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Water Production Functions of Wheat Irrigated with Saline Water Using Line Source Sprinkler System under the Mediterranean Type Climate

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Abstract

An experiment was conducted to determine the effect of water-salinity-yield relations of winter wheat and crop salt tolerance level along with salt distribution in the soil profile during the 2009 and 2010 growing seasons under rain-shelter in the Irrigation and Agricultural Structures Department, Faculty of Agriculture at Çukurova University in Adana. A line source sprinkler irrigation system was used to create different salt and water gradients. The results revealed that different irrigation water with different qualities affected grain yield and yield components. As the salinity level of the irrigation water increased crop water use and grain yield decreased. Saline irrigation water resulted in increased soil salinity in the profile and higher salt concentration in the soil affected some physical properties of the soil. Irrigation water use efficiency (IWUE) increased, however water use efficiency (WUE) decreased as a result of saline irrigation application. Salinity threshold level of 5.107 dS/m was found for winter wheat from two year experimental data. Application of saline water with sprinkler system resulted in yield reduction at relating lower salinity levels and yield response factor (ky) of 1.46 was determined due to weather condition inside rain-shelter and soil salinity.

Keywords: Wheat, saline water, rain-shelter, line source sprinkler system, yield response factor

Akdeniz İkliminde Çizgi Kaynaklı Yağmurlama Sistemiyle Tuzlu Sulama Suyu Uygulamasının Buğdayda Su Üretim Fonksiyonlarını

Özet

Bu çalışma, yağmur korunaklı serada kışlık buğdayın su-tuz-verim ilişkileri ile bitkinin tuza dayanım düzeyleri ve toprakta tuz dağılımlarının belirlenmesi amacıyla, 2009 ve 2010 yetişme dönemlerinde Adana, Çukurova Üniversitesi Ziraat Fakültesi Tarımsal Yapılar ve Sulama Bölüm'ü deneme arazisinde yağmur korunağında yürütülmüştür. Çalışmada, çizgi kaynaklı yağmurlama sistemi kullanılarak farklı su ve tuz düzeyleri oluşturulmuştur. Sonuçta, farklı nitelikteki sulama sularının buğdayda verimi ve verim bileşenlerini etkilediği saptanmıştır. Sulama suyu tuzluluğu arttıkça bitki su tüketimi ve verim azalmıştır. Uygulanan tuzlu sulama suyu toprakta tuz birikimine neden olduğu ve yüksek derişimdeki tuz toprağın bazı fiziksel özelliklerini etkilemiştir. Sulama suyu tuzluluğunun artmasıyla sulama suyu kullanma randımanının (IWUE) azaldığı, ancak toplam su kullanma randımanının (WUE) yükseldiği belirlenmiştir. Tuzluluk eşik değeri her iki deneme yılı verileri kullanılarak 5.107 dS/m olarak hesaplanmıştır. Sera koşullarında yapılan tuzlu su çalışmalarında verim tepki etmeninin (ky), ortamın iklim özelliklerinden ve toprak tuzluluğundan etkilendiği ve çalışma sonunda yüksek ky değeri (1.46) belirlenmiştir.

Anahtar Kelimeler: Buğday, tuzlu sulama suyu, yağmur korunağı, tek kaynaklı yağmurlama sistemi, verim etmeni

Introduction

It is the biggest challenge of next century to meet food and fiber needs of ever increasing world population. Increasing production of cereals is therefore strategically very important to ensure food self sufficiency (Sezen and Yazar, 1996).

World wheat production is 713 million t, the total area planted to wheat is 219 million ha and average wheat yield is 3265 kg ha^{-1}. Wheat, regarding total planted area and production, holds the first ranking of all agricultural production in Turkey. Wheat production is 22.1 million t, the total area planted to wheat is 7.8 million ha and average yield is 2837 kg ha^{-1} (FAOSTAT, 2013).

In Turkey, available water is 1692 m^3 per person per year. Thus, in terms of water resources, Turkey is among countries with limited water resources. While average annual rainfall is 631 mm in Turkey, the average rainfall decreased 15 % in 1999 and 7% in 2000 (Türkeş, 1999). Besides reduced rainfall, sharp fluctuations in the measured rainfall regime are striking. These obstacles have negative effects on agricultural production. On the other hand, more severe draughts and greater water availability problems should be expected if the mentioned problems prevail in the future. The reduction in water resources as a result of climate change will make it more important for lower Seyhan basin to find optional water resources. Studying possibilities of the use of diluted sea water for irrigation may be a plausible option in the basin. Important evidence has been found suggesting that it will not be possible to grow wheat in the lower Seyhan basin in the future (ICCAP, 2007). If this holds true, wheat will be less affected by salty irrigation conditions and may be grown in closed areas, as this study tries to demonstrate.

