Alfalfa and soil chemical properties response to irrigation in saline-sodic soil region (#33526)

First submission

Editor guidance

Please submit by **20 Feb 2019** for the benefit of the authors (and your $200 publishing discount).

Structure and Criteria
Please read the 'Structure and Criteria' page for general guidance.

Raw data check
Review the raw data. Download from the materials page.

Image check
Check that figures and images have not been inappropriately manipulated.

Privacy reminder: If uploading an annotated PDF, remove identifiable information to remain anonymous.

Files
Download and review all files from the materials page.

7 Figure file(s)
3 Table file(s)
1 Raw data file(s)

Structure and Criteria

Structure your review

The review form is divided into 5 sections. Please consider these when composing your review:

1. **BASIC REPORTING**
2. **EXPERIMENTAL DESIGN**
3. **VALIDITY OF THE FINDINGS**
4. General comments
5. Confidential notes to the editor

You can also annotate this PDF and upload it as part of your review

When ready submit online.

Editorial Criteria

Use these criteria points to structure your review. The full detailed editorial criteria is on your guidance page.

BASIC REPORTING

- Clear, unambiguous, professional English language used throughout.
- Intro & background to show context. Literature well referenced & relevant.
- Structure conforms to PeerJ standards, discipline norm, or improved for clarity.
- Figures are relevant, high quality, well labelled & described.
- Raw data supplied (see PeerJ policy).

EXPERIMENTAL DESIGN

- Original primary research within Scope of the journal.
- Research question well defined, relevant & meaningful. It is stated how the research fills an identified knowledge gap.
- Rigorous investigation performed to a high technical & ethical standard.
- Methods described with sufficient detail & information to replicate.

VALIDITY OF THE FINDINGS

- Impact and novelty not assessed. Negative/inconclusive results accepted. *Meaningful* replication encouraged where rationale & benefit to literature is clearly stated.
- Data is robust, statistically sound, & controlled.
- Speculation is welcome, but should be identified as such.
- Conclusions are well stated, linked to original research question & limited to supporting results.

Standout reviewing tips

The best reviewers use these techniques

Tip	***Example***
Support criticisms with evidence from the text or from other sources	*Smith et al (J of Methodology, 2005, V3, pp 123) have shown that the analysis you use in Lines 241-250 is not the most appropriate for this situation. Please explain why you used this method.*
Give specific suggestions on how to improve the manuscript	*Your introduction needs more detail. I suggest that you improve the description at lines 57- 86 to provide more justification for your study (specifically, you should expand upon the knowledge gap being filled).*
Comment on language and grammar issues	*The English language should be improved to ensure that an international audience can clearly understand your text. Some examples where the language could be improved include lines 23, 77, 121, 128 – the current phrasing makes comprehension difficult.*
Organize by importance of the issues, and number your points	*1. Your most important issue* *2. The next most important item* *3. …* *4. The least important points*
Please provide constructive criticism, and avoid personal opinions	*I thank you for providing the raw data, however your supplemental files need more descriptive metadata identifiers to be useful to future readers. Although your results are compelling, the data analysis should be improved in the following ways: AA, BB, CC*
Comment on strengths (as well as weaknesses) of the manuscript	*I commend the authors for their extensive data set, compiled over many years of detailed fieldwork. In addition, the manuscript is clearly written in professional, unambiguous language. If there is a weakness, it is in the statistical analysis (as I have noted above) which should be improved upon before Acceptance.*

Alfalfa and soil chemical properties response to irrigation in saline-sodic soil region

Hongtao Yang [1, 2] , **Fenghua An** [2] , **Fan Yang** [2] , **Zhichun Wang** [Corresp. 2]

1 University of Chinese Academy of Sciences, Beijing, China
2 Northeast Insitute of Geography and Agroecology, Chinese Academy of Sciences, Changchun city, Jilin Province, China

Corresponding Author: Zhichun Wang
Email address: wangzhichu@iga.ac.cn

Background. In livestock systems in western Jilin province, its forage production stability relies on the irrigation. Improving forage yield, water use efficiency (WUE) and soil properties under irrigation is very important for food and ecology security in water shortage region.

Methods. A field experiment was conducted to study the effects of irrigation on artificial grassland productivity and soil chemical properties from 2015 to 2018. Irrigation treatments in this study were 263.5 × 2 mm, 265.3 mm, 263.5 × 3 mm and 0 mm of water were supplied at regreen + branch (I1), regreen + anthesis (I2), branch + anthesis (I3), regreen (I4), branch (I5), anthesis (I6), regreen + branch + anthesis (I7), CK (no irrigation) respectively.

Results. Results showed that irrigation significantly ($P < 0.01$) increased the dry yield (DM) from 114 g m^{-2} to 1703 g m^{-2}, heightened the stem height (SH) from 55 cm to 124 cm, promoted the water use efficiency (WUE) from 1.33 kg m^{-3} to 2.50 kg m^{-3}, and 1.87 % of the ratio of stem to leaves (SLR) was increased. In addition, ~~the~~ there were no difference of SPAD between irrigation treatments and CK. The soil electronic conductivity (EC), sodium absorption ratio (SAR), and total alkalization (TA) (depth of 0 ~ 100 cm) were reduced 182 ~345 μS cm^{-1}, 8.95 ~ 9.00 $(mmol_c/L)^{1/2}$, and 3.29 ~ 4.65 $mmol_c\ L^{-1}$ respectively. The soil pH increased 0.13 ~ 0.56 at the depth of 40 ~ 60 cm, and 0.01 ~ 0.80 decreased at the depth of 0 ~ 40 cm and 80 ~ 100 cm. Considering the precipitation, evaporation, water resources, and soil chemical properties, 236.5 mm of irrigation water were recommended at branching stage of alfalfa for the eastern Songnen plain, northeast China.

Alfalfa and soil chemical properties response to irrigation in saline-sodic soil region

Hongtao Yang [1,2], Fenghua An [2], Fan Yang [2], Zhichun Wang [2,*]

[1]University of Chinese Academy of Sciences, Beijing 100049, (China)

[2]Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Changchun 130102, (China)

Corresponding Author:

Zhichun Wang

Shengbei Street No. 4888, Changchun city, Jilin Province, 130102, China

Email address: wangzhichun@iga.ac.cn

Alfalfa and soil chemical properties response to irrigation in saline-sodic soil region

Abstract

Background.

In livestock systems in western Jilin province, its forage production stability relies on the irrigation. Improving forage yield, water use efficiency (WUE) and soil properties under irrigation is very important for food and ecology security in water shortage region.

Methods.

A field experiment was conducted to study the effects of irrigation on artificial grassland productivity and soil chemical properties from 2015 to 2018. Irrigation treatments in this study were 263.5 × 2 mm, 265.3 mm, 263.5 × 3 mm and 0 mm of water were supplied at regreen + branch (I1), regreen + anthesis (I2), branch + anthesis (I3), regreen (I4), branch (I5), anthesis (I6), regreen + branch + anthesis (I7), CK (no irrigation) respectively.

Results.

Results showed that irrigation significantly ($P < 0.01$) increased the dry yield (DM) from 114 g m^{-2} to 1703 g m^{-2}, heightened the stem height (SH) from 55 cm to 124 cm, promoted the water use efficiency (WUE) from 1.33 kg m^{-3} to 2.50 kg m^{-3}, and 1.87 % of the ratio of stem to leaves (SLR) was increased. In addition, the there were no difference of SPAD between irrigation treatments and CK. The soil electronic conductivity (EC), sodium absorption ratio (SAR), and total alkalization (TA) (depth of 0 ~ 100 cm) were reduced 182 ~345 μS cm^{-1}, 8.95 ~ 9.00 $(mmol_c/L)^{1/2}$, and 3.29 ~ 4.65 $mmol_c$ L^{-1} respectively. The soil pH increased 0.13 ~ 0.56 at the depth of 40 ~ 60 cm, and 0.01 ~ 0.80 decreased at the depth of 0 ~ 40 cm and 80 ~ 100 cm. Considering the precipitation, evaporation, water resources, and soil chemical properties, 236.5 mm of irrigation water were recommended at branching stage of alfalfa for the eastern Songnen plain, northeast China.

Keywords: artificial grassland; grassland productivity; irrigation schedule; soil chemical properties; saline-sodic soils utilization

Introduction

Salt-affected soils cover an area of 9.55 × 10^8 ha worldwide, 5.60 × 10^8 ha ~~of which~~ are saline-sodic soils (Tanji, 1990). Such soils commonly distribute in arid and semi-arid regions and they are characterized by excessive Na^+, which causes damage to soil structure, reduction in soil infiltration rate and fertility (Qadir & Schubert, 2002; Qadir et al., 2005). It has been reported that saturation hydraulic conductivity is only 0.02 ~ 0.22 mm d^{-1} (Chi & Wang, 2010), and the infiltration rate decreases quickly after 10 min irrigation and tends to 0 mm d^{-1} after 15 min irrigation (Wang et al., 2004). The soil pH ranges from 8.5 to 10.5 with 30% to over 70% of exchangeable sodium percentage (ESP) (Li et al., 2006). Nowadays, water shortage as well as soil salinity-sodicity have been considered as the most constrains limiting plant survival and growth (Bandeoğlu et al., 2004; Shi & Wang, 2005). Moreover, the collaborative movement salts and water makes the water deficit and ineffectiveness, and threats to the sustainable yield of crop and forage and thus to the fragile ecosystems in the salt affected areas.

Alfalfa (*Medicago sativa* L.)~~, which~~ is a C3 and one of the most important perennial legume forage around the world because of its good nutritional forage quality for husbandry and its ability to improve soil fertility (Guo et al., 2005; Dincă et al., 2017). However, it's generally accepted that alfalfa is a high water requirement specie compare to other crops due to its high yield and long growing season (Bauder et al., 1992). Numerous studies have indicated that seasonal evapotranspiration of alfalfa is approximately 700 ~ 1600 mm depending on climate and growing period (Sahin & Hanay, 1996; FAO, 2002). The challenges for western Songnen plain, northeastern China in coming decades of food security and food self-sufficient are linked to the increasing natural resources pressures, particularly in water shortage and soil salinity-alkalinity regions. ~~Ways of alleviating~~ water shortage and soil salinity-~~alkalinity are~~ by enhancing the WUE ~~or crop productivity~~ and ameliorating the saline-sodic soils. However, there are large areas of saline-sodic soils distributing in western Songnen plain, and the annual precipitation is 370 ~ 400 mm, 80% of which occurred in July and August, and the annual pan evaporation reaches 1700 ~ 1900 mm (Chi & Wang, 2010). There is huge gap between annual precipitation and water demand of alfalfa. Thus, irrigation is a crucial factor for alfalfa to gain maximum forage yield in this region.

