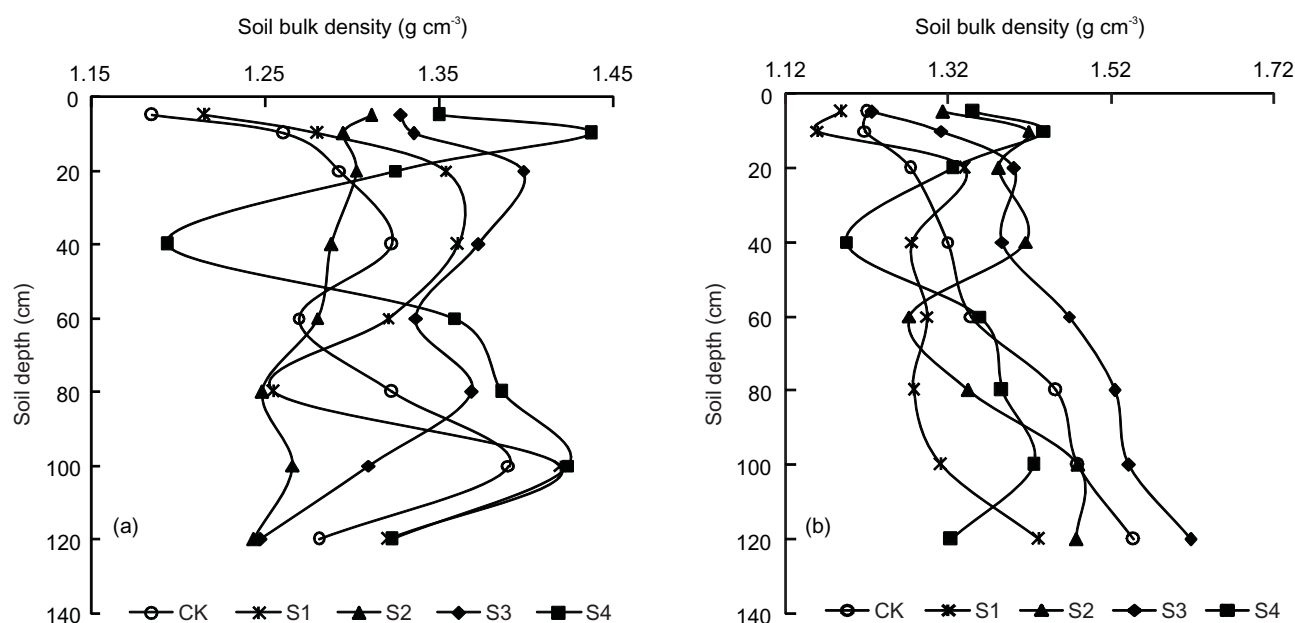


Fig 1 Soil bulk density at different depths in different salinization gradient plots; (a) Alfalfa, (b) Barley; CK: a salinization negligible field, S1: Slightly salinized field, S2: Moderately salinized field, S3: Severely salinized field, S4: Very strongly salinized field. The same as below.

Soil temperature

Soil temperatures in different gradient plots are shown in Fig 2. For alfalfa in CK, in soil depth of 0-20 cm, soil temperature was relatively lower than that in other salinized gradient plots; and the trend showed a low-high-low fluctuation with salinization and the maximum soil temperature mostly occurred in S2 and S3. For barley, in soil depth of 0-20 cm, soil temperature was decreased along salinization gradients at heading stage; at 0-5 cm soil horizon, compared to CK, soil temperature of different gradient plots decreased by 2.10, 3.27, 3.43 and 4.10°C.

Variation of soil nutrient in soil salinization

Soil organic matter, total nitrogen and total phosphorus Result showed that in the two crop grown fields, soil organic matter in soil depth of 0-20 cm was all significantly decreased with salinization gradient increased, and that in CK was lower than in S1 and the decrease rate was faster in soil depth of 0-10 cm than that in soil depth of 10-20 cm.

In the two farmlands, soil total nitrogen, total phosphorus and total potassium in soil depth of 0-20 cm were different in different salinized plots. In alfalfa grown field, the trend of soil total nitrogen and total phosphorus in

