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ALLEVIATION OF SALINITY AND DROUGHT STRESS IN CORN PRODUCTION USING A NON-IONIC SURFACTANT

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ABSTRACT

Deficit irrigation strategies have been developed to improve water use efficiency in arid and semi-arid regions. Implementation of deficit irrigation in saline soils, however, is complicated. In a field study, we evaluated if the application of a non-ionic surfactant along with irrigation water can improve the performance of deficit irrigation for corn (*Zea mays* L.) forage production in a saline soil and water condition. Irrigation regimes were included of full irrigation (no stress), moderate deficit, and severe deficit irrigation. Control plots received irrigation water without surfactant while other plots received water plus surfactant. Moderate and severe deficit irrigation resulted in 12.3 and 22.8% lower forage yield. Surfactant application positively influenced corn forage production, especially when deficit irrigation was induced. Wheat (*Triticum aestivum* L.) grain yield following corn was also higher in plots that received surfactant during the previous growing season. The results of this experiment showed that treating irrigation water with a non-ionic surfactant significantly enhanced forage yield when full or deficit irrigation regimes were implemented in corn production under soil and water salinity. The effect of surfactant remained in the soil for more than one growing season where wheat yield in the treated plots was higher than that in the control plots in the following growing season. This result clearly demonstrates the potential of surfactant application to improve crop production and WUE under salinity stress.

Keywords, Drought stress; Forage; Salinity; Limited irrigation; Surfactant.

Abbreviation: W_{70}: irrigation after 70 mm evapotranspiration; W_{100}: irrigation after 100 mm evapotranspiration; W_{130}: irrigation after 130 mm evapotranspiration; W: irrigation water without surfactant; W+S: irrigation water plus surfactant. IWUE: irrigation water use efficiency.

INTRODUCTION

Scarcity of good quality water and soil salinity are among the major obstacles to food and feed production in arid and semi-arid regions of the world (Chen *et al*. 2010; Afshar *et al*. 2014; Aragüés *et al*. 2014; Jahansouz *et al*. 2014; Jahanzad *et al*., 2013). In the central regions of Iran, soil salinization is the most important land degradation process (Farifteh *et al*. 2006). Soil salinization and rapid depletion of the groundwater resources in these regions are serious and chronic challenges which tremendously threaten the country's food security in the near future (Taghizadeh-Mehrjardi *et al*. 2014).

Various techniques have been developed to remediate these restrictions in order to improve the sustainability of farming systems in arid and semi-arid regions. Deficit irrigation regimes are among the means developed to improve irrigation water use efficiency (IWUE) and to enhance water conservation (Afshar *et al*. 2014; Jahansouz *et al*. 2014). The goal of deficit irrigation is to improve IWUE by reducing the volume of water used at each irrigation interval and/or by reducing the number of irrigation events (Afshar *et al*. 2014; Jahansouz *et al*. 2014). However, when water scarcity is accompanied by salinity stress in the soil or water, managing the irrigation practice becomes so complicated.

In saline soils, reducing the salinity level of the root zone through leaching is crucial. When water availability is not limited, this can be achieved through flushing soluble salts from the root zone by application of excessive water at each irrigation (Corwin *et al*. 2007). However, when water scarcity exists and deficit irrigation is implemented, salt buildup in the soil surface layer may worsen the situation for the plant to be grown. Moreover, water movement and proliferations in the profile of saline soils create lots of difficulties to manage irrigation practice. It has been reported that implementation of deficit irrigation can reduce the chance of salt leaching and increase salt concentration in the root zone, which ultimately results in yield reduction (Aragüés *et al*. 2014). In a three-year study conducted in an arid region of northwest China, Chen *et al*. (2010) concluded that deficit irrigation using saline waters was not sustainable for cotton (*Gossypium hirsutum* L.) production due to the accumulation of salts in the soil beyond the levels that cotton can tolerate.