Irrigation is widely used to maintain higher forage yield of alfalfa in arid and semi-arid regions (Guo et al., 2007). However, it is hard to decide the right time and reasonable water amount to irrigate alfalfa artificial grasslands in this region, since it could require complex economic and environmental analysis to maximum economic and ecological benefits returns. A common method to irrigation scheduling for crops is to calculate the allowable soil water depletion, which depends on the soil type, evapotranspiration and the crop species. Previous studies on artificial grassland have mainly focused on comparison of irrigation modes and water use efficiency (WUE) of alfalfa (Grimes et al. 1992; Estill et al., 1993; Potters et al., 2007; Kuslu et al., 2010; Singh et al., 2010). In addition, comprehensive or individual effects of leguminous forage cultivations on soil desalinization and amelioration or have been carried out for the purposes of irrigation scheduling for non-saline-sodic soil regions or saving water by using reused water (Heidarpour et al., 2007). ~~Whereas~~ there is lack of information on the effects different irrigation schedules on alfalfa artificial grassland productivity, saline-sodic soil chemical property changes and suitable water strategies for western Songnen plain, northeastern China. The objectives of this study were to figure out the following questions: 1) which irrigation schedule would be optimal for promoting the artificial grassland productivity in western Songnen plain? 2) How would the irrigation schemes affect the soil chemical properties?

Materials and methods

Study site

The experiment site (N 45°34′36″ ~ N 45°34′29″, E 123°2′24″~ E 123°2′47″, shown in figure 2) ~~locates at~~ 15 km east of Baicheng City, Jilin province, China. The climate of study site is temperate continental monsoon climate with the annual precipitation 380 ~ 450 mm and the annual evaporation more than 1500 mm (Figure 1). The field experiment was conducted from September 2015 to July 2018 on an alfalfa artificial grassland, which was established in the spring of 2009 by incorporating 20 cm sandy soil into a degraded nature grassland. Alfalfa cultivar of Gongnong No. 1 of *Medicago sativa* cv. were used as the plant material in this experiment and the alfalfa were harvested in July and October every year.

Figure 1 The annual precipitation and evaporation of the study site (recorded from 2008.1.1 to 2018.7.31)

The average soil bulk density (0 ~ 100 cm) was 1.59 g cm^{-3} and has a wide range soil pH (8.52 ~ 10.45). The electronic conductivity (EC) averaged ≥ 200 μS cm^{-1}.

Table 1 The soil properties of experiment site (0 ~ 100 cm)

Note, EC, electrical conductivity; SAR, sodium absorption ratio; TA, total alkalinity

Experimental design

The spatial distribution of the experimental plots followed a randomized block design. Each plot was 5 m × 4 m = 20 m^2. Water was supplied from a local well (pH = 7.5, EC = 50 μS cm^{-1} depth > 100 m).

There were eight irrigation treatments based on the three growing stages of alfalfa with three replications (Table 2). The irrigation water amount was calculated as following:

$$I = C \times ETc$$

$$ETc = ETo \times Kc$$

ETc, alfalfa evapotranspiration or crop water use (mm); C, designed irrigation coefficient, 30%, 60%, 90% and 0% in this study; Kc, crop coefficient, 0.83 (Gulik, 2001); ETo, reference ET for alfalfa (mm), calculated by Penman-Monteith method (Allen et al., 1998).

Table 2 The experiment design

Note, C, designed irrigation coefficient;

Data collection

The relative chlorophyll content (SPAD) in each plant was determined using a SPAD-502 chlorophyll Meter (Minolta Co. Ltd., Osaka, Japan). Five stems will be selected at random from each plot for measuring the stem height from base of stem till its end. The SPAD was measured every week since the beginning of regreen stage of alfalfa. Then the mean values of SPAD were calculated.

Dry yields (DM) were measured by harvesting a 1.0 m × 1.0 m quadrat from the center of each plot when alfalfa reached 50%-anthesis. Samples were air-dried in a repository. The DM was calculated by the 1st and 2nd harvest of alfalfa dry yield.

Each subsample of alfalfa was separated into leaves and stem fractions for detecting the ratio of stem to leaf (SLR). The SLR was achieved through calculate the average of 1st and 2nd harvest SLR of alfalfa.

The soil water balance and alfalfa evapotranspiration (ETc) were calculated by following equation (Carter and Sheaffer, 1983).

$$ETc = P + I - D - R \pm \Delta W \tag{1}$$

ETc, evapotranspiration, mm; P, precipitation, mm; I, irrigation, mm; D, downward drainage out of root zone, mm; R, surface runoff, mm; ΔW, change in soil water storage, mm;

Drainage below the root zone was assumed to be zero since water applied with each irrigation was less than or equal to water deficit in the 1 m soil profile of the fully irrigated treatment. Runoff was considered zero because the experimental plots were surrounded by 0.15 m ~~height~~ and 20 m ~~length~~ plastic levees around its perimeter and basins were meticulously prepared to be level.

The meteorological data (from 2015 to 2018), including precipitation (P), were collected by meteorological station (HOBO U30 Weather station, Onset Computer Corporation, USA). The actual amount of irrigation (I) were recorded by the water meter set up in each plot. Neutron probe tubes were installed for measuring the ΔW weekly at the depth of 0 ~ 100 cm.

The irrigation should be slightly and water use efficiency (WUE, kg m^{-3}) were calculated ~~as~~ according to Equation 2 (Ojedaa et al., 2018):

$$WUE = Y/ETc \qquad (2)$$

Y, yield, g m^{-2};

The water consumption (WC, mm) of different treatments ~~of~~ per harvest were calculated by the following equation.

$$WC = I + P \pm \Delta W \qquad (3)$$

The water table significantly declined by extreme drought in the spring from 2015 to 2017, and large areas of new paddy fields were devolved. Thus, hydraulic pressure was too low to support all plot equally. This might induce ~~the~~ non-significant difference of actual water consumption among the treatments.

The alfalfa water sensitive indexes of different growth stages were calculated as (Jensen, 1968):

$$\frac{Y}{Y_{\mathbf{m}}} = \prod_{i=1}^{\mathbf{n}} \left(\frac{ET_i}{ET_{mi}} \right)^{\lambda_i} \qquad (4)$$

n, stage number of alfalfa; i, serial number of alfalfa growth stages; Y, actual yield, (kg ha^{-1}); Ym, maximum or potential grain yield with water not limiting production, (kg ha^{-1}); ETi, actual evapotranspiration in growth stage i, (mm); ETmi, maximum or potential evapotranspiration in growth stage i, (mm); λ_i, water sensitive index in growth stage i;

The soil samples of September 2015 and October 2017 were collected for measuring soil chemical properties, such as soil pH, EC, sodium absorption ratio (SAR) and total alkalinity (TA). The collected soil samples were air-dried, mixed, sieved through 2-mm sieve, and then analyzed according to the methods described by USDA (1954).

Soil pH and EC were measured in a soil-water suspension with a 1:5 soil/water ratio by using pH and EC meter (Mettle Toledo, Shanghai, China). The K^+ and Na^+ concentrations from the soil-water suspension were analyzed by flame photometry (Shanghai Precision Co. Ltd. China), whereas the concentrations of Ca^{2+} and Mg^{2+} were determined by atomic absorption spectrometry (Haiguang GGX 605, shanghai, China). The SAR and TA were calculated by the Equations below.

$$SAR = \frac{[\mathrm{Na}^{+}]}{\sqrt{\frac{1}{2}([\mathrm{Ca}^{2+}]+[\mathrm{Mg}^{2+}])}} \quad (5)$$

$$TA = [CO_3{}^{2-}] + [\mathrm{HCO_3}^{-}] \quad (6)$$

The differences of the soil pH, EC, SAR and TA at 2015 and 2017 were calculated for representing the soil chemical properties changes.

$$\Delta\ \mathrm{pH} = \mathrm{pH}_{2015} - \mathrm{pH}_{2017} \quad (7)$$

$$\Delta\ \mathrm{EC} = \mathrm{EC}_{2015} - \mathrm{EC}_{2017} \quad (8)$$

$$\Delta\ \mathrm{SAR} = \mathrm{SAR}_{2015} - \mathrm{SAR}_{2017} \quad (9)$$

$$\Delta\ \mathrm{TA} = \mathrm{TA}_{2015} - \mathrm{TA}_{2017} \quad (10)$$

Data analysis

For each soil, one-way ANOVA was performed on SLR, DM, SH, SPAD and WUE using SPSS ($P < 0.05$) (Version 20.0, IBM). Multiple linear regression was conducted to determine the relationship between the actual alfalfa yield and the predictable alfalfa yield.

Origin 8.0 (OriginLab Corporation, Northampton, MA, USA) was employed for figuring.

Results

The precipitation and evaporation of growing season in study site

During the growing season (from April to October), 325 mm and 457.4 mm rainfall were recorded in 2016 and 2017, respectively. However, 982.1 mm and 1076.4 mm of water were evaporated at the same period.

Figure 2 The precipitation and evaporation during the growing season in 2016 and 2017 (P, precipitation, mm; E, evaporation, mm)

Approximately 90% of annual precipitation in 2016 and 2017 occurred in growing season, and about 4% of annual evaporation were recorded at the same period. Maximum precipitation and evaporation of 2016 were 98.9 mm (August) and 187 mm (April) and the maximum precipitation and evaporation of 2017 occurred at June (176.3 mm) and April (231.3 mm). The Alfalfa regreened at late April, when maximum evaporation and minimum precipitation happened.

The bio-characteristics of alfalfa under different treatments

The stem height (SH, cm), SPAD, dry yield (DM, g m^{-2}) and the ratio of stem to leaves (SLR) of different treatments were shown in the Table 3.

Table 3 Biomass, SLR, SH and SPAD of alfalfa under different treatments

Note, SLR, mass ratio of stems to leaves; DM, dry yield, g m^{-2}; SH, stem height of alfalfa, cm; I1, irrigate at regreen and branch stages; I2, irrigate at branch and anthesis stages; I3, irrigate at regreen and anthesis stages; I4, irrigate at branch stage; I5, irrigate at branch stage; I6, irrigate at anthesis stage; I7, irrigate at regreen, branch and anthesis stages; CK, no irrigation;

It was clear that the DM, SLR, and SH were significantly ($P < 0.05$) influenced by irrigation in western Songnen plain. The DMs of irrigated plots were 455.26% ~ 1393.86% heavier than DM of CK. The SH of irrigation treatments were 79.04% ~ 124.61% higher than the SH of CK. In addition, SLRs of irrigation treatments were 1.87% higher than the SLR of CK. Furthermore, irrigation treatment enhanced the chlorophyll concentration than the SPAD of CK but there were no notable differences ($P < 0.05$).