Weather fluctuations are a bane for crop production in arid and semi-arid regions. To ensure high productivity, concerted efforts have been made to introduce irrigation through inter basin transfer of water. To prevent widespread crop failure, the concept of protective irrigation implying a limited water supply to agricultural lands, has been introduced (Chauan, et al., 2008). Consequently, crops suffer from moisture stress (Tyagi et al., 2003) and to this fact overall low productivity has been traced in many irrigation projects.Yet, spectacular results have been obtained when canal water is supplemented with groundwater (Dhawan, 1989). Since groundwater in many parts of arid and semi-arid regions is saline/sodic, groundwater has not been exploited for fear of adverse effects on crops and/or soils. Consequently, farmers switched over to less water requiring crops or crops that are more tolerant to salts. Earlier works related to the use of saline water in agriculture, however, proved the potential of these waters as a source of irrigation in conjunction with fresh water (Vyas et al., 1986; Singh et al., 1992; Minhas, 1998; Oster and Grattan, 2002).

In this study, diluted sea water was used to irrigate wheat under rain-shelter. The purpose of the study was to determine the effects of sprinkler irrigation with sea water on soils and plants under covered conditions. Another objective was to obtain results that can lead to explaining the relationships between sprinkler irrigation and soil-plant-salinity. It is expected that the results could be used to estimate the level of the salinity caused in the soil.

Materials and Methods

A field experiment was conducted an rain-shelter during 2009 to 2010 at the area of Irrigation Department, Agricultural Faculty, Çukurova University, Adana, located at 36°59' N latitude, and 35°18' E longitude and 20 m above mean sea level. The average annual rainfall in this region was 555 mm for the period 1932–2007. Around 90% of the total rainfall occurs during November-May while the remaining 10% occurs during the rest of the year. The rainfall fluctuated during the wheat growing seasons that was conducted research and was the lowest in 2009/10 (87 mm) while it was relatively high and well distributed in 2008/09 (61 mm).

The soil of this site is classified as Mutlu soil series (Palexerollic Chromoxeret) and clay-loam textured. Gravimetric soil water contents at field capacity and permanent wilting point are 29.6 g/g and 35.8 g/g, respectively. The permeability is fair and the vertical movement of water is not noticeably impeded. Owing to the relatively large depth of the water table during the study period, groundwater contribution to crop water use was almost negligible. Mean bulk density varies from 1.19 to 1.51 g/cm^3.

Water is obtained from a saline water pool (EC ranges from 2.1 to 19.4ds/m). The saline waters for the various treatments were prepared by mixing open channel water and sea water at appropriate ratios to obtain the desired EC (>9 dS/m).

The seedbed was then prepared by plugging followed by planking. A wheat variety (cv. Vorana-CNO79/Kauz) was sown on 18 November 2008 and 26 November 2009, respectively. The driller setting was such that it applied seed 250 kg ha^{-1}, at 5 cm soil depth with 20 cm row spacing. Fertilizer applications were based on soil analysis recommendations. All treatment plots received the same amount of total fertilizer. A compound fertilizer of (18-46-0) was applied (32 kg N and 82 kg P2O5 as pure matter per ha) at planting. The rest of N fertilizer was applied during tillering at a rate of 170 kg/ha (33% Ammonium Nitrate)

Line sources sprinkler irrigation system was used in the study (Hanks et al., 1975; Sezen and Yazar, 2006). In the rain-shelter study, treatments were laid out according to the line source sprinkler system, namely TA, TB and TC (Figure 1). Decreasing water-salt levels were applied as the distance from the lateral increased at 2 m intervals (TA, TB, and TC in East and West). The strips neighboring the lateral (TA) had more water, and as a result more salt, while the farther strips (TC) had less water and hence less salt (Figure 1).