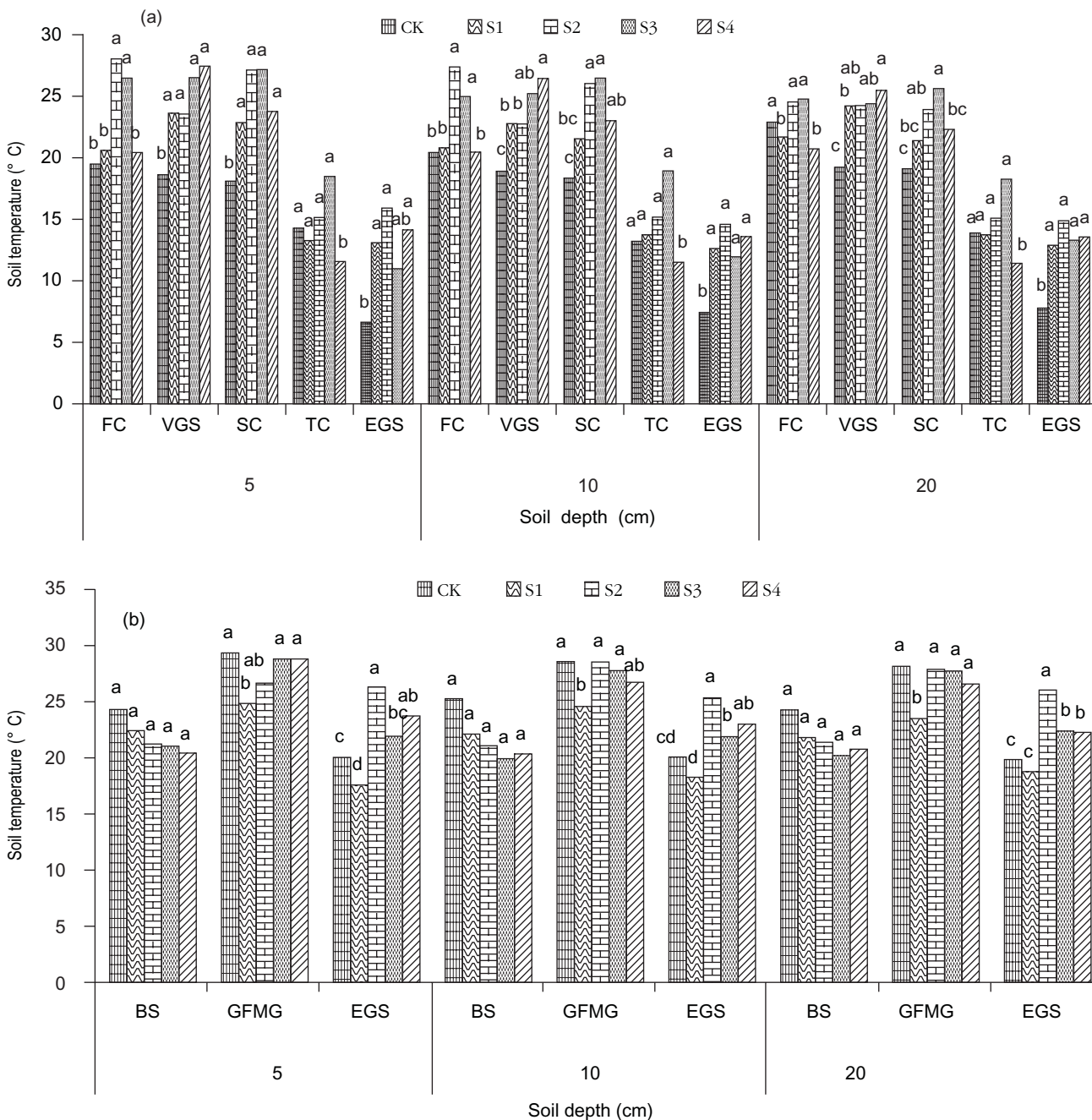


Fig 2 Average soil temperature of 14:00-18:00 pm at topsoil depths in different salinization gradient plots; (a) Alfalfa, FC: First-cut, VGS: Vegetative growth stage, SC: Second-cut, TC: Third-cut; (b) Barley, BS: Booting stage, GFMG: Grain filling and mature stage, EGS: End of growth season. Note: Values in each growing stage with the same letter are not significantly different at 0.05 level.

soil depth of 0-10 cm and 10-20 cm was similar to soil organic matter, which were all significantly reduced with salinization gradient increased ($P < 0.05$), and in CK, it was lower than that of S1; however, soil total potassium was likely reduced with salinization gradient increased. In barley grown field, the trend of soil total nitrogen in soil depth of 0-10 cm and 10-20 cm was similar to soil organic matter, which were significantly reduced with salinization gradient increased ($P < 0.05$), while total phosphorus and total potassium fluctuately changed and had no obvious trend (Table 1).

Result showed that in the two crop grown fields, along salinization gradients increased, alkali-hydrolyzable nitrogen was all significantly decreased, while available potassium was all significantly increased ($P < 0.05$). But there had obvious difference in the change range of alkali-hydrolyzable nitrogen and available potassium in barley and alfalfa grown fields. For example, compared to CK, in S4, alkali-hydrolyzable nitrogen was decreased by 54.45% and 47.21%, respectively in soil depth of 0-10 cm and 10-20 cm in alfalfa grown field, whereas for barley grown field, it was decreased by 66.23% and 55.77%, and available potassium was increased by 470.72% and 365.61% in alfalfa grown field whereas for barley grown field it was increased by 290.00% and 101.35%. Besides, in the two crop grown fields, available phosphorus were all fluctuately changed along salinization gradients. However, in alfalfa grown field, although available phosphorus in soil depth of 0-10 cm had difference in

different gradient plots, the differences were all not significant ($P > 0.05$), and available phosphorus in soil depth of 10-20 cm had also no obvious trend. For barley grown field, the highest of available phosphorus in soil depth of 0-10 cm and 10-20 cm appeared in S4 and the difference of available phosphorus was relatively smaller among other salinized gradient plots (Table 1).