New technologies have been developed worldwide to improve crop production in areas facing drought or salinity restrictions. Soil surfactant is a wetting agent that lowers surface tension of a liquid and allows it to spread more easily. By changing the flow dynamics of water, surfactants improve the hydrological condition in soils, creating a better growing environment for plants and offer opportunities for water saving (Moore *et al*. 2010). It has been shown that surfactant can improve uniformity of soil moisture distribution and root zone moisture holding capacity, thus; enhance crop yield (Wolkowski *et al*. 1985; Chaichi *et al*. 2015). Better growth of tomato (*Solanum lycopersicum* L.) under salinity stress when irrigation water was treated with surfactant has been observed in our previous experiments (Chaichi *et al*., 2016). Application of soil and water amendments like surfactant tends to increase water use efficiency either by better water retention in light and medium textured soils or better water movement in saline and heavy textured soils (Chaichi *et al*. 2015). The objective of this study was to determine the potential of using surfactant to alleviate the adverse effect of deficit irrigation on corn forage yield in a region with saline soil and water resources. We also examined the residual effects of surfactant application on wheat yield planted in the following growing season.

MATERIALS AND METHODS

A two year field experiment (2010-2011) was conducted at the Qom Agricultural Research Station (34°38′N, 50°52′E, and 935m above sea level), Qom province, Iran. Crop production in this region is extensively limited by serious water shortage, soil salinity (EC>8 dS m^{-1}), and extreme saline water resources (EC>10 dSm^{-1}). The climate of this region is characterized as a semiarid-semidesert with dry-hot summers and cold winters. Environmental condition during the present study is shown in Table 1. Also, the characteristics of soil and water are given in Table 2.

The experiment was arranged as split-split plot in a randomized complete block design with four replications. Irrigation regime and surfactant treatments were assigned to the main plots and the sub-plots, respectively. Individual sub-plots were 5m wide and 7m long. Irrigation was scheduled based on the crop evapotranspiration (ETc) calculated as follows:

$$ETc = ETo \times Kc$$

Where ETc is crop evapotranspiration, ETo is reference evapotranspiration and Kc is localized crop coefficient (the ratio of the crop evapotranspiration rate to the reference evapotranspiration rate). The Kc value of the mid-season stage of corn was 1.2 in this experiment which was retrieved from FAO reports (FAO, 2012). Reference evapotranspiration was estimated according to the FAO Penman- Monteith method (Allen *et al*., 1998) using meteorological data from Qom Synoptic Weather Station. In full irrigation regime (W_{70}), plots were irrigated to field capacity after 70 mm cumulative ETc while in moderate (W_{100}) and severe deficit irrigation regimes (W_{130}), irrigation was applied after 100 and 130 mm cumulative ETc, respectively.

Control plots received irrigation water without surfactant while other plots received water treated with a non-ionic surfactant. The surfactant used in this experiment was a nonionic surfactant comprising 10% alkyl polyglycoside, 7% EO/PO block copolymer and 83% water that was applied at a constant rate of 1000 ml per ha per irrigation**.** This application rate was determined as the best rate for corn production in our preliminary experiments and our previous study (Chaichi *et al*., 2015).

Corn seeds (S.C. 704) were sown in early July at the population of ~130,000 plants ha^{-1} on rows 75 cm apart and 10 cm within rows spacing. Due to unfavorable soil and water condition, a big proportion of the seeds usually do not germinate or die at early growth stages. Therefore, the actual population after full establishment was ~65,000 plants ha^{-1}.

Application of farmyard manure every four to five years is a common practice in this region. Accordingly, before the experiment began, 20 ton ha^{-1} farmyard manure (sheep compost) was used as a base fertilizer. The plant nitrogen requirement (240 kg N ha^{-1}) was provided by ammonium sulfate (also to lower soil pH) according to the soil test results. No phosphorus (P) and potassium (K) fertilizers were applied since soil test results indicated sufficient availability of P and K in the soil.

At kernel milk stage (kernel moisture content of about 70-80%), whole-plant was harvested at ground level from the middle rows to determine the forage fresh weight. Biomass was oven dried at 75 °C to a constant weight, then forage dry yield was determined. Another sample was taken from each plot to determine leaf to stem ratio.

In the following fall season (after harvesting corn), winter wheat was planted in the experimental unit. Neither deficit irrigation regime nor surfactant treatment was applied on wheat crop following corn in rotation. Wheat grain yield was measured to evaluate the residual effect of surfactant application from the preceding corn crop.