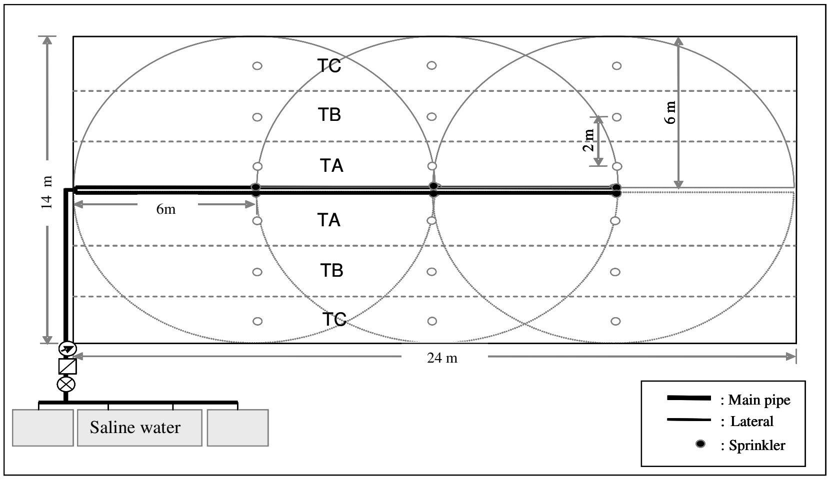

Figure 1. Layout of the experiments under rain-shelter

Dimension of rain shelter is 24x14 m and the only top of rain shelter was coated to prevent precipitation with PVC sheets and measured the temperature of rain shelter by a dry and wet thermometer daily. Research area is located in Mediterranean climate condition.

The soil water content measurements were made at 14-day intervals until harvest in the three replications for all treatments by gravimetric sampling in 0-120 cm for the experimental soil.

At harvest, all plants in the two 2 m rows were cut at ground level and grain and straw were separated by hand and weighed. The harvest was done on 25 May 2009 and 23 May 2010. Evapotranspiration (ET) was calculated with the water balance equation (Howell et al., 1990). Water use efficiency (WUE) was calculated as grain yield divided by seasonal ET (Howell et al., 1990). The water use-yield relationship was determined using the Stewart model in which dimensionless parameters in relative yield reduction and relative water consumption are used (Doorenbos and Kassam, 1997). For soil salinities exceeding the threshold of any given crop, relative yield (RY) can be estimated with the following equation (Maas and Hoffman, 1977):

$$RY = 100 - b(ECe - a) \tag{1}$$

where, a is the salinity threshold expressed in dSm-1, b the slope expressed in % per dSm-1, and ECe is the mean electrical conductivity of a saturated-soil extract taken from the root zone.

Seasonal values of the seed yield response factor (ky), which represent the relationship between relative yield reduction [1- (Ya /Ym)] and relative evapotranspiration deficit [1-(ETa/ETm)], were determined using the equation given by Doorenbos and Kassam (1996):

$$1 - \left(\frac{Ya}{Ym}\right) = ky\left(1 - \frac{ETa}{ETm}\right) \tag{2}$$

where ETa and ETm are the actual and maximum crop evapotranspirations (mm), respectively; and Ya and Ym are the corresponding actual and maximum seed yields (kg ha-1).

Results

Under rain-shelter, average water amounts ranged from 196 to 301 mm in 2008/09 and 254-427 mm in 2009/10. The difference in number of irrigation and total amount of irrigation water applied among the experimental years was due to the differences in rainfall amount and distribution as well as differences in temperature. Highest grain yield of 5500 kg/ha was obtained from TA treatment plots adjacent to the line-source in 2008/2009 growing season of wheat in the rain shelter. In 2009/10 growing season irrigation water was higher than threshold value of saline water (>9 dS/m). It is resulted that the lowest grain yield in the TA treatment and the highest grain yield in TC treatment (Table 1).

In rain shelter, seasonal water use varied from 328 mm in TC to 615 mm in TA treatment plots in the experimental years. Evapotranspiration was significantly influenced by irrigation levels. Water use decreased with increasing distance from the sprinkler line-source in 2008/09 and 2009/10 experimental years (Table 1)

WUE ranged from 8.0 to 15.8 kg/ha/mm under rain shelter conditions in the experimental years. The maximum WUE was recorded in TC treatments over the 2 years, as expected from information on yield and seasonal ET. In general, the values of WUE in this study were higher than those (4.0-8.8 kg/ha/mm) for irrigated winter wheat (Schneider and Howell, 1997), but they are close to those (10.8-11.9 kg/ha/mm) for winter wheat in the Mediterranean region (Zhang and Oweis, 1999) and for winter wheat (8.4-13.9 kg/ha/mm) in the North China plain (Zhang et al., 1999). Nielsen and Halvarson (1991) reported average wheat WUE value of 9.66 kg/ha/mm and for winter wheat (7.3-9.3 kg/ha/mm) under rain-fed conditions and 7.7-14.6 kg/ha/mm under irrigated conditions in the Loess Plateau of China (Kang et al., 2002).

