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RESEARCH ARTICLE

INVESTIGATION OF THE YIELD AND YIELD COMPONENTS OF RICE IN AREAS WITH SHALLOW WATER TABLE AND SALINE

Masoud Pourgholam-Amiji[a]*, Abdolmajid Liaghat[a], Arezoo Ghameshlou[a]*, Mojtaba Khoshravesh[b], Muhammad Mohsin Waqas[c]

[a]Department of Irrigation and Reclamation Engineering, College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran
[b]Water Engineering Department, Faculty of Agricultural Engineering, Sari Agricultural Sciences and Natural Resources University, Sari, Iran
[c]Department of Agricultural Engineering, Khwaja Fareed University of Engineering and Information Technology, Rahim Yar Khan, Pakistan
**Corresponding Author Email: a.ghameshlou@ut.ac.ir*

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ABSTRACT

Since rice is one of the most important strategic plants for the country's economy and the people of the north of Iran regions. On the other hand, the problem of soil salinity in some paddy fields there is in the Caspian Sea region due to being located in areas with the saline water table at a very low depth. Therefore, it is necessary to study the possibility of rice production in the presence of shallow water table and saline; because soil salinity in the coastal areas of Mazandaran province in the north of Iran is a big problem that threatens the cultivation of rice in this region. Research was conducted in 2018 using large lysimeter at the Climate Research Center of Agricultural and Natural Resources College of the University of Tehran. The present study was performed in an insulated metal lysimeter under two main treatments with non-saline water (NSW) and high saline water (HSW), both in the presence of a shallow water table. The irrigation water salinity was equal to 0.94 dS m^{-1} for both treatments, and the shallow water table salinity at a depth of 40 cm below the soil surface for HSW treatment was adjusted to 20 dS m^{-1} as artificial feeding. The results of comparing the average yield parameters showed that the shallow static surface salinity on leaf area index (LAI), root length (RL), plant height (PH), membrane stability index (MSI), chlorophyll (SPAD), relative water content (RWC) and biomass (BIO) parameters did not have a significant effect on the two treatments and caused a small difference between the yield parameters. The difference between the rice yield parameters of the control treatment and the salinity treatment was about 1 to 12 percent. Meanwhile, grain and biological yield in HSW treatment compared to NSW decreased by 3.2% and 4.5%, respectively. Also, the harvest index in the two treatments NSW and HSW was almost equal and was calculated to be 57.55% and 58.31%, respectively. Therefore, according to the result of this study, it can be find that there is exploring the possibility of cultivation and production of rice in the presence of shallow water table and saline.

KEYWORDS

Groundwater, Shallow and Saline, Lysimeter, Rice Yield, Salinity Profile.

1. INTRODUCTION

The growing population, the need for water and more crop production, climate change and droughts have led to an increase in water demand in recent years (Ma et al., 2020, Pourgholam-Amiji et al., 2020a). The World Health Organization estimates that more than 1.8 billion people will suffer due to the increasing competition between the urban and non-urban water demand by the end of 2025 (WHO, 2019). Agriculture being the largest consumer of water, the arrowhead will be on this side and efforts to reduce water consumption in this sector and increase in yield and water productivity, use of saline water as well as non-conventional water are a necessary and essential scenario (WWAP , 2019, Pourgholam-Amiji et al., 2019). On the other hand, about 70% of the world's population lives in rainfed lands and 30% in irrigated lands; therefore, without irrigation and agriculture, it is not possible to provide enough food for the current population of the world (Gany et al., 2019).

Rice is one of the most important and popular crops cultivated in the world. About 75% of the world's rice is produced from irrigated paddy fields (Alberto et al., 2011; Carracelas et al., 2019). Despite the need to increase food production due to the increase in the world's population to about 9 to 10 billion people by 2050 (Wichelns and Qadir, 2015). The aforementioned forecasts suggest that during this period, due to continuous urban development, the cultivable area will be reduced by about 10%. Under these conditions, paddy fields, which occupy one-third of the world's arable land, play an important role in feeding half of the world's population (Carracelas et al., 2019).

For about half of the world's population, rice accounts for about 80% of their food consumption. Due to the flexibility with natural conditions, rice is planted in about 113 countries (FAO, 2011). Rice cultivated lands of the world increased from about 157.8 million hectares in 2008-2009 to 60.6 million hectares in 2014-2015, which accounts for about 30% of the world's irrigated lands (Lampayan et al. 2015).