Seedbed preparation for wheat included chisel plow and two perpendicular light disking. Wheat was planted on 12 November 2010 at approximately 2.5 cm depth and 25 cm row spacing using a seed drill at a rate of 300 kg seed ha^{-1}. Nitrogen fertilizer (urea) was applied in two equal splits of 100 kg N ha^{-1}: before the last disking, and at stem elongation. Based on soil test results and current recommendation, no P and K fertilizers were applied. Wheat was harvested on 9 Jun 2011.

Data analyzed using PROC GLM of SAS. When F test showed significant differences, LSD test (P<0.05) was used to separate the means.

RESULTS

Effect of deficit irrigation and surfactant application on corn forage production: In both years of the experiment, lower forage yield was obtained when deficit irrigation was implemented compared with full irrigation (W_{70}) (Table 3). Irrespective to the irrigation regime, application of surfactant with irrigation water enhanced corn forage production which was consistent in both years of the experiment (Fig. 1). In W treatment (irrigation water without surfactant), forage yield followed a declining trend as water deficiency intensified. However, when surfactant was applied (W+S), not a significant difference was found between forage yield in moderate (W_{100}) and severe levels of deficit irrigation (W_{130}) in the first year of the experiment. In 2011, however, the response trend of forage yield to irrigation regime was similar in W and W+S treatments. As moderate deficit irrigation was imposed, surfactant application resulted in an acceptable forage yield, which was not statistically different with that obtained from full irrigation.

Changes in corn leaf to stem ratio in response to deficit irrigation differed between the surfactant treated and non-treated plants (Fig. 1). In non-surfactant treated plots, leaf to stem ratio followed a declining trend in response to water deficiency. When irrigation water was treated with surfactant, however, an opposite trend was observed. In W+S treatment, leaf to stem ratio remained stable in full and moderate deficit irrigation and even increased when drought stress was intensified. This observation was due to greater impacts of surfactant application on leaf growth rather than that on stem growth when severe drought stress occurred. Averaged across all irrigation regimes, leaf to stem ratio was smaller in plants treated with surfactant. Leaf to stem ratio is considered as an important index determining corn forage quality, as leaf usually contains more protein and less fiber than stem. Although, leaf to stem ratio in W_{70} and W_{100} watering treatments were lower when surfactant was applied, at severe deficit irrigation surfactant application resulted in a greater leaf to stem ratio.

Surfactant residual effects on wheat yield following corn: As shown in Fig. 2, wheat yielded 58% greater in plots that received surfactant-treated irrigation water during the previous growing season; reflecting that the effect of surfactant remained in the soil for more than one growing season.

Table 1. Monthly average air temperature, average relative humidity (RH), cumulative rainfall, and pan evaporation (E) during corn growing season in 2010 and 2011 at Qom, Iran.

Month	2010				2011			
	Temp (ºC)	RH (%)	Rainfall (mm)	E (mm)	Temp (ºC)	RH (%)	Rainfall (mm)	E (mm)
Apr	18	46	8	209	14	52	56	194
May	23	48	17	270	21	47	12	275
Jun	30	22	1	442	27	33	20	402
Jul	34	20	0	481	32	23	0	498
Aug	30	23	0	428	32	24	0	453
Sep	27	28	0	255	27	31	6	349
Oct	24	31	0	260	21	34	1	225

Table 2. Soil and water characteristics of the targeted region (Qom, Iran).

Soil		Irrigation water	
Texture	Clay loam	EC (dS m^{-1})	10.42
EC (dS m^{-1})	8.45	pH	7.1
pH	7.4	T.D.S[1] (mg L^{-1})	6668
O.C. (%)	0.86	HCO_3 (meq L^{-1})	2.8
Total N (%)	0.09	Cl (meq L^{-1})	10.2

Available P (ppm)	25	SO_4 (meq L^{-1})	18.8
Available K (ppm)	210	Ca (meq L^{-1})	40.3
Fe (mg kg^{-1})	5	Mg (meq L^{-1})	25.2
Zn (mg kg^{-1})	1.20	Na (meq L^{-1})	77.4
Cu (mg kg^{-1})	1.13	K (meq L^{-1})	0.3
Mn (mg kg^{-1})	5.52	Total hardness (mg L^{-1})	3250
B (mg kg^{-1})	1.20		

[1]Total dissolved solids

Table 3. Analysis of variance for the effect of irrigation regime and surfactant application on corn forage yield and leaf to stem ratio in a saline soil and water condition.