Changes in soil salinity in salinization process

Result showed that in alfalfa grown field, the major anion is SO_4^{2-} in different salinization gradient plots, meanwhile there had a little of Cl^- and HCO_3^- ions; the major cation is Ca^{2+} followed by Mg^{2+} , $\text{Na}^+ + \text{K}^+$ concentration was the least. In barley grown field, the major anion was still SO_4^{2-} followed by Cl^- , and HCO_3^- concentration was relatively the least in different salinization gradient plots; the major cation is Ca^{2+} followed by Mg^{2+} , and $\text{Na}^+ + \text{K}^+$ concentration was the least but which could be higher than Ca^{2+} concentration in later growing seasons (Table 2).

In the two crop grown fields, along salinization gradients increased, concentration of soil soluble salt ions were all significantly increased. However, there was difference in mean concentration of different salt ions between the same salinization gradient plots in the two farmlands. For example, in barley grown field, the concentration of Cl^- and $\text{Na}^+ + \text{K}^+$ were obviously higher in CK and S1 than that of corresponding salinized plots in alfalfa grown field and the change ranges of different salt ions concentration were lower among different gradient plots than that among

Table 1 Changes of soil nutrients in salinization

| Crop | Soil depth (cm) | Salinization gradient | Organic matter (g/kg) | Total nitrogen (g/kg) | Total potassium (K) (g/kg) | Total phosphorus (P) (g/kg) | Alkali-hydrolyzable nitrogen (mg/kg) | Available phosphorus (P) (mg/kg) | Available potassium (K) (mg/kg) |
|---------|-----------------|-----------------------|-----------------------|-----------------------|----------------------------|-----------------------------|--------------------------------------|----------------------------------|---------------------------------|
| Alfalfa | 0-10 | CK | 11.74 ab | 0.66 a | 15.00 a | 1.94 a | 49.44 a | 34.98 a | 136.67 c |
| | | S1 | 13.41 a | 0.73 a | 14.33 a | 2.04 a | 54.40 a | 43.53 a | 143.33 c |
| | | S2 | 11.05 ab | 0.70 a | 12.67 b | 1.56 b | 33.73 b | 30.44 a | 510.00 ab |
| | | S3 | 9.73bc | 0.58 ab | 12.33 b | 1.56 b | 28.54 bc | 40.40 a | 496.67 b |
| | | S4 | 8.23 c | 0.46 b | 11.00 c | 1.42 c | 21.53 c | 36.58 a | 780.00 a |
| | 10-20 | CK | 9.33 ab | 0.53 ab | 14.67 a | 1.55 ab | 37.22 a | 17.07 b | 106.67 b |
| | | S1 | 10.89 a | 0.60 a | 14.00 a | 1.65 a | 43.32 a | 21.00 ab | 103.33 b |
| | | S2 | 9.81 ab | 0.58 a | 12.67 b | 1.35 bc | 27.06 b | 18.29 b | 423.33 a |
| | | S3 | 8.49 ab | 0.46 ab | 12.00 bc | 1.44 abc | 27.00 b | 33.87 a | 420.00 a |
| | | S4 | 7.27 b | 0.39 b | 11.00 c | 1.29 c | 19.65 b | 16.31 b | 496.67 a |
| Barley | 0-10 | CK | 15.84 a | 1.08 a | 12.67 ab | 1.45ab | 63.76 a | 12.41 b | 200.00c |
| | | S1 | 13.62 ab | 0.87 ab | 13.00 a | 1.55a | 57.60 ab | 19.32 ab | 226.67c |
| | | S2 | 11.68 abc | 0.69 ab | 12.33bc | 1.28c | 46.63 ab | 7.52 b | 416.67b |
| | | S3 | 9.19 bc | 0.57 b | 12.00 c | 1.34bc | 37.79 bc | 11.34 b | 446.67b |
| | | S4 | 8.23 c | 0.46 b | 11.00 d | 1.42abc | 21.53 c | 36.58 a | 780.00a |
| | 10-20 | CK | 10.45 b | 0.63 b | 13.00 a | 1.39ab | 44.43 b | 3.02b | 246.67bc |
| | | S1 | 16.25 a | 0.94 a | 13.00 a | 1.61a | 68.57 a | 10.31a | 220.00c |
| | | S2 | 10.85 b | 0.65 b | 11.33 bc | 1.29b | 37.54 bc | 3.28b | 376.67abc |
| | | S3 | 8.44 b | 0.56 b | 12.33 ab | 1.32b | 36.33 bc | 3.48b | 393.33ab |
| | | S4 | 7.27 b | 0.39 b | 11.00 c | 1.29b | 19.65 c | 16.31a | 496.67a |

Note: Values in each column with the same letter are not significantly different at 0.05 level. The same as below.

Table 2 Changes in ionic composition of soil profile (at 0-120 cm depth) in different salinization gradient plots