In Iran, the agricultural year of 2015-2016, the cropped area was 11 million hectares, the area of cereals was 68.6 %, beans 7.8%, industrial products 5.4%, vegetables 4.7%, and summer crop 2.6%, Fodder plants were 9.7% and other crops were 1.3%. Rice with an area of 0.62 million hectares, has produced 3.1 mega tons of products, which means that the

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average yield of rice in Iran is 4.9 ton per hectare (Ahmadi et al., 2019).

Water uptake by roots depends on Place and time, and other factors such as plant characteristics, available water quality, and climatic conditions affect it. Mass transfer, diffusion process, and capillary rise are some of the ways of transferring solutions (water and salts) in environments with saline of water and soil. Also, drainage of paddy fields improves the growth conditions of the plant, prevents flooding, and leaching away excess salts in the root zone and creates a suitable situation for the plant to absorb water (Jouni et al., 2018). The salinity of water and soil resources is becoming a growing problem in the world. Soils affected by salinity are highly dispersed and found everywhere. However, about 50 percent of the agricultural land under cultivation is affected by different degrees of salinity (Igbal, 2018).

One of the ways to deal with the shortage of irrigation water resources is to use low-depth water table to irrigate the plant, especially in areas with groundwater close to the soil surface; however, the rise of salt to the root zone due to capillary flow is a limiting factor for the use of shallow groundwater for irrigation (Zarei et al., 2010; Carracelas et al., 2019; Phan & Kamoshita, 2020). Clermont-Dauphin et al. (2010) examined the yield of rice in saline water and soil conditions in Thailand. The results showed that water stress significantly affects yield and yield components; however, soil salinity had little effect on nutrient uptake and rice growth. Since in the region, the electrical conductivity of soil saturation extract at a depth of 0-20 cm was 16 and on average in the region was 8 dS m^{-1}, the decrease in rice yield in these conditions compared to the control treatment was reported to be about 20%.

Official statistics from the Ministry of Agriculture-Jihad (2006) indicate that in the province of Mazandaran, located in the North of Iran, coastal zone areas suffer from the problem of soil salinity and these districts with an area of 30000 *ha*, consists 14% of the total land areas of this province. The water table in these coastal lands is saline and shallow (30 to 150 cm). It is not possible to cultivate any crop on land with a water table of less than one meter due to upward movement and salt accumulation in the root zone. For solving this problem in rice farming, a layer of soil at a depth of 20 to 30 cm is used for agricultural operations. This layer, calling *hardpan*, is created due to tillage in rice cultivation (Pourgholam-Amiji et al., 2019). However, the Ministry of Agriculture-Jihad (2014) indicates that cultivating different types of in Mazandaran province rice is possible because of constant waterlogging, continuous downward flow, and the presence of a hardpan in-depth 30 cm for preventing the upward movement of soils.

In times of crisis, one way to increase crop production is to make optimal and multi-purpose use of agricultural land to produce food that has saline water and soil problems. Many coastal paddy fields have sufficient water resources, but due to the proximity to the sea and the advancement of saline water, the salinity problems of groundwater in these lands are high and cultivation in it requires special management (Pourgholam-Amiji et al., 2019). Considering the above points and the importance of rice and on the other hand, its proximity to the sea and the salinization of groundwater in lowland paddy lands, a scientific study is necessary considering these two factors and requires careful study; Therefore, the aim of this study is to compare the yield and yield components of rice under shallow water table and saline and non-saline conditions.

2. Materials and Methods

2.1 Site Characteristics

The experiments were conducted at the Climate Research Center of Agricultural and Natural Resources College of the University of Tehran (35° 55′ N; 50° 54′ E) elevation 1293 *m* above the sea level in Alborz province, Karaj, Iran, from 1 July to 23 October 2018. According to long-term statistics and data (1988-2018), the region has a Mediterranean climate with a maximum and minimum monthly mean air temperature of $26^{°C}$ and $1^{°C}$, respectively. The mean air temperature is $15.9^{°C}$ which the minimum and maximum absolute values recorded at $-17^{°C}$ and $+42^{°C}$, respectively. Furthermore, the mean annual precipitation in Karaj is 247.8 mm (Pourgholam-Amiji et al., 2020a). Table 1 shows the summary of meteorological information in the period of rice cultivation at the site of the research.