The DMs irrigated at only one alfalfa growth stage were significantly ($P<0.05$) lower than the DMs with irrigating at two growth stages of alfalfa. It was clear that DM of I2 reached up to 980 g m^{-2}, which was the highest yield among the deficit treatments, then followed by I1 (953.33 g m^{-2}). The highest DM, which irrigated at one growth stage of alfalfa, was observed at the I5 treatment (786.67 g m^{-2}). Evidence observed in this study showed that the effect of irrigation treatments on SLR was not significantly ($P < 0.05$). The SLRs of I1, I4 and I5 were decreased and the SLRs of I2, I3, I6 and I7 were increased by irrigation. Highest SLR was 2.62, which was observed at full irrigation treatment (I7) and then followed by SLR of I2 (2.24) and I2 (2.24). The SHs of 8 irrigation treatments ranged from 55.11 cm to 123.78 cm. Results of SH showed that I7, which irrigation at regreen, branching and anthesising stages, performed the best effects on alfalfa stem height increase then followed by I2 and I6 treatments. The values of SPAD increased from 53.33 to 64.87 among the eight treatments. Maximum SPAD value (64.87) was observed from the I7 treatment and the minimum (53.33) from CK treatment.

The actual water consumption and water use efficiency

As seen in Figure 3, the total amount of water applied to alfalfa ranged between 85 mm and 755 mm in different irrigation treatments. The actual water consumption of I1, I2 and I3 were 385 mm ~ 410 mm, respectively. Additional, the actual water consumption of I4, I5 and I6 were 288 mm ~ 314 mm and I7 consumed 733 mm water. Because of the precipitation of per harvest, 112 mm of water was supplied to CK treatment (Figure 3).

Figure 3 The WUE and WC of different treatments ($P < 0.05$)

The WUE of 7 treatments with irrigation ranged from1.33 kg m^{-3} ~ 2.50 kg m^{-3} and were significantly higher than the WUE of CK (P = 0.026 < 0.01, $F_{0.01}(7, 16) > F = 3.199 > F_{0.}$, 16), Figure 3), however, no differences among the WUEs of irrigation treatments were found (P < 0.05). The water use efficiency of alfalfa without irrigation was 1.33 kg m^{-3}. There were no ~~significantly difference~~ (P < 0.05) between the treatments of I1 (2.47 kg m^{-3}), I2 (2.42 kg m^{-3}) and I3 (2.28 kg m^{-3}), these irrigated at two growth stages of alfalfa. Compared to I4 and I6, which irrigated at one growth stage of alfalfa, I5 has reached the highest WUE (2.50 kg m^{-3}). This might imply ~~us~~t irrigate at branching stage has an important effect on WUE of alfalfa.

Irrigation schedule for western Songnen plain

The water insensitive ~~index~~ of alfalfa at regreen, Branch and Anthesis were shown in the Figure 4 below.

Figure 4 The water sensitive index of alfalfa (R, regreen period; B, branch period; A, anthesis period)

As shown in Figure 4, the water sensitive index (WSI) of branch period was significantly higher (P < 0.05, Sig. = 0.035) than the WSIs of regreen and anthesis periods. In addition, there was no significantly (P < 0.05) difference between WSI of regreen and anthesis.

$$\frac{Y}{Y_{m}} = \left(\frac{ET_1}{ET_{m1}}\right)^{0.5202} \times \left(\frac{ET_2}{ET_{m2}}\right)^{1.2393} \times \left(\frac{ET_3}{ET_{m3}}\right)^{0.6313} \quad (11)$$

The water production function of alfalfa in western Songnen plain was determined with λ_1, λ_2 and λ_3 these was shown in Figure 4. Then the water production function of alfalfa in Songnen plain was displayed in Equation 11.

Dtermination orrelation coefficient (r = 0.719) between alfalfa yield and irrigation amoun presented that Jensen model was reliable for western Songnen plain due to the critical coefficient between simulated yield and irrigation amount was 0.30 ~ 0.93 (at confidence level of α = 0.05). The simulated yield obtain from Jensen model of western Songnen plain was lower than the actual yield (Figure 5). However, the simulated yield would be ~~clo~~ to the actual yield when the irrigation amount reached at 150 mm ~ 350 mm.

Figure 5 Actual and simulated of alfalfa yield and the relations to the irrigation amount (DM-J, alfalfa yield simulated by Jensen Model; DM-R, actual alfalfa yield, g m^{-2})

Figure 6 The relation between amount of irrigation and actual alfalfa yield

The relationship between alfalfa yield and irrigation amount of artificial grassland in western Songnen plain can be simulated with cubic curve ($y = 125.188 + 3.449\,x + 0.002\,x^2 - 10^{-6}\,x^3$, $650 > x > 0$, $R^2 = 0.908$, $F = 65.607 > F_{0.01}\,(3, 20) = 4.938$) (Figure 6). Alfalfa yield could rapid increase coupled with irrigation amount increase when less than 650 mm water were supplied.

Based on the data above, 236.5 mm of irrigation water were recommended at branching stage of alfalfa for the eastern Songnen plain, northeastern China.

Effects of irrigation on soil chemical properties

Results of soil chemical properties changes after two-year irrigation were shown in the figure below.

Figure 7 The soil chemical properties changes at depth of 0 ~ 100 cm (from 2015 to 2017)

Irrigation had significant effects on soil chemical properties of different soil depth (0 ~ 100 cm, Figure 7). For example, the soil EC, SAR and TA of irrigation treatments showed better declined effects than CK. During the growing season, the average soil EC of different irrigation treatments decreased 265.83 ~ 342.87 μS cm^{-1}, and the average soil EC of CK decreased 181.98 μS cm^{-1}. The results of soil SAR (average of 0 ~ 100 cm) revealed that irrigation diminished 10.12 ~ 11.03 $(mmol_c/L)^{1/2}$, and on the contrast, the average soil SAR of CK decreased only 8.85$(mmol_c/L)^{1/2}$ from September 2015 to October 2017.

The highest decrease of soil TA was observed at I7 irrigation treatment (2.94 $mmol_c\ L^{-1}$), while the lowest decrease of soil TA was found at the I3 treatment (1.53 $mmol_c\ L^{-1}$), and the soil TA without irrigation decreased 0.84 $mmol_c\ L^{-1}$. The effects of irrigation soil pH were complicated, for instance, the soil pH at depth of 0 ~ 40 cm and 80 ~100 cm decreased at 0.01 ~ 0.80 and 0.13 ~ 0.56 increase of soil pH at the depth 40 ~ 60 cm were found.

As shown in Figure 7, I2, I4, and I5 showed better decrease effect on soil pH (0 ~ 100 cm, $\Delta pH = 0.24 \sim 0.30$) than the other treatments. The soil EC of I4 and I5 decreased 287.25 μS cm^{-1} and 283.89μS cm^{-1}, which were larger than other treatments. The soil SAR decreases 8.80 $(mmol_c/L)^{1/2}$ ~ 8.96 $(mmol_c/L)^{1/2}$, which were observed at the I2, I3, and I5 treatments; the soil TA under the condition of I5, I6, and I7 ($\Delta TA = 4.14 \sim 4.65$ $mmol_c\ L^{-1}$) showed more effective than the other treatments.

Discussion

Alfalfa is a high water consumption crop (Bauder et al., 1992), the yield of alfalfa depends on the stem height, area and amount of leaves those would be decreased when soil water deficit occurred (Saeed & El-Nadi, 1997). The DM of alfalfa with irrigation treatments in this study reached up to 633 ~ 1703 g m^{-2} correlated to SH ($r = 0.607$, $P < 0.01$) significantly, which agreed to the study of Davis and Baker (1966) who reported that the 65% of alfalfa yield was determined by shoot height. Previous studies indicated that SH could be restricted by water stress caused by water deficit or water availability (Saeed & El-Nadi, 1997; Esechie et al., 2002; Munns et al., 2006). Because of that the cell elongation, photosynthesis and nutrient uptake of alfalfa can be influenced by water stress (Saeed & El-Nadi, 1997). Hence, the alfalfa yield could be influenced by irrigation significantly. ~~Considering the background of shrinking water resources, one of the way of alleviating water shortage is by promoting the water use efficiency (Singh et al., 2010). An understanding of water use efficiency was necessary for estimating the relative high yield in arid and semi-arid regions where irrigation water was a limiting factor (Johnson & Henderson, 2002).~~ According to results of Kuslu et al. (2010) and Estill et al. (1993), DM and WUE of alfalfa were decreased by ~~the expansion of~~ water shortage. Irrigation is a key factor to maintain and promote the WUE and water productivity of artificial grassland (Potters et al., 2007). We also found a significant positive correlation ($r = 0.417$, $P < 0.05$) between WUE and irrigation amount in this study. The water use efficiency of alfalfa in this study was promoted from 1.33 kg m^{-3} to 2.50 kg m^{-3}, which was similar to ~~the results of many researches these reported in literatures ranged from~~ 1.1 kg m^{-3} to 2.3 kg m^{-3} in cooler, more northerly climates (Stanhill, 1986; Bogler & Matches, 1990; Grimes et al., 1992; Saeed & El-Nadi, 1997). ~~Increasing SLR led to decreased forage quality (Matt & Wedin, 1988).~~ Results showed that the effect of irrigation treatments on SLR was not significantly ($P < 0.05$). However, the CK treatments decreased the SLR compared with I1, I4 and I5 treatments, indicating that the forage quality might increase under irrigation. Therefore, for long-term artificial grassland productivity in western Songnen plain, perennial crops such as alfalfa should be irrigated. Results of this experiment demonstrated that ~~the saline-sodic soils could be suitable for artificial grassland after ameliorating with sandy soils and~~ if there were water supplied to the artificial grassland, the DM and WUE of alfalfa would be distinct increased ($P < 0.05$).