Table 1. Grain yield, irrigation amount, water use, water use efficiency of different treatments in the experimental years

Years	Treatments	Yield, kg/ha	Irrigation, mm	ET, mm	WUE, kg/m^3
	TA	5500	301	615	8.9
2008/09	TB	4610	248	575	8.0
	TC	4290	196	522	8.2
	TA	3950	426	436	9.1
2009/10	TB	4430	350	378	11.7
	TC	5170	254	328	15.8

Under rain-shelter condition, soil water content was higher than 50% of available water until DAS 140 and reduces sharply till harvesting period of wheat in TA, TB and TC treatments in 2008/09. In the second experimental year soil water value was higher than 50% of available water all growing season of wheat in TA and lower than 50% of available water in TB and TC treatments from DAS 110 until harvesting.

Salt distribution in the soil: In the rain shelter study, soil samples were taken in three growing stages of wheat (early, medium, harvest). In order to determine the effect of salty water concentration on soil salt balance, the distribution of salt in the soil profile was analyzed (Figure 2). Spatial and temporal accumulations were observed in salt levels in the soil profiles. Irrigation water level affected the salt levels and the measured salt levels varied in different growing stages. Salt levels were 0.68-0.82 dS/m in TA treatment, 0.57-0.64 dS/m in TB treatment, and 0.42-0.51 dS/m treatment in 2009 while the salt levels were 2.92-12.92 dS/m, 2.52-10.76 dS/m, and 1.74-6.75 dS/m in TA, TB, and TC treatments, respectively in 2010. Temporal variation was obvious as the salt level increased and reached the highest level towards the end of the growing stage of wheat. Spatially, salt levels varied based on the amount of water applied and the salt concentration, distance from the water source, and soil layers (Figure 2).

In the second year, irrigation water had salt levels greater than the threshold (>9.0 dS/m). As a result, soil saltiness increased in all treatments with an average of 6.75-12.92 dS/m. The greatest salt levels were measured in the top layers of TA treatments which were the nearest to the sprinklers. Meiri and Plaut (1985), Bahçeci (1995) exclaimed that salt would be deposited in the soil profile due to deficiency of winter precipitation and surface runoff. Also Noble (1987) and Singh et al. (2009) stated that the increase in salt concentration in irrigation water increases the soil saltiness. This study showed that significant amount of salt can accumulate in the plant root zone as a result of salty water application if the there is no efficient drainage and irrigation system. The accumulation of salt is related to the amount of water applied, decreases with increased soil depth, and reaches the peak salt concentrations towards the maturity stages of the plant.