Table 1: Summary of meteorological information on the site of the research

Months of the year	Average total temperature (°C)	Average total humidity (%)	Total evaporation monthly (mm/month)	Total monthly precipitation (mm/month)
Jul-Agu	27.81	33	348.4	0
Agu-Sep	25.38	30	294	0
Sep-Oct	17.4	44	185.8	6

2.2 Data collection and brief information about the experiment

The chemical properties of the irrigation water sample are measured in the water quality laboratory (see Table 2). The lysimeter ($length \times width \times depth = 3 \cdot 8\,m \times 1\,m \times 1\,m$) has Plexiglas walls. The actual length of the lysimeter is 4 m, but due to the required space for controlling the water table and groundwater supply of the saline on one side of the lysimeter, we left about 0.2 *m* of this physical model blank. We installed Piezometers on the body of the lysimeter to get required soil solution samples. Similar to the controlled drains in the paddy fields of the north of Iran, we fitted some holes at the bottom of the lysimeter for water drainage as needed. The lysimeter has a space for feeding and some holes in the body to control the water table. Additionally, it has an insulation sheet for separating saline and non-saline plots. Figure 1 illustrates the details of the physical model.

Table 2: Chemical properties of the irrigation water

EC	pH	Nitrate	Chlorine	Carbonate	Bicarbonate	Calcium	Magnesium
dS/m		mg/l	meq/l	meq/l	meq/l	meq/l	meq/l
0.941	7.83	16.04	2.8	0	4.4	1.1	6.7

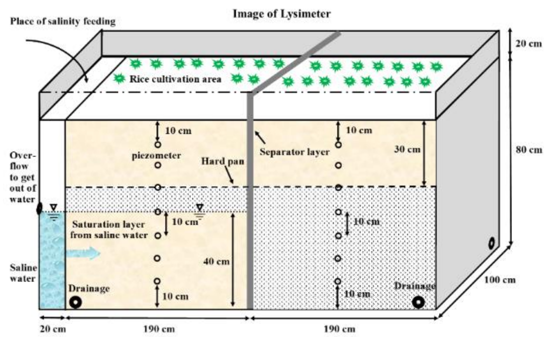

Figure 1: The used lysimeter in the research and all related appendices

The soil in the lysimeter was obtained without any disruption from the paddy fields of the north of Iran. The lysimeter prepared with the simulating soil layering in three different layers; the top layer in a depth of 20 cm of soil surface doing soil preparation on it; the middle layer in the next depth of 20 cm of soil surface as hardpan. The point in this section is that, in rice cultivation and tillage operations, a relative hardpan form near the surface of the earth, and the hardpan, even in cold seasons, remains intact for subsequent crops; and the bottom layer in the next depth of 40 *cm*, respectively. Table 3 shows the physical properties of paddy soil, including the percentage of clay, silt, and sand in different described layers.

Table 3: Physical properties of the soil

Layer name	Depth (cm)	Texture	Clay (%)	Silt (%)	Sand (%)	Bulk density (g/cm³)	Saturation moisture (%)	Field Capacity (%)	Initial salinity (dS/m)
Top layer	20	Clay loam	31.4	42.2	26.4	1.34	51	41	1.7
Hardpan	20	Clay	50.56	25.34	24.1	1.22	57	43	1.89
Bottom layer	40	loam	13.68	41.61	44.71	1.3	47	39	2.45

The measurements and analyses for the soil texture class followed the standard method (Gee & Or, 2002). The soil was classified as mostly heavy in different described layers which is appropriate for rice cultivation in the paddy fields for water retention. The field capacity for determining the apparent density evaluated using the pressure plate and the cylindrical steel (ring method) (Pourgholam-Amiji et al., 2020b).

2.3 Treatments studied

Soil tillage and preparation of the upper layer of soil were carried out in a depth of 30 , and the seeds of rice, early Tarom type, were planted. The precooked and transplanted seedlings transferred to the lysimeter. The amount of rice fertilized for growth, proportional to the conventional method in rice fields, was applied with an N: P: K^1 ratio of 15:10:10 m^{-2}. In the lysimeter, we considered two different treatments for irrigation; non-saline water (NSW) and saline water (HSW), both in the presence of a shallow water table. In HSW, the water table salinity was applied in the lower layer through free space at the end of the lysimeter. The salinity concentration, equivalent to the salinity of groundwater in agricultural lands of the coastal zone of the Caspian Sea, 20 dS m^{-1}. Additionally, the salt concentration of the irrigation water was 0.94 dS m^{-1}. Then, in the rice cultivating period, which lasted about 90 days, the mid-season and the end of the season drainage was applied to the paddies.