Soil salinity and alkalinity stresses are major factors that cause tremendous yield losses in many arid and semi-arid regions around the world. It was demonstrated that the changes of land utilization led to changes of salts distribution (Zhao et al. 2004). For instance, Nosetto et al. (2007) reported that the vegetation-dominated covers changes have ~~notably~~ effects on soil salts distribution. Furthermore, research of Dong et al. (2001) indicated that the soil pH (depth of 0 ~ 20 cm) declined from 8.1 to 7.6, and soluble salts decreased about 65.5 % at depth of 0~ 40 cm after planting alfalfa for 7 years. The soil EC (0 ~ 20 cm) and HCO_3^- concentration decreased markedly after planting alfalfa for 3 years (Cao et al., 2012). Influenced by different irrigation treatments in this study, the soil chemical properties (depth of 0 ~ 100 cm) of alfalfa artificial grassland, such as soil EC, SAR and TA reduced 182 ~ 345 μS cm^{-1}, 8.95 ~ 9.00 $(mmol_c/L)^{1/2}$, and 3.29 ~ 4.65 $mmol_c$ L^{-1}, respectively. These results might ascribe to the deep taproot system of alfalfa, which could improves soil quality (Raiesi, 2007; Yong, 2007). Moreover, soil evaporation and soil salts in surface soil could be decreased by cultivating salt tolerant forages (Ghaly, 2002; Qadir et al., 1996). Additional, the forage harvested every year absorbed salts from the soil, and there were no or less salts from irrigation and precipitation, and finally this might contribute to the soil chemical properties changes in western Song plain.

Conclusions

Results of this study indicated that Results of this experiment demonstrated that the saline-sodic soils could be suitable for artificial grassland after ameliorated with sandy soils, and if there were water supplied to the artificial grassland, the DM and WUE of alfalfa would be distinct increased. For example, the artificial grassland productivity was promoted from 114 g m^{-2} to 170 g m^{-2} and WUE was heightened from1.33 kg m^{-3} to 2.50 kg m^{-3} by irrigation. Additional, soil EC, SAR and TA (at depth of 1.0 m) were also decreased by irrigation. Considering the local precipitation, evaporation, water resources, and soil chemical properties, 236.5 mm of irrigation water at branch stage were recommended for artificial grasslands in western Songnen plain. The findings of this study are very important implications for decision makers and alfalfa farmers.

Acknowledgements

We appreciate the foundation support from the foundations of National Natural Science Foundation of China (41571210, 41771250), Technology development project of Jilin province (20180201012SF), National key research and development program of China (2016YFC0501200), National science and technology basic work of China (2015FY110500) and National natural science foundation (NSCF, 41701335).

Reference

Allen [illegible] Pereira LS, Raes D, Smith M. 1998. Crop Evapotranspiration: guidelines for Computing Crop Water Requirements. Food and Agriculture Organization of the United Nations, Rome.

Bin Li, Zhichun Wang, Chunming Chi. 2006. Parameters and characteristics of alkalization of sodic soil in Da'an City. *Journal of Ecology and Rural Environment* **22**:20-23 (in Chinese with English abstract).

Bogler TP, Matches AG. 1990. Water use efficiency and yield of sainfoin and alfalfa. *Crop Science* **30**:143-148.

Chunming Chi, Zhichun Wang. 2010. Characterizing salt-affected soils of Songnen Plain using saturated paste and 1:5 soil-to-water extraction methods. *Arid Land Research and Management* **24**(1):1-11.

CY Wang, ZJ Wu, YL Shi, RY Wang. 2004. The resource of saline soil in the Northeast China. *Chinese Journal of Soil Science* **35**(5), 643-647 (In Chinese with English abstract).

DC Shi, DL Wang. 2005. Effects of various salt-alkaline mixed stresses on *Aneurolepidium chinense* (Trin.) Kitag. *Plant and Soil* **271**:15-26.

E Bandeoğlu, F Eyidoğan, M Yücel, HA Öktem. 2004. Antioxidant responses of shoots and roots of lentil to NaCl-salinity stress. *Plant Growth Regulation* **42**:69-77.

Esechie HA, Al-Barhi B, Al-Gheity S, Al-Khanjari S. 2002. Root and shoot growth in salinity stressed alfalfa in response to nitrogen source. *Journal of Plant Nutrition* **25**:2559-2569.

EV Maas, GJ Hoffman. 1977. Crop Salt Tolerance, Current Assessment. *Journal of the Irrigation and Drainage Division* **103**:115-134.

FAO. 2002. Deficit irrigation practices. FAO Water Report No. 22, Rome.

FM Ghaly. 2002. Role of natural vegetation in improving salt affected soil in northern Egypt. *Soil & Tillage Research* **64**:173-178.

GA Bee, G Laslett. 2002. Development of a rainfed Lucerne-based farming system in the Mediterranean climatic region of Southwestern Australia. *Agricultural Water Management* **53**:111-116.

Geert Potters, Taras P Pasternak, Yves Guisez, Klaus J Palme. 2007. Stress-induced morphogenic responses: growing out of trouble. *Trends in Plant Science* **12**(3):98-105.

Grimes DW, Wiley PL, Sheesley WR. 1992. Alfalfa yield and plant water relations with variable irrigation. *Crop Science* **32**:1381-1387.

Jing Cao, Xianting Li, Xiaole Kong, Rengel Zed, Liping Dong. 2012. Using alfalfa (*Medicago sativa* L.) to ameliorate salt-affected soils in Yingda irrigation district in Northwest China. *Acta Ecologica Sinica* **32**(2):68-73.

JJ Ojedaa, OP Caviglia, MG Agnusdei, PM Errecart. 2018. Forage yield, water- and solar radiation-productivities of perennial pastures and annual crops sequences in the south-eastern Pampas of Argentina. *Field Crops Research* **221**:19-31.

Johnson BL, TL Henderson. 2002. Water use efficiency. Water use patterns of grain amaranth in the Northern Great Plains. *Agronomy Journal* **94**:1437-1443.

JW Bauder, JS Jacobsen, WT Lanier. 1992. Alfalfa emergence and survival response to irrigation water quality and soil series. *Soil Science Society of America Journal* **56**:890-896.

K Estill, RH Delaney, RL Ditterline, WK Smith. 1993. Water relations and productivity of alfalfa populations divergently selected for leaflet size. *Field Crops Research* **33**:423-434.

KK Tanji. 1990. Nature and extent of agricultural salinity. In: Agricultural salinity assessment and management. (ed. K.K. Tanji), pp. 1-17. American Society of Civil Engineers, New York, NY.

Kuslu Y, Sahin U, Tunc T, Kiziloglu FM. 2010. Determining water-yield relationship, water use efficiency, seasonal crop and pan coefficients for alfalfa in a semiarid region with high altitude. *Bulgarian Journal of Agricultural Science* **16** (4):482-492.

M Heidarpour, B Mostafazadeh-Fard, J Abedi Koupai, R Malekian. 2007. The effects of treated wastewater on soil chemical properties using subsurface and surface irrigation methods. *Agricultural Water Management* **90**:87-94.

M Qadir, AD Noble, JD Oster, S Schubert, A Ghafoor. 2005. Driving forces for sodium removal during phytoremediation of calcareous sodic and saline-sodic soils: a review. *Soil Use and Management* **21**:173-180.

M Qadir, RH Qureshi, N Ahmad, M Ilyas. 1996. Salt-tolerant forage cultivation on a saline-sodic field for biomass production and soil reclamation. *Land Degradation & Development* 7:11-18.

M Qadir, S Schubert. 2002. Degradation processes and nutrient constraints in sodic soils. *Land Degradation and Development* **13**:275-294.

Marcelo D Nosetto, Esteban G Jobbágy, Tibor Tóth, Carlos M Di Bella. 2007. The effects of tree establishment on water and salt dynamics in naturally salt-affected grasslands. *Oecologia* **152**:695-705.

ME Jensen. 1968. Water comsumption by agricultural plants. TT Kozlowski (Ed.), Water Deficits in Plant Growth, 1, pp. 1-22. Academic Press, New York, USA.

Niculae Dincă, Daniel Dunea, Stefano Casadei, Nicolae Petrescu, Sebastian Barbu. 2017. An assessment of the water use efficiency in alfalfa cnopy under the climate regime of trgoviste piedmont plain. *Agronomy*, **LX**:235-240.

Raiesi F. 2007. The conversion of overgrazed pastures to almond orchards and alfalfa cropping systems may favor microbial indicators of soil quality in Central Iran. *Agriculture Ecosystems & Environment* **121**:309-318.

Rana Munns, Richard A. James, André Läuchli. 2006. Approaches to increasing the salt tolerance of wheat and other cereals. *Journal of Experimental Botany* **57**:1025-1043.

Ravender Singh, Kundu DK, Bandyopadhyay KK. 2010. Enhancing Agricultural Productivity through Enhanced Water Use Efficiency. *Journal of Agricultural Physics* **10**:1-15.

RL Davis, RJ Baker. 1966. Predicting yields from associated characters in *Medieago sativa* L. *Crop Science* **2**:492-494.

Saeed IAM, El-Nadi A. H. 1997. Irrigation effects on the growth, yield, and water use efficiency of alfalfa. *Irrigation Science* **17**:63-68.

Stanhill G. 1986. Water use efficiency. *Advances in Agronomy* **39**:53-85.

Ted Van der Gulik T. 2001. Crop coefficients for use in irrigation scheduling. Ministry of Agriculture, Food and Fisheries of British Columbia. Agdex 561. http://irrigationtoolbox.com/ReferenceDocuments/Extension/BCExtension/577100-5.pdf

U Sahin, A Hanay. 1996. Irrigation scheduling for the planned crop-pattern to be grown in Daphan plain of Erzurum by means of computer techniques. *Turkish Journal of Agriculture and Forestry* **20**:415-423.

United States Department of Agriculture (USDA) (1954) Diagnosis and Improvement of Saline and Alkali Soils. Agriculture Handbook No. 60. United States Salinity Laboratory, Riverside, CA.

Xiaoxia Dong, Hongmei Guo, Ling'an Kong. 2001. Effects of alfalfa cultivation in costal saline soil region on soil fertilizer and salts. *Shandong agriculture sciences* **1**(12):24-25. (In Chinese)

Zhongsu Yong. 2007. Soil carbon and nitrogen sequestration following the conversion of cropland to alfalfa forage land in northwest China. *Soil & Tillage Research* **92**:181-189.

Chuanyan Zhao,Zhaodong Feng, Guodong Chen. 2004. Soil water balance simulation of alfalfa in the semiarid Chinese Loess Plateau. *Agricultural Water Management* **69**:101-114.