| Crop | Salinization gradient | Soil depth (cm) | HCO ₃ ⁻ (cmol/kg) | Cl ⁻ (cmol/kg) | SO ₄ ²⁻ (cmol/kg) | Ca ²⁺ (cmol/kg) | Mg ²⁺ (cmol/kg) | Na ⁺ +K ⁺ (cmol/kg) |
|---------|-----------------------|-----------------|---|---------------------------|---|----------------------------|----------------------------|---|
| Alfalfa | CK | 0-120 | 0.32 | 0.06 | 9.10 | 7.94 | 1.26 | 0.21 |
| | S1 | 0-120 | 0.31 | 0.08 | 8.73 | 7.66 | 1.16 | 0.27 |
| | S2 | 0-120 | 0.34 | 1.28 | 10.83 | 7.56 | 1.70 | 3.25 |
| | S3 | 0-120 | 0.35 | 1.49 | 12.24 | 7.49 | 2.21 | 4.61 |
| | S4 | 0-120 | 0.42 | 2.48 | 18.84 | 8.47 | 3.97 | 9.47 |
| Barley | CK | 0-120 | 0.48 | 0.11 | 3.55 | 2.48 | 1.12 | 0.48 |
| | S1 | 0-120 | 0.53 | 0.14 | 3.74 | 2.20 | 1.46 | 0.82 |
| | S2 | 0-120 | 0.47 | 0.16 | 7.62 | 5.11 | 1.93 | 1.46 |
| | S3 | 0-120 | 0.46 | 0.28 | 7.25 | 3.79 | 2.09 | 2.41 |
| | S4 | 0-120 | 0.42 | 2.48 | 18.84 | 8.47 | 3.97 | 9.47 |

different gradient plots in alfalfa grown field (Table 2).

Result showed that in the two grown fields, soil layers of appearing the highest of soil EC_p were different in different salinized gradient fields. In barley grown field, the highest of soil EC_p appeared at 20-40 cm soil layer in CK and S1, whereas in S2 and S3, the highest of soil EC_p appeared at 0-5 cm soil layer. In alfalfa grown field, the highest of soil EC_p appeared at 100-120 cm, 5-10 cm and 0-5 cm soil layer, respectively in CK, S1, S2 and S3. In S4, the highest of soil EC_p appeared at 0-5 cm soil layer. It showed that cultivated crop could made the highest of soil EC_p moved down in soil profile, and the role of alfalfa was obviously superior to barley (Table 3).

From the vertical perspective, variations of soil EC_p in the whole profile were different in different salinization gradient fields in the two farmlands. In barley grown field, in whole growing seasons, soil EC_p of the whole profile presented arc-shaped in CK and the maximum value of soil

EC_p appeared in soil depth of 40-50 cm; soil EC_p of the whole profile had slight variation in S1; soil EC_p of the whole profile was reduced with soil depth increased in S2 and S3. In alfalfa grown field, in whole growing seasons, seasonal variation of soil EC_p of the whole profile was increased with soil depth increased in CK; soil EC_p of the whole profile was firstly increased and then trended to stability with soil depth in S1; soil EC_p of the whole profile was firstly increased and then reduced and finally trended to stability with soil depth increased in S2. Overall, coefficient values of seasonal variation in soil EC_p (soil depth 0-120 cm) were in the following order: CK (0.12) > S4 (0.104) > S2 (0.101) > S3 (0.04) > S1 (0.03) in barley grown field; in alfalfa grown field, it was S2 (0.24) > CK (0.23) > S3 (0.24) > S1 (0.13) > S4 (0.08). It indicated that the seasonal change of soil EC_p was stronger in different salinization gradient plots in alfalfa grown field than that in barley grown field.

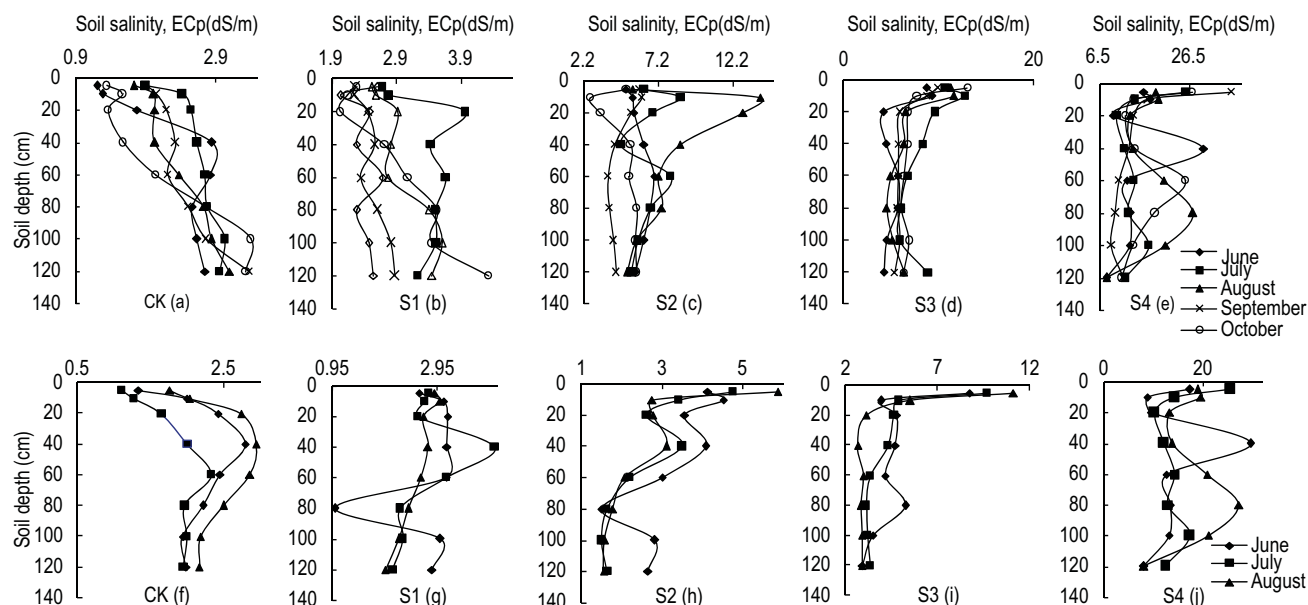


Fig 3 Seasonal changes of soil EC_p in soil depth of 0-120 cm in different salinization gradient farmlands; (a,b,c,d,e) alfalfa, (f,g,h,i,j) barley