2.4 Measurements

The morphological characteristics of the plant such as chlorophyll or leaf greenness (SPAD), relative water content (RWC), plant height (PH), root length (RL), wet and dry weight of plant or biomass (BIO), electrolyte leakage and membrane stability index (MSI), leaf area index (LAI) of rice were evaluated from mid to late end of cultivation period. The biological, physiological, and grain yield characteristics of the rice were also examined at the end of the growing season, and the mean comparison of rice yield and yield components parameters under two conditions was performed with Minitab software.

For the relationship between grain yield and biological yield, the Harvest Index (HI) is defined as follows to establish a relationship between economic and biological yield. The harvest index can be calculated using Equation 1 (Pourgholam-Amiji et al., 2019):

$$HI = \frac{EY}{BY} \times 100 \quad (1)$$

Where EY is the economic yield or grain yield (kg ha^{-1}), BY is the biological yield (kg ha^{-1}) or biomass (dry matter) and HI is the amount of the harvest index (%).

All parameters were measured in both NSW and HSW treatments to determine the effect of low-depth and saline stasis on final rice yield. Since there is a close relationship between the amount of photosynthesis and leaf nitrogen in rice, chlorophyll density measurement was used instead of chlorophyll measurement. Chlorophyll is a chemical compound of a plant that causes the green color in plants and can be used to detect the presence or absence of various stresses such as drought and salinity in the plant. The device used is the SPAD 502 Plus Chlorophyll Meter and shows a dimensionless number. This parameter was measured from healthy leaves in two treatments.

RWC index measurement was performed after the growth of greenery was complete and before clustering and fall of the plant. In both NSW and HSW treatments, sampling of the last developed leaf was performed and at each stage, part of the fresh leaf of the plant was examined. Relative water content was calculated using Equation 2 (Pourgholam-Amiji et al., 2019):

$$RWC = \frac{(FW - DW)}{(WT - DW)} \times 100 \quad (2)$$

Where FW, wet leaf weight (gr); DW, leaf dry weight (gr); WT, leaf amass weight (gr); and RWC, Relative water content (%) are respectively.

To measure MSI, the electrical conductivity of distilled water with the sample was measured as the initial leakage (L_1) with an EC meter. Secondary leakage (L_2) was also measured by measuring the electrical conductivity of the samples after heating them for one hour at 100 ^{0}C in a hot water bath (Bain Marie). The membrane stability index is calculated through equation 3 (Pourgholam-Amiji et al., 2019):

$$MSI = (1 - \left(\frac{L_2}{L_2}\right)) \times 100 \quad (3)$$

To measure LAI in this experiment, after rice growth was complete, at the end of the growing season and before clustering, the leaf area index was sampled and recorded. To do this, a leaf area meter - delta t England device was used.

3. Results and Discussion

3.1 Soil salinity profile

The measurement of the average electrical conductivity of soil saturation extract in the area of plant root development, the salinity effect on plant growth and yield can be determined. According to the FAO 56 guidelines for computing crop water requirements (Allen et al., 1998), the allowable salinity limit of the root zone or threshold for reducing crop yield for rice is about 3-3.5 dS m^{-1} and then the percentage of crop yield reduction per one the unit for increasing the electrical conductivity of soil saturated extract (dS m^{-1}) in the area of plant root development is estimated to be about 12%; therefore, rice is considered a salinity-sensitive product. Based on investigations conducted in the root zone (from zero to 30 cm below the soil surface), it was found that the salinity of the soil profile did not reach the allowable and tolerable limit of rice and there would be no significant reduction in yield (Wichelns & Qadir, 2015; Iqbal, 2018).

Figure 2 shows the salinity of the soil saturation extract (ECe) in the NSW control treatment after soil sampling. Sampling dates from soil profiles are after mid-season drainage, end- season and leaching, respectively. The salinity changes of soil profile are minimal in this treatment and in the range of soil salinity and irrigation water are located. Figure 3 also shows the salinity profile of the soil in the HSW treatment at different dates. The process of soil profile salinity changes during the four sampling stages is the same as the process of changes in NSW treatment. The difference is that the salinity in the bottom layer of this treatment (HSW) is much higher than the previous treatment (NSW). The process of change to a depth of 30 cm and the root zone is similar to the NSW treatment and the rate of change is small.