Zhenggang Guo, Huixia Liu, Suomin Wang, Fuping Tian, Guodong Cheng. 2005. Biomass, persistence, and drought resistance of nine lucerne varieties in the dry land environment of West China. *Australian Journal of Experimental Agriculture* **45**:59-64.

Zhenggang Guo, Huixia Liu, Yanrong Wang, Kunhu Yu, Jingning Yang. 2007. Irrigating at podding and regrowth stages increases seed yield and improves pod distribution in lucerne grown in the Hexi Corridor in China. *New Zealand Journal of Agricultural Research* **50**:285-290.

Figure 1(on next page)

Figure 1 The annual precipitation and evaporation of the study site (recorded from 2008.1.1 to 2018.7.31)

Figure 1 The annual precipitation and evaporation of the study site (recorded from 2008.1.1 to 2018.7.31)

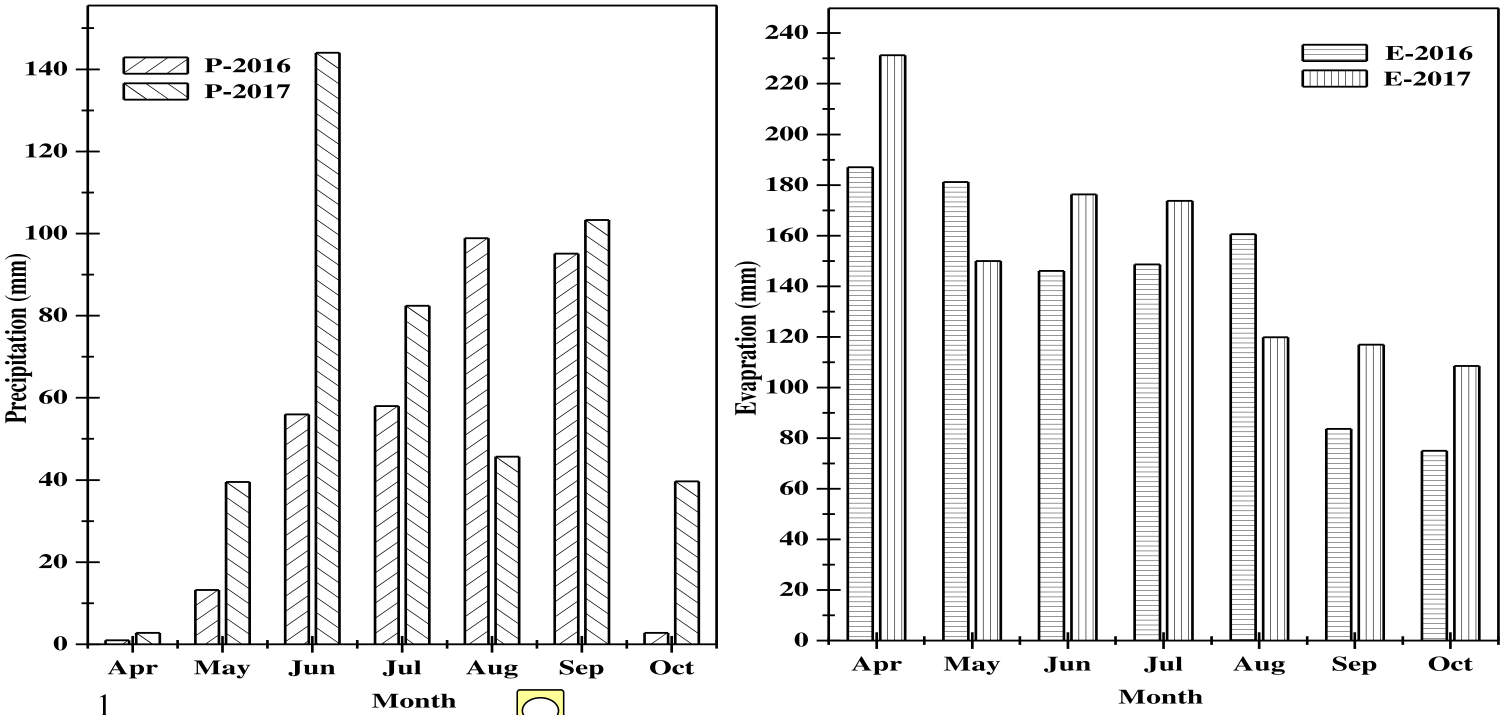


Figure 1 The annual precipitation and evaporation of the study site (recorded from 2008.1.1 to 2018.7.31)

anges at depth of 0 ~ 100 cm (from 2015 to 2017)

Figure 2(on next page)

Figure 2 The precipitation and evaporation during the growing season in 2016 and 2017 (P, precipitation, mm; E, evaporation, mm)

Figure 2 The precipitation and evaporation during the growing season in 2016 and 2017 (P, precipitation, mm; E, evaporation, mm)

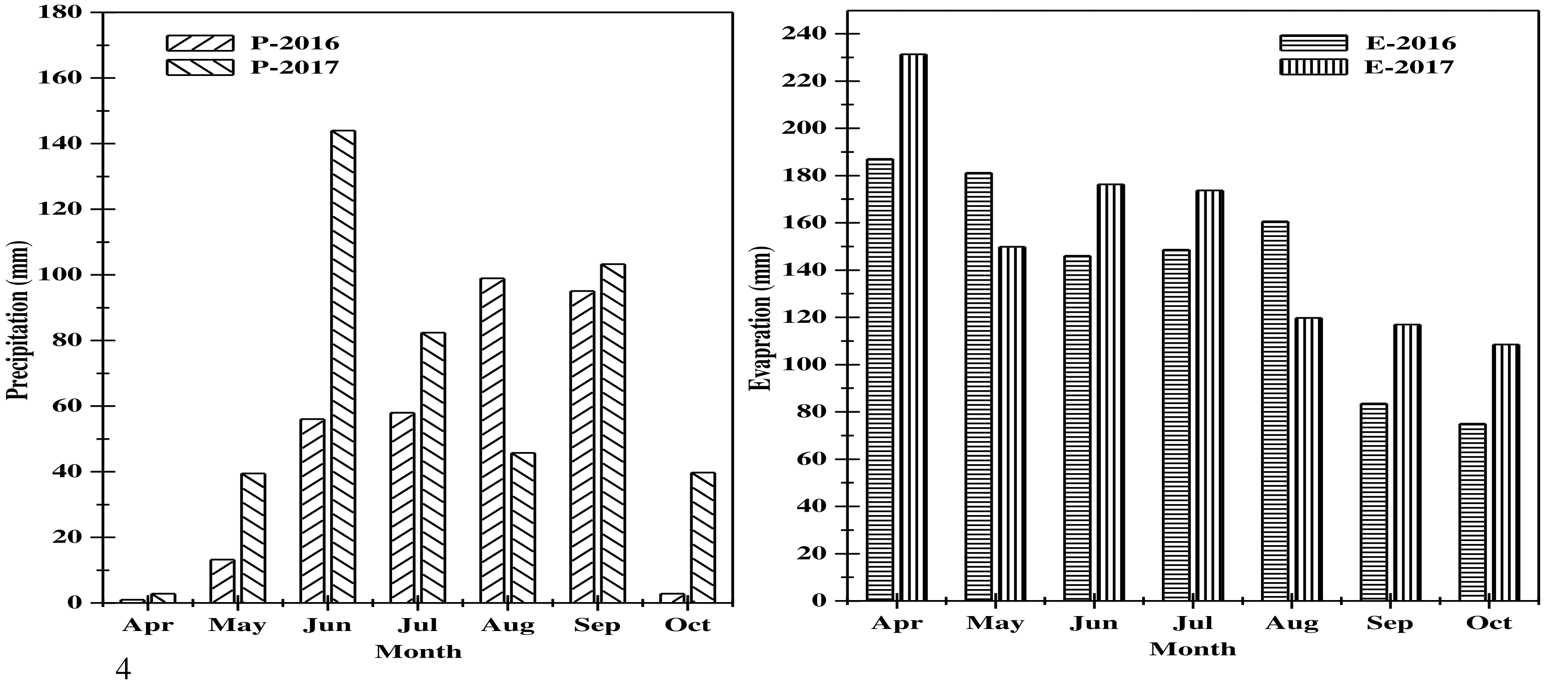


Figure 1 The precipitation and evaporation during the growing season in 2016 and 2017 (P, precipitation, mm; E, evaporation, mm)

ges at depth of 0 ~ 100 cm (from 2015 to 2017)

Figure 3(on next page)

Figure 3 The WUE and WC of different treatments (P < 0.05)

Figure 3 The WUE and WC of different treatments (P < 0.05)