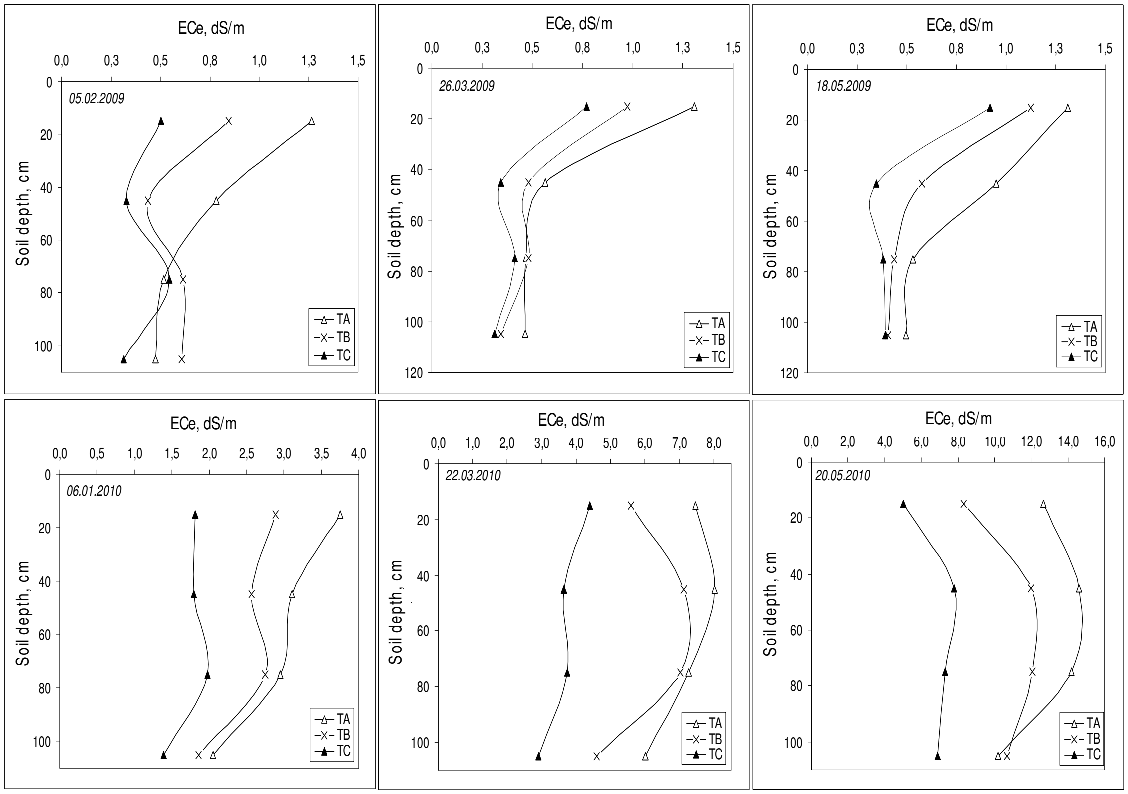

Figure 2. Soil salinity builds up in the rain shelter

Saltiness Threshold Limit: Relative wheat yield decreased with increasing soil saltiness. Salt level that causes a decrease in wheat yield is determined to be 5.107 dS/m. Based on this; electric conductivity of soil (ECe) level can be considered the saltiness threshold limit value for wheat plant. Bingham et al. (1985), Ayers and Wescot (1989), and Maas and Grieve (1990) reported a saltiness threshold limit value of 5.8-6.0 dS/m for wheat, which is 12-15% greater than the limit value found in this study. The difference might be due to soil texture, applied amount of water, irrigation method, and climate (temperature, relative humidity, and precipitation) differences. The present study was conducted in a covered area under sprinkler irrigation method. Plants are exposed to salt through the roots and the leaves. The figures suggested by Maas and Grieve (1990) are for medium textured soils irrigated by surface irrigation methods in wheat (Munns and Termaat, 1986; McFarland et al., 2000; Hillel, 2000; Hoffman et al., 1990).

Yield response factor (ky): Correlations between proportional evapotranspration reduction and proportional yield response were determined by using the first year rain shelter data. This evaluation was not done for the second year data since excess rates of salt was applied with water. Yield response factor (ky) was found to be 1.36. According to this factor, one unit of reduction in evapotranspration will result in 1.36 unit of reduction in yield. Doorenbos and Kassam (1997) determined ky to be 1.05 for winter wheat. Sezen and Yazar (1996) determined a value of 1.01 for ky in Çukurova conditions. Greater yield response factor found in this study may be attributed to climate and soil conditions of the rain shelter. Bahçeci (1995), who conducted a similar study for soybeans, found a higher ky value and stated that this could have been due to variations in climate and soil conditions.

1000 seed grain weight: Weight of thousand seed grain is given in Table 2. The measured values varied depending on the amount of irrigation water in the first year of experiments, and salt contents in the second year. As for the effect of water, the highest thousand grain weight was found in TA with 48.4 g. As for the salt content effect, the greatest value was found in the farthest location from the lateral in TC with 37.7 g. That is, weight of thousand seed grain is affected by water and salt stress levels. In addition, it could be concluded that water stress has more effect on grain weight compared to water stress. A number of researchers (Frenkel et al., 1990, Bahçeci, 1995; Ödemiş, 2001, Zheng et al., 2009, Singh et al., 2009) employed line source sprinkler irrigation in their studies and determined that the yield reduces as water decreases and salt increases. It can be stated that if the wheat plant is exposed to increasing water-salt stresses during the growth, the kernel fill will be negatively affected.