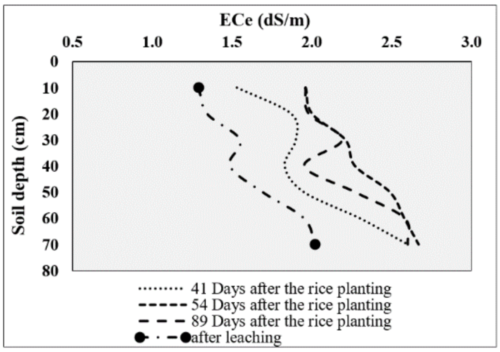

Figure 2: Salinity profile of soil saturation extract in NSW treatment

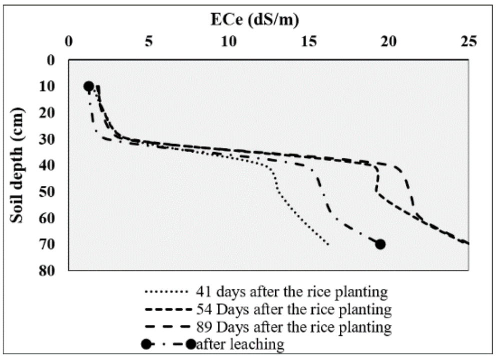

Figure 3: Salinity profile of soil saturation extract in HSW treatment

3.2 Grain yield and harvest index

To evaluate the applied treatments, various indicators such as grain yield or economical yield, biomass yield or biological yield and physiological and morphological yield (morphological traits including root length, plant height, greenery or leaf chlorophyll, leaf area and physiological traits including relative water content and ions leakage) There are. In this section, each of these indicators for rice crop is separated and examined.

The amount of grain yield or "economical yield" of rice in NSW control treatment is 1.150 kg and in HSW treatment is 1.070 kg (see table 4) and after generalizing the area of two square meters of each treatment to a hectare, the amount of grain yield 5525 and 5350 kg ha^{-1} was obtained, which is close to the amount of rice yield in paddy fields because the amount of yield potential of rice in paddy lands of northern Iran for Tarom cultivar is between 6.5-7.5 ton ha^{-1}. The difference from the present study about the amount of potential performance, especially in control conditions (NSW), can be due to differences in climatic conditions, especially the relative humidity of the environment; because the most appropriate relative humidity is 71 to 81 percent during flowering. In relative humidity, less than 41% and more than 91% are disturbed in flowering. Despite being covered with plastic about a meter high, around the cultivated area to minimize the effects of wind and humidity but the average relative humidity in Table 1 was less than 41%, which could affect the reduction in final yield. Comparing the average grain yield in the two treatments showed that they were slightly different; Therefore, accepting a slight reduction in yield (about 3.2%) in the HSW treatment compared to the NSW control treatment, it is expected that the results of this study can be generalized to soils with similar layers to this experiment and have a shallow water table and saline problem. The results of this section are consistent with the findings of Clermont-Dauphin et al. (2010), Pourgholam-Amiji et al. (2019), and Phan & Kamoshita (2020).

Table 4: Evaluation of harvest index, economical yield (grain) and biological (biomass)

Treatment	Economical yield (EY)	Biological yield (BY)	harvest index (HI)
	Kg	kg	%
NSW	1.105	1.920	57.55
HSW	1.070	1.835	58.31

To determine the "biological" or biomass yield of the two treatments, at the end of the growth period, plant samples were harvested in both NSW and HSW treatments. The amount of dry matter in NSW treatment was calculated to be 1.920 kg and HSW treatment was calculated to be 1.835 kg (Table 4) which is consistent with the results of the Ministry of Agriculture-Jihad (Ahmadi et al., 2019) and Phan & Kamoshita (2020). However, a small decrease in this amount (about 4.5%) in HSW treatment can be attributed to the climatic and environmental conditions of this test site compared to paddy fields in the north of Iran.

A comparison of the mean biomass parameter in the two treatments using the T-Student test (Table 5) showed that shallow saline groundwater feeding has achieved a 12% difference between the mean biomass parameter of the two treatments. This is due to the small effect of the shallow saline water table on the plant and the biomass of each treatment. According to Table 4, the amount of harvest index in both NSW and HSW conditions is almost the same, which means that even with the reduction of part of the leaves and aerial parts, it does not affect grain yield. The harvest index for NSW treatment was 57.55% and HSW treatment was 58.31%.