S.O.V	Dry forage yield	Leaf to stem ratio
2010		
Block	**	ns
Irrigation regime	**	**
Surfactant treatment	**	ns
Irrigation× Surfactant	ns	**
2011		
Block	ns	ns
Irrigation regime	**	*
Surfactant treatment	**	ns
Irrigation× Surfactant	ns	**

*, **, and ns are significant at $P<0.05$, $P<0.01$ and non-significant at $P<0.05$, respectively.

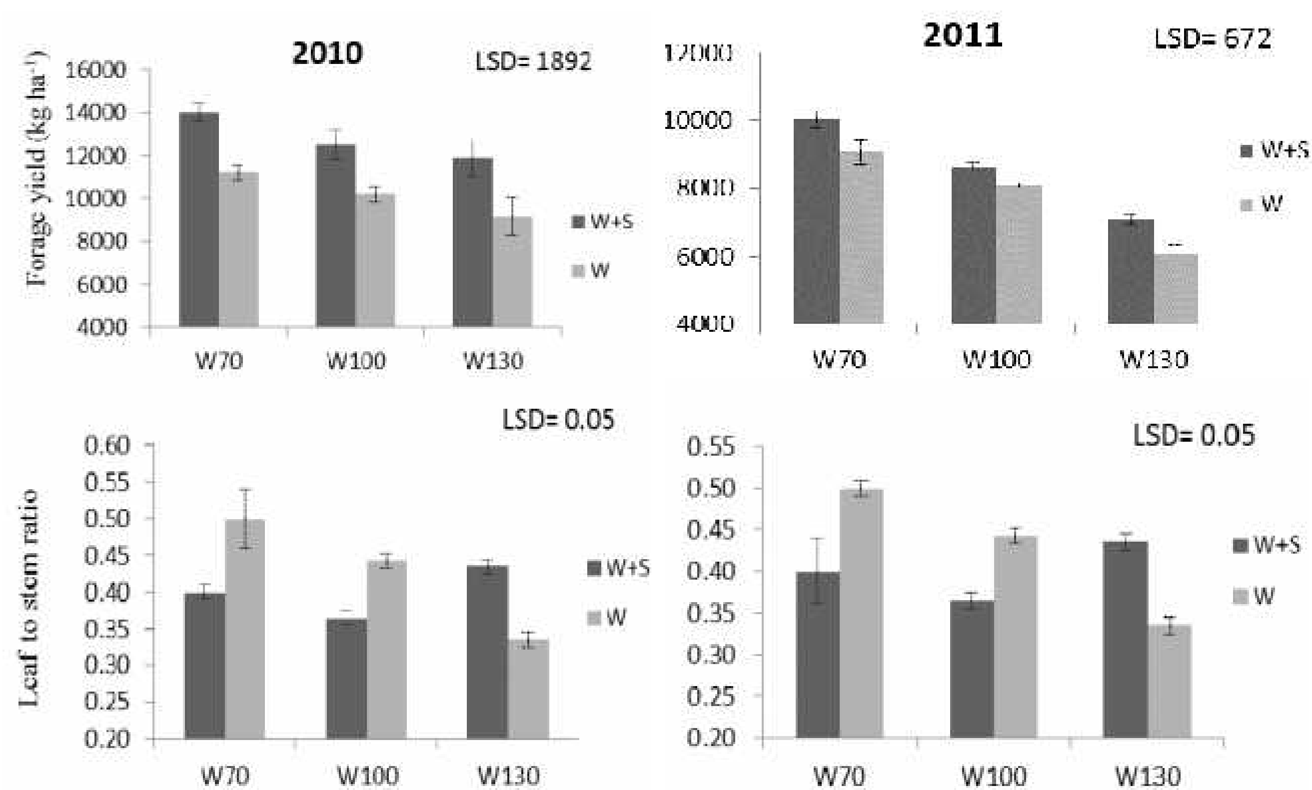

Figure1. Corn forage yield and leaf to stem ratio as influenced by irrigation regime and surfactant application. Vertical bars represent standard error (n=4). Means are separated using LSD test ($P<0.05$).