Table 2. 1000 seed grain weight, Harvest index, Protein ratio and gluten of different treatments in the experimental years

Year	Treatments	1000 seed grain weight, g	Protein ratio %	Gluten, %
2008-2009	TA	48.4	10.83	25.5
	TB	47.4	11.56	26.6
	TC	46.8	12.18	28.2
2009-2010	TA	19.3	13.62	40.6
	TB	25.0	11.42	35.3
	TC	37.7	6.77	20.8

Protein ratio: The highest protein ratios were found in high water and salt stresses (Table 2). The greatest figures were found in TC in the first year and in TA in the second year. Additionally, the differences between the treatments were smaller in the first year than those of the second year. For instance, the protein ratio reduced by 11% as the amount of water was increased in the first year, and 50% as the salt increased in the second year. It can be stated that the protein content is affected more by salt stress than the water stress. François et al. (1986) stated that durum and bread wheat were not affected up to a value of 6-8 dS/m, salt stress increased the quality of durum wheat, and did not affect drum wheat.

Yield differences caused by salt-water effects from one year to the second year significantly affected wheat protein ratios/levels. The protein content may be affected by climate, soil type, and the properties of the plant under consideration (Kün, 1988; Akaya, 1994). Zheng et al. (2009) found protein contents of ekmeklik wheat to be 10.2-13.8% irrigated with different salt concentrations. Additionally, they found the highest protein level in the case of the lowest yield as a result of highest salt application. Similarly, Çağlar (1990) and Gallegos and Salazar (1991) found similar results with an average protein rate of 11.15-13.85% for wheat varieties. Akkaya (1994) stated that there is an inverse relationship between kernel yield and protein content. The present study also shows similarities with previous research.

Gluten is one of the most important quality indicators of wheat, which determines wheather a wheat variety could be used as bread wheat (Pena, 1997). The wet based gluten values are given in Table 2. Like the protein contents, the greatest wet based gluten contents were obtained generally from the high water and salt stress treatments, i.e. in TC (first year) and TA (second year). Considering these treatments causing the highest gluten contents, 9% and 49% reductions occurred in the gluten contents of the kernels, respectively in the first year and the second year. As a result, it can be stated that salt stress has more effect on wet based gluten than that of the water stress. Hendavey (2009) reported that wet based gluten contents varied between 28 and 51.6% as a result of applying high rates of salty irrigation water (7-19 dS/m). Similar results were found by other researchers (Sharma and Minhas, 2005; Singh et al., 2009; Torbica et al., 2007) as well.

Conclusion

Evapotranspiration values of issues showed the difference from year to year. Calculated water consumption for different levels of water and salt influenced by salty irrigation water. Second year under rain-shelter experiment, because of high salty irrigation water, sufficient waters usability in the root area have decreased. First year in research, the highest yield is 550kg on TA topic nearest lateral. Second year, same topic is obtained lower yield about 395 kg. A yield of TC topic which getting minimum water, first year is 429 kg, second year is 517 kg. A yield of TB which another irrigation water level is 461 kg and 443 kg.

Grain yield of getting issues, first year decreased from the distance lateral; second year against first year. First year yields changes because of water stress, second year yields changes because of salt stress. In both research years, a value of irrigation water usage efficiency (IWUE) increased when farther from lateral. Increased of irrigation water salty cause to increased of total water usage efficiency (WUE).

First year between the evapotranspiration and grain yield have linear relation, water consumption increased with yield. Evapotranspiration decreases with yield and this is occuring water stress. In the second year, between the evapotranspiration and grain yield have linear reverse relation. Efficiency have reduced when evapotranspiration increases. Yield response factor (ky) value, for the first research year is calculated to be 1.36. This value is obtained from the experiments conducted in the same region as well as to the values to be higher than in the literature connected research is being carried out greenhouse environment, climate, soil property and water-soil salinity.

Temporal and spatial dimensions on the topics of the experiment the salt accumulations occurred in the soil profiles. Salt quantities, both the level of the irrigation and periods of growth, depending on changed. In time, amount of salt in the soil profile, towards the end of the growing season, reached the highest values. In the event of failure or lack of winter precipitation in the wash water, salt is entering the profile with irrigation water and increase, increasing irrigation water salinity is concluded that the increase in soil salinity.

Salinity threshold value, calculated 5.107 dS/m using from both test year data values. This value was found to be lower 12-15% than literature about the values for wheat. This deviation occur the total amount of irrigation water applied and the method, climatic conditions (temperature, relative humidity and rainfall) as a result.

Soil water in the plant roots deep, both in the year of research, laterally on the nearest TA did not drop below 50% of available capacity. However, TB and TC issues, starting with the blooming period, faced with severe water stress.

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