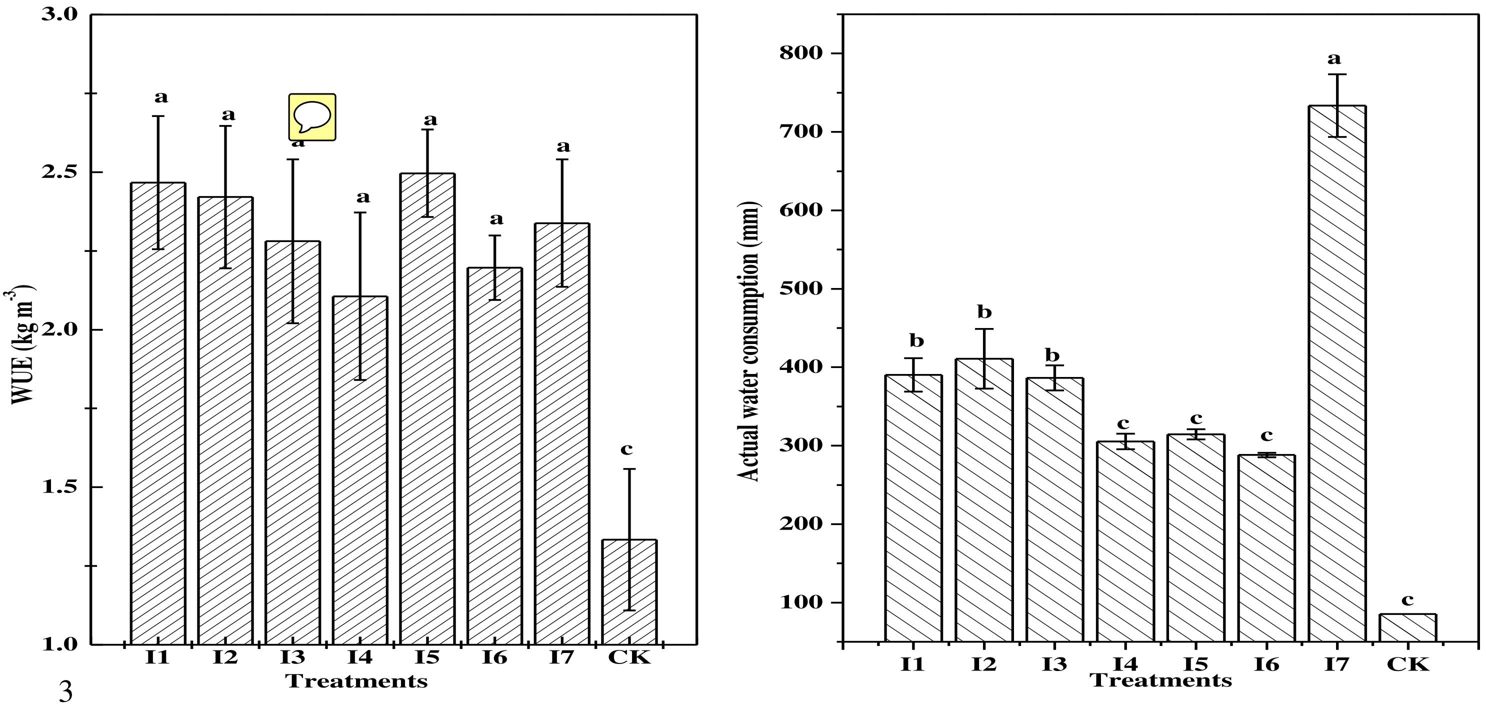


Figure 1 The WUE and WC of different treatments ($P < 0.05$

Figure 4 (on next page)

Figure 4 The water sensitive index of alfalfa (R, regreen period; B, branch period; A, anthesis period)

Figure 4 The water sensitive index of alfalfa (R, regreen period; B, branch period; A, anthesis period)

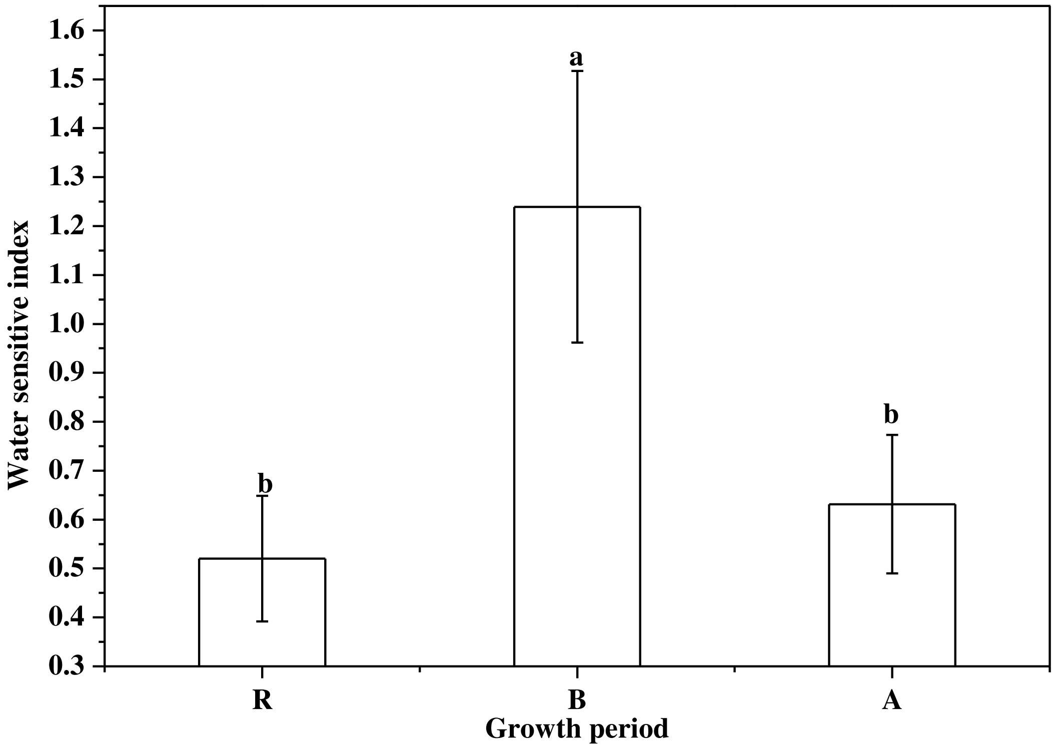


Figure 1 The water sensitive index of alfalfa (R, regreen period; B, branch period; A, anthesis period)

Figure 5(on next page)

Figure 5 Actual and simulated of alfalfa yield and the relations to the irrigation amount (DM-J, alfalfa yield simulated by Jensen Model; DM-R, actual alfalfa yield, g m^{-2})

Figure 5 Actual and simulated of alfalfa yield and the relations to the irrigation amount (DM-J, alfalfa yield simulated by Jensen Model; DM-R, actual alfalfa yield, g m^{-2})

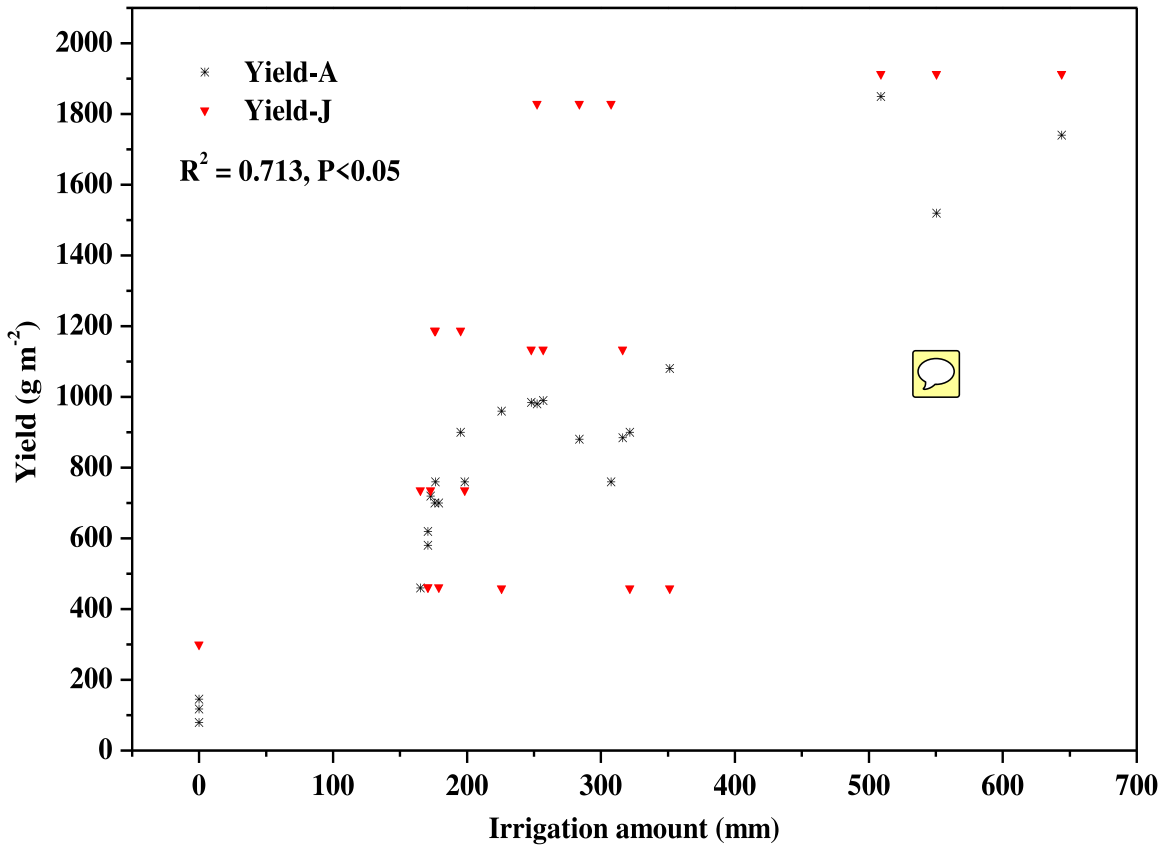


Figure 1 Actual and simulated of alfalfa yield and the relations to the irrigation amount (DM-J, alfalfa yield simulated by Jensen Model; DM-R, actual alfalfa yield, g m^{-2})

Figure 6(on next page)