W_{70}, W_{100} and W_{130} refer to irrigation after 70 (full irrigation), 100 (moderate deficit irrigation) and 130 mm (severe deficit irrigation) cumulative ETc, respectively. W and W+S mean watering without and with surfactant, respectively.

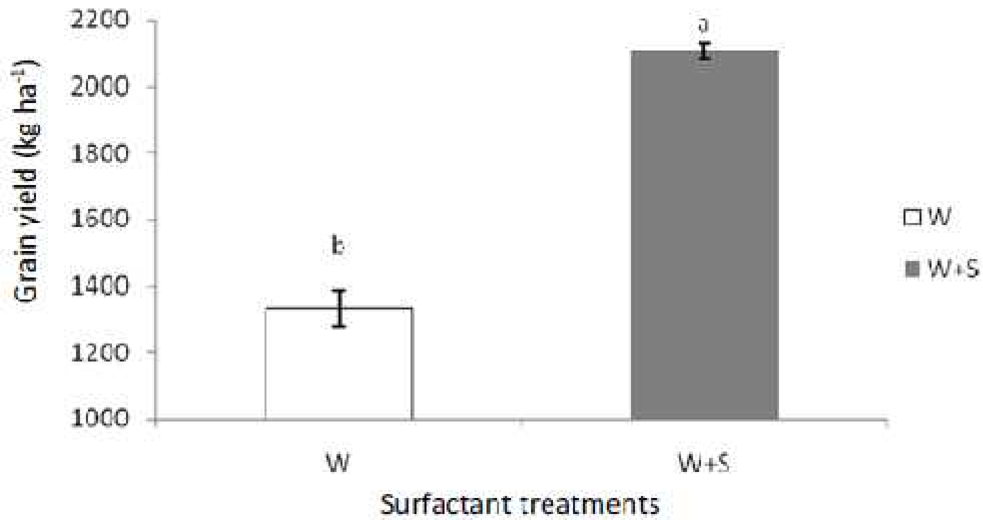

Figure 2. Residual effects of surfactant application on the subsequent wheat grain yield. Means are separated using LSD test (*P*<0.05). Vertical bars represent standard error (*n*=4).

W: yield obtained from plots that did not receive surfactant treatment during the previous growing season. W+S: Yield obtained from plots that received surfactant treatment during the previous growing season.

DISCUSSION

Application of surfactant positively influenced corn forage yield, especially under water deficit conditions, in this semi-arid region. To our knowledge, no published data is available regarding the effects of surfactant application on crop yield under salinity stress. Nevertheless, positive impacts of surfactant application on plant growth and performance in non-saline soils, have been documented (Cisar *et al*. 2000; Brumbaugh and Petersen 2001; Park *et al*. 2004; Chaichi *et al*. 2015), which have been attributed to higher retention of surfactant-treated water in dry soils compared with untreated water (Lehrsch *et al*. 2011). It is likely that higher retention due to the surfactant effects improves infiltration rate and accelerates the dryness of the soil top layer which further minimizes evaporation rate from the soil surface (Lemon, 1956). In our previous experiment we found that surfactant application under salinity stress (at the rate of 1 mg L^{-1} irrigation water) helped tomato plants to maintain their ionic balance, especially declining Na uptake, thus; improved tomato growth (Chaichi *et al*., 2016). More research efforts are needed to determine the surfactant mode of action in improving plant-soil water relations under salinity stress. According to the results of this study, there is a good potential for application of surfactant in accompanying with deficit irrigation systems for corn production in saline soils. As reflected in wheat yield planted after corn, the impacts of surfactant application are likely to remain in the soil for an extended period of time (at least for more than one growing season). Therefore, more caution is needed for the application of this chemical, since any inappropriate utilization could have relatively long-term effects on the soil. Further studies are required to evaluate the possible long-term effects of this chemical on soil and the environment.

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The authors declare that they have no conflict of interest (financial or non-financial).

REFERENCES

Afshar, R.K., M. Ansari Jovini, M.R. Chaichi, and M. Hashemi (2014). Grain sorghum response to Arbuscular mycorrhiza and phosphorous fertilizer under deficit irrigation. Agron J. 106:1212–1218.