Table 3 Average soil salinity (EC_p) of soil profile in farmland plots of different salinized gradients (dS/m)

| Soil depth (cm) | Alfalfa | | | | | Barley | | | | |
|-----------------|---------|------|------|-------|-------|--------|------|------|------|-------|
| | CK | S1 | S2 | S3 | S4 | CK | S1 | S2 | S3 | S4 |
| 0-5 | 1.62 | 2.47 | 5.53 | 10.73 | 24.74 | 1.40 | 2.76 | 4.92 | 9.88 | 20.65 |
| 5-10 | 1.87 | 2.35 | 7.39 | 10.02 | 16.57 | 1.77 | 2.92 | 3.56 | 4.81 | 14.20 |
| 10-20 | 1.99 | 2.76 | 6.79 | 6.62 | 11.98 | 2.27 | 2.80 | 2.98 | 4.21 | 11.13 |
| 20-40 | 2.29 | 2.75 | 5.83 | 6.35 | 16.56 | 2.58 | 3.31 | 3.56 | 3.92 | 18.46 |
| 40-60 | 2.45 | 2.90 | 6.24 | 5.93 | 16.80 | 2.55 | 2.96 | 2.42 | 3.53 | 15.85 |
| 60-80 | 2.68 | 3.06 | 6.08 | 5.63 | 16.45 | 2.23 | 1.88 | 1.64 | 3.77 | 17.82 |
| 80-100 | 2.94 | 3.16 | 5.54 | 5.70 | 14.92 | 2.04 | 2.50 | 1.97 | 3.23 | 17.20 |
| 100-120 | 3.11 | 3.28 | 5.25 | 6.25 | 10.31 | 2.03 | 2.30 | 1.95 | 3.09 | 9.52 |
| Mean | 2.37 | 2.84 | 6.08 | 7.16 | 16.04 | 2.11 | 2.68 | 2.87 | 4.56 | 15.60 |

Changes of dry matter partitioning ratio of different parts of plant in salinization

Result showed that for alfalfa, in vegetative growth stage after returning-green, in different salinization gradient plots, dry matter partitioning ratios of different parts were all in the following order: stem>leaves>roots. ANOVA showed that there had significant difference in dry matter partitioning ratio of leaves between S3 and the S1 and S2 ($P<0.05$), however, dry matter partitioning ratio of other parts had not significantly different among different salinization gradient plots ($P>0.05$). The reason may be that for alfalfa, leave organ was its vegetative organ, in order to get more soil environment resources, such as soil moisture and nutrients, compared to CK and other salinization gradients plots, in S3, plant total dry matter was more distributed to leave. At first-cut, dry matter partitioning ratio of different parts were in the following order: stem>leaves>roots in CK and S1 and S2, while in S3, the order was roots>leaves>stem. The reason may be the same, that was, in S3, soil environment were very poor, thus plant dry matter was more transferred to roots organ so as to absorb relatively more nutrients, so dry matter partitioning ratio of roots was the most while dry matter partitioning ratio of stem was the least. However, ANOVA showed that dry matter partitioning ratio of different parts had not significantly different in different salinization gradient plots ($P>0.05$). At second-cut, dry matter partitioning ratios of different parts were in the following order: stem>roots>leaves in CK, and stem>leaves>roots in salinization plots. ANOVA showed that dry matter partitioning ratio of stem was significantly different between S1 and the S2 and S3 ($P<0.05$), while dry matter partitioning ratios of other parts had no significant difference in different salinization gradient plots ($P>0.05$). At third-cut, dry matter partitioning ratios of different parts were in the following order: stem>roots>leaves in CK, and roots>stem>leaves in salinization plots. ANOVA showed that dry matter partitioning ratio of different parts had no significant difference in different salinization gradient plots ($P>0.05$). In conclusion, at any given growth stage, along salinization gradient increased, plant total dry matter was more distributed to leave and root, while dry matter partitioning

ratio of stem was gradually reduced by which plant could adapted to effect of salt stress on its growth and development. In shape construction, alfalfa plant was gradually developing to be that of having relatively developed root system and leaves of little and density.