Figure 6 The relation between amount of irrigation and actual alfalfa yield

Figure 6 The relation between amount of irrigation and actual alfalfa yield

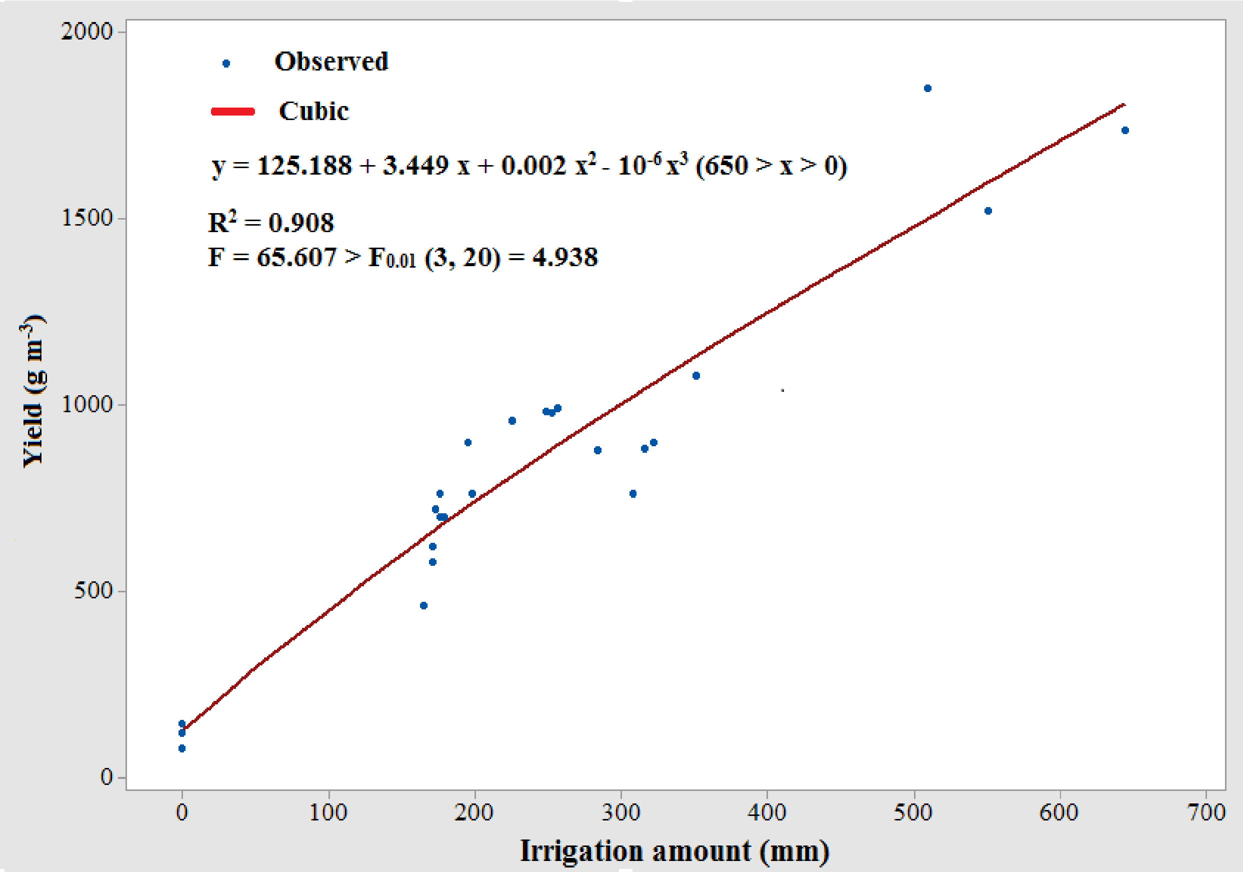
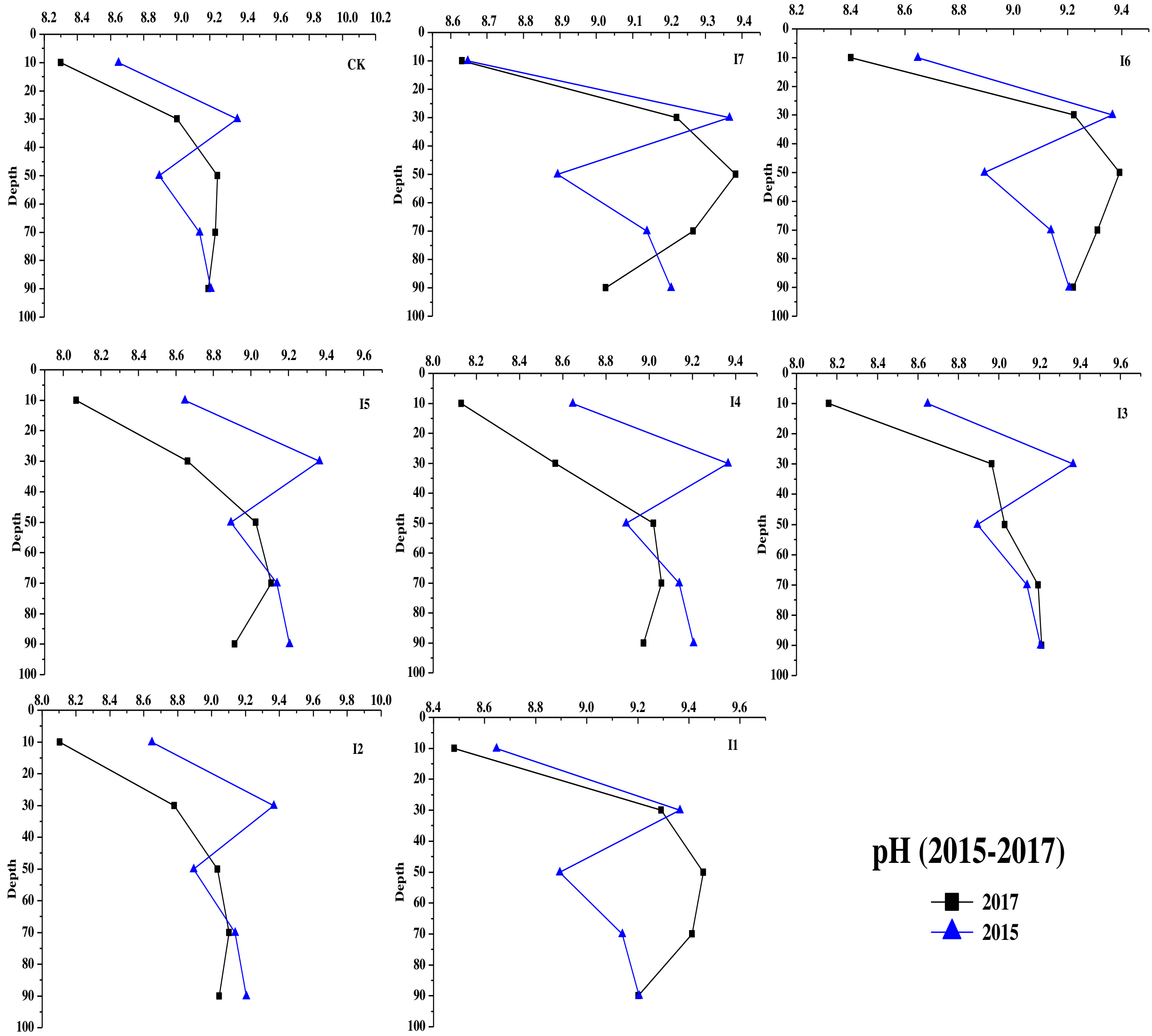


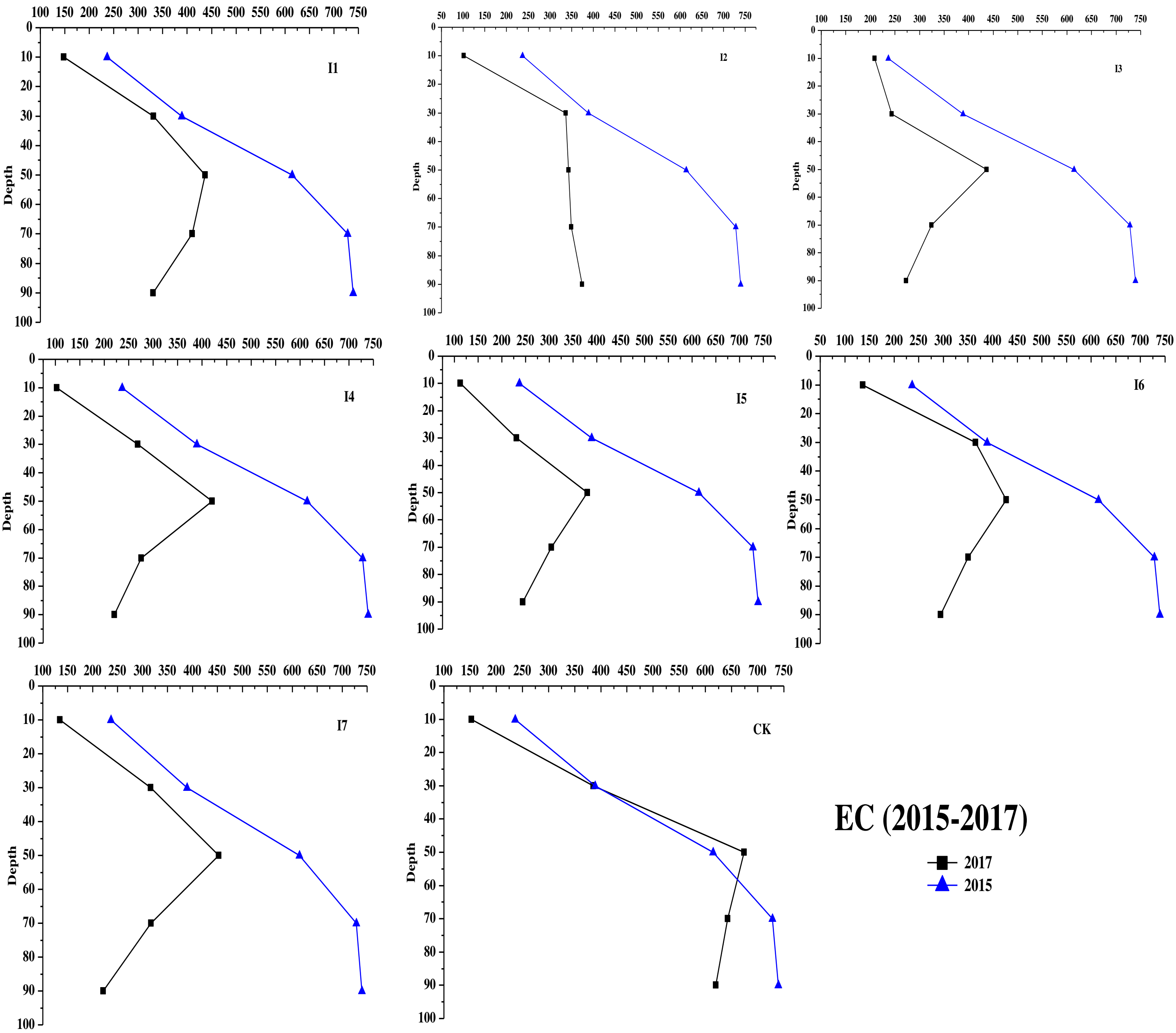
Figure 1 The relation between amount of irrigation and actual alfalfa yield

Figure 7(on next page)