3.3 Yield components

A comparison of the mean of the simple effect of treatments for the traits studied is shown in Table 5. It is expected that as the concentration of solutes in the root zone increases, the osmotic pressure of the soil solution increases, thus increasing the amount of energy the plant expands to absorb water from the soil (Zarei et al., 2010). This reduces water absorption, increases respiration, lowers plant height and yield; However, the results of comparing the mean of the indicators in this study (Table 5) showed that there was a small difference between the average root length and plant height in both conditions and the percentage of root length and plant changes in HSW treatment compared to NSW were 2.27 and 2.63%, respectively. The results in Table 5 also show that there is a small difference between the mean measured chlorophyll or greenness in both NSW and HSW treatments, and the shallow water table and saline do not affect plant greenness or chlorophyll. The percentage change in this parameter in the two conditions was only 5.91 percent. The results of this section are consistent with the findings of Alberto et al. (2011), Pourgholam-Amiji et al. (2019) Carracelas et al. (2019).

The relative water content of the leaves is one of the most important physiological characteristics to identify and compare plants in salinity and drought stress conditions. The reason for the decrease in the relative water content in drought and salinity stress conditions is the decrease in leaf water potential and then the reduction of water uptake from the roots in these conditions. Based on the comparison of the average, we found that there was no significant difference between the mean of RWC parameter in NSW and HSW treatments and the performance reduction was 3.28%. This indicates that the treatment applied did not affect the leaf water content and did not cause stress on the rice.

Table 5: Results from the mean comparison of the indicators in the treatments using by T-Student test

Row	Parameters	Average NSW	Average HSW	Changes compared to control treatment (%)
1	Biomass (BIO)	33.8	29.6	12.42
2	Root length (RL)	26.4	25.8	2.27
3	Plant height (PH)	87.4	85.1	2.63
4	Chlorophyll (SPAD)	37.2	35	5.91
5	Relative water contect (RWC)	88.3	85.4	3.28
6	Membrane stability index (MSI)	84.5	83.8	0.82
7	Leaf area index (LAI)	2.43	2.15	11.52

Environmental stresses such as salinity produce active oxygen species, which are expected to damage the cell wall and eventually leak its contents. The higher the amount of the MSI (membrane stability index), the greater the plant's resistance to the leakage of content within the plant to the external environment (Lampayan et al., 2015; Iqbal, 2018). According to the results of Table 5, the shallow water table and saline have no effect on the mean amount of the MSI between the two treatments NSW and HSW and there is a difference of less than one percent. This indicates that the MSI index has not decreased under water table salinity conditions, the cell wall structure has not been damaged, and the amount of electrical conductivity of the plant-derived effluent solution has not changed.

The leaf area index shows the amount of aerial and green organ development of the plant, and according to it, the effect of the presence of shallow water table and saline on the development of green vegetation can be examined. The results of comparing the mean performed in Table 5 showed that the shallow water table with high-salinity did not significantly differentiate the mean LAI amount of the two treatments NSW and HSW, and there was an 11.52% difference between HSW and NSW conditions. The results of this section are consistent with the findings of Clermont-Dauphin et al (2010), Wichelns & Qadir (2015), Pourgholam-Amiji et al. (2019), and Phan & Kamoshita (2020) studies.

4. Conclusions

This study was conducted to investigate of the yield and yield components of rice in areas with shallow water table and saline. The results of this study showed that by cultivating in lands with a shallow water table and saline problems similar to the conditions of this experiment, the rice crop can be cultivated with slightly reducing the amount of final yield. Under these conditions, it is not necessary to deep drainage to reduce the salt concentration in the soil especially in the root zone. In the soil salinity profile section, a shallow water table with high-salinity (20 dS m^{-1}) did not affect root growth and then rice yield. The main concerns in the lands with water table salinity problems are related to the mixing of salt and fresh water, and in this study, it was proved that the hardpan (between 30 and 40 cm depth from the soil surface), it prevents the mixing of fresh water due to deep percolation from the hardpan and the upward rise of the salt water in the water table. A comparison of the mean between the yield components parameters showed that the shallow water table and saline, except for the two biomass and the leaf area index, caused a slight difference in the yield components parameters between the two treatments. The grain yield did not differ much in these conditions. Therefore, as a general result it can be said that by rice cultivation in this fields, non-conventional water and soil resources can be used usefully.

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