For barley, result showed that in tillering stage, dry matter partitioning ratio of different parts were in the following order: root>leaves>stem in CK and S3, leaves>root>stem in S1 and S2. The reason was may be that in CK, there was enough soil environment resource which promoted growth and development of barley root system, so dry matter partitioning ratio of root was the most. While in S3, soil environment were very poor, and soil moisture and soil nutrients were very little, effect of salt stress on plant development was very significant, thus dry matter partitioning ratio of root was also the most so as to absorb relatively more nutrients. However, ANOVA showed that dry matter partitioning ratio of different parts of barley had not significant difference in different salinization gradient plots ($P>0.05$). In jointing stage, dry matter partitioning ratio of different parts were in the following order: stem>leaves>root in CK, stem>root>leaves in S1, root>stem>leaves in S2 and leaves>root>stem in S3. ANOVA showed that dry matter partitioning ratio of leaves had significant difference between S3 and other salinization gradients ($P<0.05$). It indicated that in jointing stage, along salinization gradients increased, dry matter partitioning ratio of stem was gradually reduced and dry matter partitioning ratios of leaves and root were increased so as to get more soil moisture and nutrients to maintain growth and development of plant itself. In grain filling and mature stage, dry matter partitioning ratios of different parts were in the following order: ear>stem>root>leaves in CK and S1 and S2, while in S3, the order was ear>stem>leaves>roots. ANOVA showed that there had significant difference in dry matter partitioning ratio of leaves between S3 and the CK and S2 ($P<0.05$), however, dry matter partitioning ratio of other parts had not significantly different in different salinization gradient plots ($P>0.05$). In other words, at any given growth stage, plant total dry matter was more distributed to leaves and root along salinization gradient increased, and center of accumulation and distribution of

Table 4 Dry matter partitioning ratio of different parts of barley in different salinization gradient farmlands %

| Salinization gradient | Tillering stage | | | Jointing stage | | | Grain filling and mature stage | | | |
|-----------------------|-----------------|---------|---------|----------------|---------|---------|--------------------------------|---------|---------|---------|
| | Leave | Stem | Root | Leave | Stem | Root | Leave | Stem | Ear | Root |
| CK | 38.12 a | 22.07 a | 39.81 a | 27.46 b | 47.52 a | 25.02 a | 7.22 b | 26.52 a | 51.22 a | 15.05 a |
| S1 | 40.84 a | 20.37 a | 38.80 a | 25.08 b | 41.03 a | 33.89 a | 7.99 b | 24.37 a | 53.71 a | 13.94 a |
| S2 | 40.02 a | 20.61 a | 39.37 a | 26.13 b | 35.84 a | 38.02 a | 8.88 ab | 26.37 a | 50.03 a | 14.72 a |
| S3 | 31.34 a | 25.07 a | 43.59 a | 42.68 a | 26.90 a | 30.42 a | 11.51 a | 25.79 a | 54.40 a | 8.30 a |

Table 5 Dry matter partitioning ratio of different parts of alfalfa in different salinization gradient farmlands %

| Salinization gradient | Vegetative growth stage | | | First-cut | | | Vegetative growth stage | | |
|-----------------------|-------------------------|-------------------|----------|-----------|--------------------------------|---------|-------------------------|------------------|---------|
| | Leave | Stem | Root | Leave | Stem | Root | Leave | Stem | Root |
| CK | 32.25 ab | 47.86 a | 19.89 a | 29.14 a | 51.42 a | 19.44 a | 22.49 a | 48.23 a | 29.29 a |
| S1 | 28.78 b | 46.89 a | 24.33 a | 31.45 a | 36.39 a | 32.16 a | 22.98 a | 45.05 ab | 31.97 a |
| S2 | 29.43 b | 43.73 a | 26.85 a | 31.48 a | 42.63 a | 25.89 a | 21.33 a | 41.65 ab | 37.02 a |
| S3 | 38.20 a | 43.52 a | 18.28 a | 28.76 a | 28.66 a | 42.59 a | 23.41 a | 36.48 b | 40.11 a |
| | | <i>Second-cut</i> | | | <i>Vegetative growth stage</i> | | | <i>Third-cut</i> | |
| CK | 22.41 b | 48.08 ab | 29.51a | 11.90 a | 26.60 ab | 61.50 a | 18.94 a | 43.21 a | 37.85 a |
| S1 | 33.37 a | 42.75 b | 23.88 ab | 13.80 a | 30.10 a | 56.10 a | 24.49 a | 34.40 a | 41.11 a |
| S2 | 32.04 a | 48.14 ab | 19.83 b | 19.10 a | 17.40 b | 63.50 a | 20.22 a | 31.61 a | 48.17 a |
| S3 | 31.74 a | 51.25 a | 17.01 b | 22.10 a | 17.00 b | 60.90 a | 20.31 a | 30.68 a | 49.01 a |

plant dry matter in different salinization gradients was gradually slow than CK plant.

Dry matter partitioning ratio of total shoot and root/shoot ratio

Result showed that in salinization, salt stress made the dry matter partitioning ratio of total shoot of the two crops be gradually reduced and root/shoot ratio increased in whole growing seasons (data not shown). It showed that in salinization, the one of strategies that plant adapted to salt stress was reduction in dry matter partitioning ratio of total shoot and increase in root/shoot ratio. ANOVA showed that for alfalfa, at third-cut, dry matter partitioning ratio of total shoot and root/shoot ratio had significant difference between S3 and other salinized fields ($P < 0.05$), while at vegetative growth stage after returning-green, first-cut and second-cut, there was no significant difference in different salinization gradient fields ($P > 0.05$). For barley, at jointing stage, dry matter partitioning ratio of total shoot and root/shoot ratio was no significant difference in different salinization gradient fields ($P > 0.05$).