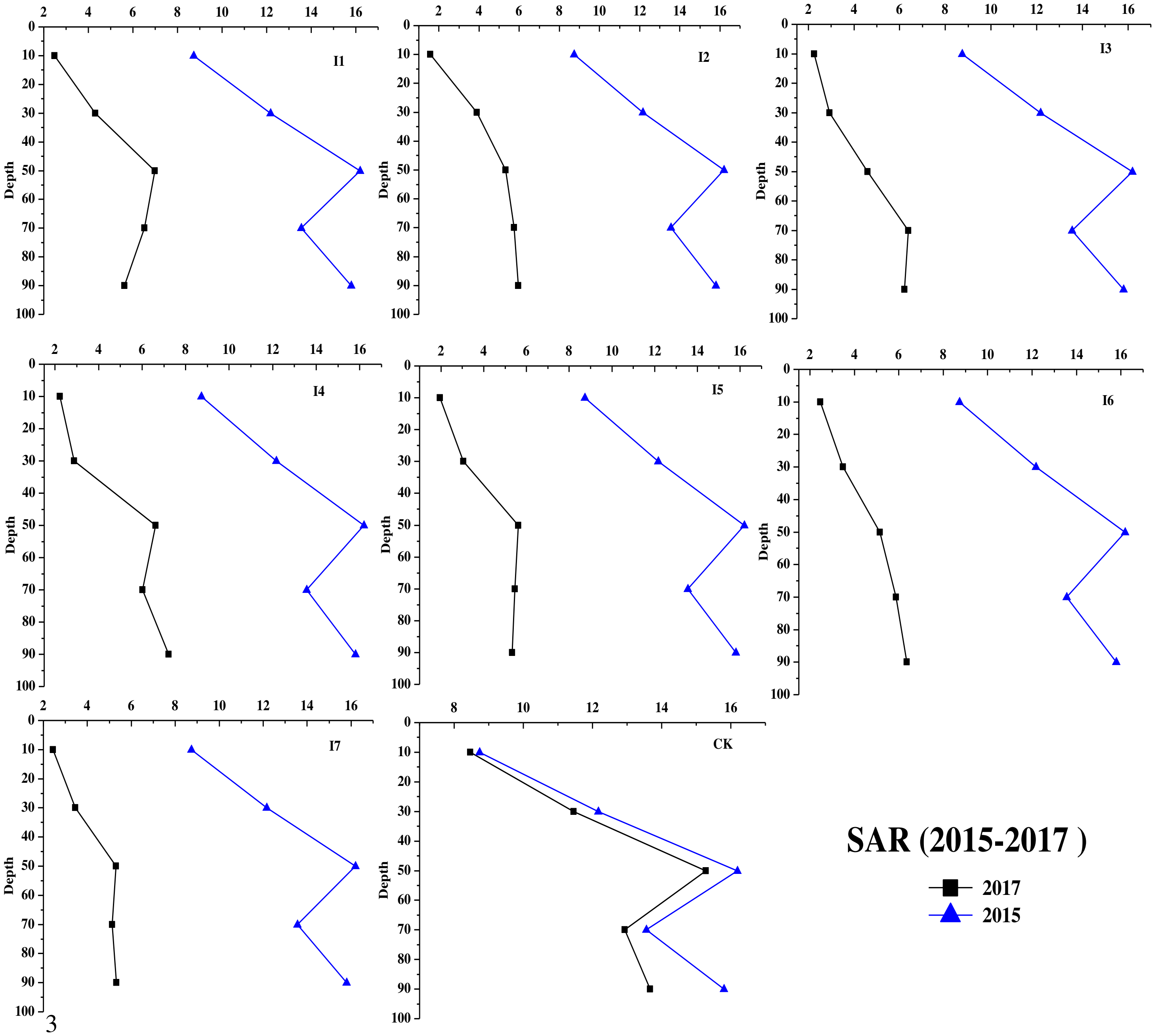
Figure 7 The soil chemical properties changes at depth of 0 ~ 100 cm (from 2015 to 2017)

Figure 7 The soil chemical properties changes at depth of 0 ~ 100 cm (from 2015 to 2017)


CK
I7
I6
I5
I4
I3
I2
I1
Depth
pH (2015-2017)
2017
2015



2



3

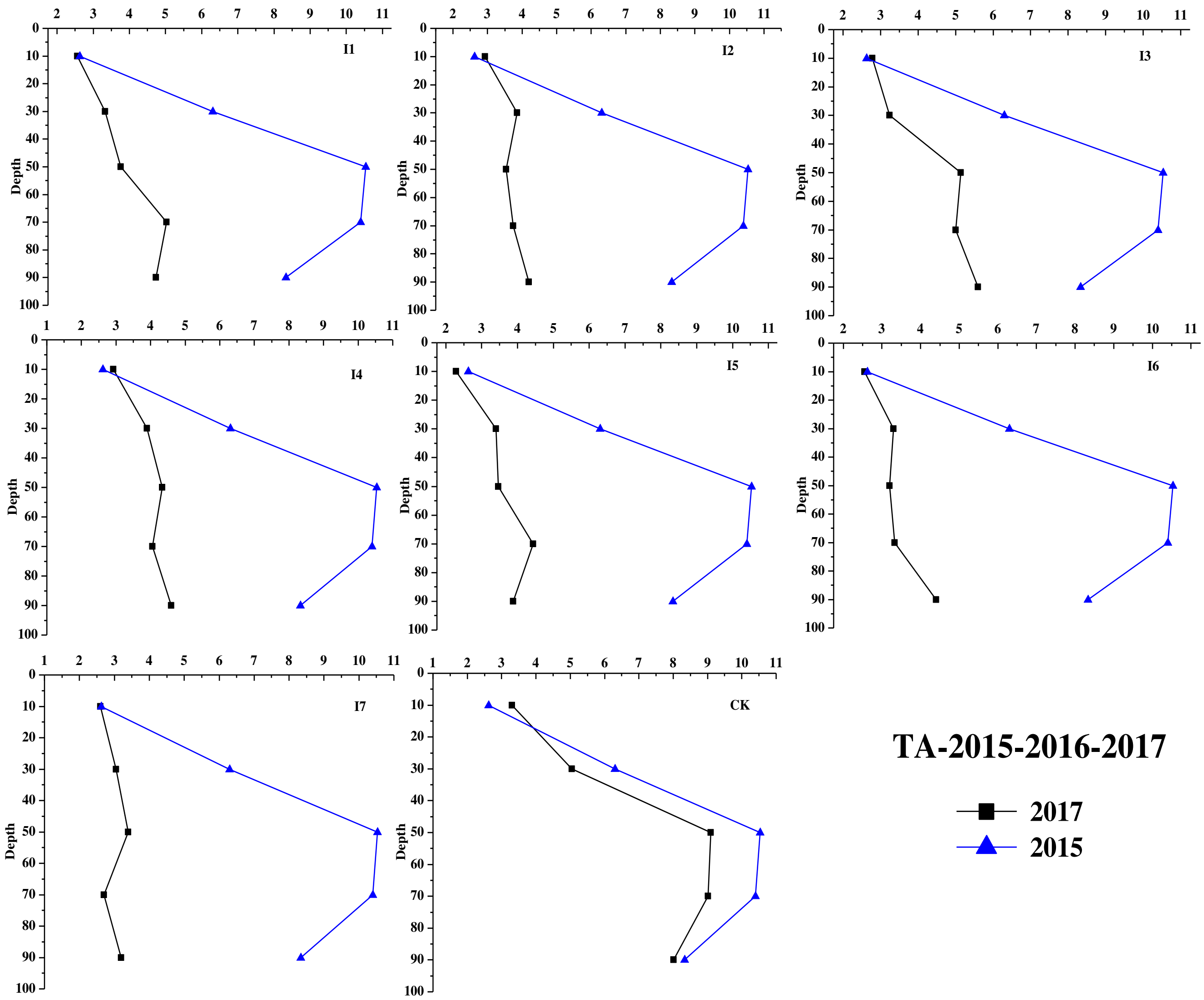


Figure 1 The soil chemical properties changes at depth of 0 ~ 100 cm (from 2015 to 2017)

Table 1(on next page)

Table 1 The soil properties of experiment site (0 ~ 100 cm)

Note, EC, electrical conductivity; SAR, sodium absorption ratio; TA, total alkalinity

Table 1 The soil properties of experiment site (0 ~ 100 cm)

Parameter	Average	Maximum	Minimum
pH	9.33 ± 0.09	10.45	8.52
EC（μS cm^{-1}）	330.18 ± 33.18	886.00	9.60
SAR（$(mmol_c/L)^{1/2}$）	7.65 ± 1.65	27.41	0.27
TA（$mmol_c$ L^{-1}）	4.35 ± 0.73	13.60	1.40
Bulk density (g cm^{-3})	1.59 ± 0.01	1.75	1.40
Field capacity (%)	37.07 ± 0.44	37.07	23.48
Porosity (%)	40.12 ± 0.36	47.29	33.81

Note, EC, electrical conductivity; SAR, sodium absorption ratio; TA, total alkalinity

Table 2(on next page)

Table 2 The experiment design

Note, C, designed irrigation coefficient; -

Table 1 The experiment design

Treatments	C	Irrigation amount(mm)	Irrigation time	Irrigation mode
I1	60%	236.5×2=473	Regreen + Branch	**Flood irrigation**
I2	60%	236.5×2=474	Branch + Anthesis	
I3	60%	236.5×2=475	Regreen + Anthesis	
I4	30%	236.5×1=236.5	Regreen	
I5	30%	236.5×1=236.6	Branch	
I6	30%	236.5×1=236.7	Anthesis	
I7	90%	236.5×3=709.5	Regreen + Branch + Anthesis	
CK	0%	0	---	---

Note, C, designed irrigation coefficient;

Table 3(on next page)

Table 3 Biomass, SLR, SH and SPAD of alfalfa under different treatments

Note, SLR, mass ratio of stems to leaves; DM, dry yield, g m^{-2}; SH, stem height of alfalfa, cm; I1, irrigate at regreen and branch stages; I2, irrigate at branch and anthesis stages; I3, irrigate at regreen and anthesis stages; I4, irrigate at branch stage; I5, irrigate at branch stage; I6, irrigate at anthesis stage; I7, irrigate at regreen, branch and anthesis stages; CK, no irrigation;

Table 1 Biomass, SLR, SH and SPAD of alfalfa under different treatments

	I1	I2	I3	I4	I5	I6	I7	CK
SLR	2.06±0.09a	2.24±0.08a	2.17±0.06a	2.08±0.07a	1.87±0.03a	2.24±0.06a	2.62±0.07a	2.14±0.01a
DM	953±34.20b	980±52.92b	873±34.64b	647±94.04c	787±59.25c	633±35.28c	1703±97.01a	114±19.16d
SH	109.78±3.61bc	110.22±1.79bc	110±4.67bc	98.67±5.35b	115.44±1.93ab	104±3.86b	123.78±2.41a	55.11±1.44e
SPAD	58.21±3.04a	58.89±1.49a	60.21±3.60a	64.28±2.20a	59.71±4.64a	61.30±3.04a	64.87±0.98a	53.33±5.71a

Note, SLR, mass ratio of stems to leaves; DM, dry yield, g m^{-2}; SH, stem height of alfalfa, cm; I1, irrigate at regreen and branch stages; I2, irrigate at branch and anthesis stages; I3, irrigate at regreen and anthesis stages; I4, irrigate at branch stage; I5, irrigate at branch stage; I6, irrigate at anthesis stage; I7, irrigate at regreen, branch and anthesis stages; CK, no irrigation;