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith (1998). FAO Irrigation and drainage paper No. 56. Rome: Food and Agriculture Organization of the United Nations, 26-40.

Jahansouz, M.R., R. Keshavarz Afshar, H. Heidari, and M. Hashemi (2014). Evaluation of yield and quality of sorghum and millet as alternative forage crops to corn under normal and deficit irrigation regimes. JJAR. 10: 699–715.

Jahanzad, E., M. Jorat, H. Moghadam, A. Sadeghpour, M.R. Chaichi, and M. Dashtaki (2013). Response of a new and a commonly grown forage sorghum cultivar to limited irrigation and planting density. Agric. Water Manage. 117: 62-69.

Aragüés, R., E.T. Medina, I. Clavería, A. Martínez-Cob, and J. Faci (2014). Regulated deficit irrigation, soil salinization and soil sodification in a table grape vineyard drip-irrigated with moderately saline waters. Agric. Water Manage. 134: 84–93.

Brumbaugh, E.H., and M. Petersen (2001). The use of a non-ionic surfactant to alleviate the effects of compacted soil on corn (*Zea mays*) yields and root growth. In: H. de Ruiter, editor, Proceedings of the 6th International Symposium on Adjuvants for Agrochemicals, Amsterdam, Netherlands. 13–17 Aug. 2001. p. 1–4.

Chaichi, M.R., P. Nurre, J. Slaven, and M. Rostamza (2015). Surfactant application on yield and irrigation water use efficiency in corn under limited irrigation. Crop Sci. 55:286–293.

Chaichi, M.R., R. Keshavarz-Afshar, B. Lu, and M. Rostamza (2016). Growth and nutrient uptake of tomato in response to application of saline water, biological fertilizer, and surfactant. J. Plant Nutr. (In press).

Chen, W., Z, Hou, L, Wu, Y, Liang, and C. Wei (2010). Evaluating salinity distribution in soil irrigated with saline water in arid regions of northwest China. Agric. Water Manage. 97: 2001–2008.

Cisar, J. L., K.E. Williams, H.E. Vivas, and J.J. Haydu (2000). The occurrence and alleviation by surfactants of soil-water repellency on sand-based turfgrass systems. J. Hydrol. 231: 352–358.

Corwin, D.L., D.J. Rhoades, and J. Simunek (2007). Leaching requirement for soil salinity control: steady-state versus transient models. Agric. Water Manage. 90: 165–180.

FAO, Corporate Documentary Repository (2012). Crop evapotranspiration- Guidelines for computing crop water requirements. Natural Resources Management and Environment Department. FAO Publication. Italy

Farifteh, J., A. Farshad, and R.J. George (2006). Assessing salt-affected soils using remote sensing, solute modelling, and geophysics. Geoderma, 130: 191–206.

Lehrsch, G.A., R.E. Sojka, J.L. Reed, R.A. Henderson, and S.J. Kostka (2011). Surfactant and irrigation effects on wettable soils: Runoff, erosion, and water retention responses. Hydrol. Process. 25:766–777.

Lemon, E.R. (1956). The potentialities for decreasing soil moisture evaporation loss. Soil Sci. Soc. Am. J. 20: 120–125.

Moore, D., S.J. Kostka, T.J. Boerth, M. Franklin, C.J. Ritsema, and L.W. Dekker (2010). The effect of soil surfactants on soil hydrological behavior, the plant growth environment, irrigation efficiency and water conservation. J. Hydrol. Hydromech. 58: 142–148.

Park, D.M., J.L. Cisar, G.H. Snyder, and K.E. Williams (2004). Alleviation of soil water repellency in sand based bermudagrass in South Florida. Acta Hortic. 661: 111–114.

Taghizadeh-Mehrjardi, R., B. Minasny, F. Sarmadian, and B. P. Malone (2014). Digital mapping of soil salinity in Ardakan region, central Iran. Geoderma, 213: 15–28.

Wolkowski, R.P., K.A. Kelling, and E.S. Oplinger (1985). Evaluation of three wetting agents as soil additives for improving crop yield and nutrient availability. Agron. J. 77: 695–698.