Yield

As can be seen in Table 5, for alfalfa, at the first-cut, second-cut and third-cut, compared to CK, yields in S1 and S2 and S3 were reduced by 51.49%, 67.23% and 88.17%; 30.93%, 59.48% and 72.36%; 17.25%, 42.17% and 70.77%. For barley, compared to CK, the reduction of grain yield and shoot yield in S1 and S2 and S3 were about 4.69%, 53.87% and 59%; 0.26%, 58.16% and 60.53%.

Effect of different land use types on soil environments

was different, including the degree and orientation of influence. Numerous studies had shown that the addition of salt to the soil altered its physical and chemical properties. For example, soil porosity, soil penetrability, soil water retention and thermal conductivity trended to decrease, soil bulk density increased and so on. In this study, in the two farmlands (*Hordeum vulgare* and *Medicago sativa* cultivations), effects of farmland salinization on change processes of soil physico-chemical characteristics were different. In alfalfa grown field, compared to non-saline plot, soil bulk density was increased with salinization gradients increased, whereas for barley grown field, the change of soil bulk density had no obvious trend in corresponding salinized gradient plot. Soil temperature of different salinized gradient plots in alfalfa grown field showed a low-high-low fluctuation, while that of barley grown field was increased. In the two farmlands, different salinization gradient plots had different soil depths of salt accumulation and occurring the peak of average soil EC_p . In

Table 6 Yields of alfalfa and barley in different salinization gradients

| Salinization gradient | Alfalfa | | | Barley | |
|-----------------------|------------------------------------|-------------------------------------|------------------------------------|----------------------------------|----------------------------------|
| | First-cutting (t/ha ²) | Second-cutting (t/ha ²) | Third-cutting (t/ha ²) | Straw yield (t/ha ²) | Grain yield (t/ha ²) |
| CK | 26.57 a | 30.03 a | 20.87 a | 25.33 a | 7.46 a |
| S1 | 12.89 b | 18.04 b | 17.27 a | 25.27 a | 7.11 a |
| S2 | 8.71 b | 12.17 c | 12.07 b | 10.60 b | 3.44 b |
| S3 | 3.14 c | 8.30 c | 6.10 c | 10.00 b | 3.06 b |

the composition of soil soluble salt ions and ratio, the same salinized gradient plots under the two farmlands were similar; but in alfalfa grown field, the ratios of Cl^- and $\text{Na}^+ + \text{K}^+$ ions in CK and S1 were significantly lower than that of CK and S1 in barley grown field, and the change ranges of different ions from CK to S4 were higher than that of barley. The reasons were related with the difference of biology traits of the two crops. For alfalfa, compared to barley, it had developed root systems and strongly vigorous capacity of evaporation, thus its root systems could absorbed underground water by penetrating water-resisting layer but also could significantly improve soil structure and pore structure. Therefore, in regulation of water and salt migration and so on, alfalfa was obvious superior to barley.

Land use types could caused the changes of soil nutrients (Fu *et al* 2000), effect of different land use types on the flows and transformations of soil nutrients were different (Reijneveld *et al.* 2009, Agbede 2010). There had many literatures which showed that alfalfa was deep roots crop, and its dense and well developed root systems could loose soil, but also its residues could increase soil organic matter. Therefore in the aspect of increasing soil organic matter and improving soil quality, alfalfa cultivations was obvious superior to barley cultivations. However, there was inconformity with the result of this study, which was mainly showed in non-saline plots between alfalfa and barley grown fields, that was, soil organic matter, total nitrogen, alkali-hydrolyzable nitrogen and available potassium was obvious lower in alfalfa grown field than that of barley grown field, however, total potassium, total phosphorus and available phosphorus were higher than that of barley grown field. The reason may be related with the biological nature of alfalfa and barley and the field managements. In initial period of alfalfa cultivation, due to the increase of soil air permeability, the rising of soil temperature, the vigorous microbiological activity, the decomposition of soil organic matter was quick, whereas the return of soil organic matter was still little, thus soil nutrients in alfalfa grown field was lower than barley grown field, such as soil organic matter. However, the reasons on the differences of soil organic matter and other soil nutrients in other salinized plots between the two farmlands was mainly related with soil salinity, that was, soil salinity led to the differences of the change rates of soil nutrients in salinized plots between the two farmlands.

Dry matter accumulation and distribution traits could reflect the strategy which plant adapted to the effect of salt stress and maintained itself growth and development. The yield effect of crops, however, was strongly related to this adaptation processes of dry matter in the plant. In this study, the result showed that at any given growth stage, along salinization gradient increased, plant total dry matter was more distributed to leaves and roots organs, while dry matter partitioning ratio of stem was gradually reduced, and the center of accumulation and distribution of plant dry matter in different salinization gradients was gradually slow than CK plant. Besides, in salinization, salt stress made the

dry matter partitioning ratio of total shoot of the two crops be gradually reduced and root/shoot ratio increased. It showed that, along salinized gradients increased, plant adapted to salt stress by reducing stem growth and increased at least relatively dry matter allocation into the leaves and roots fraction, leading to a declining shoot/root-ratio, which thereby led to the loss of yield of crops. This result indicated that the response of partitioning of dry matter in the plant to salt stress condition was similar to the responses of plant under drought stress condition in which leaves growth was mostly reduced and dry matter allocation into the roots fraction was at least relatively increased, leading to a declining shoot/root-ratio (Setter 1990).

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REFERENCES

- Amezketta E. 2006. An integrated methodology for assessing soil salinization, a precondition for land desertification. *Journal of Arid Environment* **4**: 594–606.
- Agbede T M. 2010. Tillage and fertilizer effects on some soil properties, leaf nutrient concentrations, growth and sweet potato yield on an Alfisol in southwestern Nigeria. *Soil and Tillage Research* **110**(1): 25–32.
- Baum M, Grando S and Ceccarelli S. 2004. Localization of quantitative trait loci for dryland characters in barley by linkage mapping. In *Challenges and Strategies for Dryland Agriculture*, pp 191–202. CSSA Special Publication.
- Bidel L P R, Pagès L, Rivière L M, Pelloux G and Lorendeau J Y. 2000. MassFlowDyn I: A carbon transport and partitioning model for root system architecture. *Annals of Botany* **85**(6): 869–86.
- Clark R B and Duncan R R. 1993. Selection of plants to tolerate soil salinity, acidity and mineral deficiencies. *Int. Crop Science* **1**: 371–9.
- De Pascale S and Barbieri G. 1997. Effect of soil salinity and top removal on growth and yield of broadbean as green vegetable. *Scientia Horticulturae* **71**(3-4): 147–65.
- Fu B J, Chen L D, Ma K M, Zhou H F and Wang J. 2000. The relationship between land use and soil conditions in the hilly area of the Loess Plateau in northern Shanxi, China. *Catena* **39**: 69–78.
- Gorka Erice, Juan J Irigoyen, Pilar Pérez, Rafael Martínez-Carrasco and Manuel Sánchez-Díaz. 2006. Effect of elevated CO_2 , temperature and drought on dry matter partitioning and photosynthesis before and after cutting of nodulated alfalfa. *Plant Science* **170**(6): 1 059–67.
- Hichem Hajlaoui, Naceur El Ayeb, Jean Pierre Garrec and Mounir Denden. 2010. Differential effects of salt stress on osmotic adjustment and solutes allocation on the basis of root and leaf tissue senescence of two silage maize (*Zea mays*L.) varieties. *Industrial Crops and Products* **31**(1): 122–30.

- Jordán M M, Navarro-Pedreño J, and García-Sánchez E, *et al.* 2003. Spatial dynamics of soil salinity under arid and semi-arid conditions: Geological and environmental implications. *Environmental Geology* **4**: 448–56.
- Jaradat A A, Shahid M and Al-Maskri A. 2004. Genetic diversity in the Batini barley landrace from Oman. Response to salinity stress. *Crop Science* **44**: 997–1 007.
- Johnson D D W, Smith S E and Dobrenz A K. 1992. Selection for increased forage yield in alfalfa at different NaCl levels. *Euphytica*, **60**: 27–35.
- Kage H, Kochler M and Stützel H. 2004. Root growth and dry matter partitioning of cauliflower under drought stress conditions: measurement and simulation. *European Journal of Agronomy* **20**(4): 379–94.
- Aye Aye Thwe, Gilles Vercambre, Hélène Gautier, Loïc Pagès, Christophe Jourdan, Frédéric Gay and Poonpipope Kasemsap. 2013. Dynamic shoot and root growth at different developmental stages of tomato (*Solanum lycopersicum* Mill.) under acute ozone stress. *Scientia Horticulturae* **150**(4): 317–25.
- Maas E V and Hoffman G J. 1997. Crop salt tolerance, current assessment. *Journal of Irrigation Drainage Div. ASCE* **103**: 115–34.
- Maas E V and Grattan S R. 1999. Crop yields as affected by salinity. *Agricultural Drainage*, pp 55–108. Skaggs R W and van Schilfgaarde J (Eds). Agron. Monograph.
- Peter Malcolm, Paul Holford, Barry McGlasson, Jann Conroy and Idris Barchia. 2007. Growth and its partitioning in Prunus rootstocks in response to root zone temperature. *Scientia Horticulturae* **112**(1): 58–65.
- Pisinaras V, Tsihrintzis V A, Petalas C and Ouzounis K. 2010. Soil salinization in the agricultural lands of Rhodope District, northeastern Greece. *Environmental Monitoring and Assessment* **166**: 79–94.
- Reijneveld A, Wensem J van and Oenema O. 2009. Soil organic carbon contents of agricultural land in the Netherlands between 1984 and 2004. *Geoderma* **152**(3-4): 231–8.
- Setter T L. 1990. Transport/harvest index: photosynthate partitioning in stressed plants. *Stress Response in Plants: Adaption and Acclimation Mechanisms*, pp 17–36. Cumming J R (Eds). Wiley-Liss, Inc, New York.
- Shi D C and Wang D L. 2005. Effects of various salt-alkaline mixed stresses on *Aneurolepidium chinense* (Trin.) Kitag. *Plant and Soil* **271**: 15–26.
- Soil Survey Division Staff. 1993. *Soil survey manual*, pp 437. In USDA handbook 18, US Gov. Printing office, Washington.
- Yang J Y, Zheng W and Tian Y. 2011. Effects of various mixed salt-alkaline stresses on growth, photosynthesis, and photosynthetic pigment concentrations of *Medicago ruthenica* seedlings. *Photosynthetica* **49**(2): 275–84.