CGIAR Challenge Program on
WATER & FOOD

# IMPROVING CROP GROWTH AND WATER PRODUCTIVITY ON SALT-AFFECTED SOILS IN THE LOWER KARKHEH RIVER BASIN

S.A. Cheraghi, N. Heydari, M. Qadir, and T. Oweis

**Improving On-farm Agricultural Water Productivity in the Karkheh River Basin Project (CPWF PN 8)**

**4**

ICARDA
International Center for Agricultural Research in the Dry Areas

AEERO
Agricultural Extension, Education and Research Organization

CGIAR Challenge Program on
WATER & FOOD

CPWF project: Improving on-farm agricultural water productivity in the Karkheh river basin (PN8)

## Research Report no. 4

# Improving Crop Growth and Water Productivity on Salt-affected Soils in the Lower Karkheh River Basin


*Edited by:*

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ICARDA
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AREO
Agricultural Research and Education Organization

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# Contents

## Abbreviations

| | |
|---|---|
| BY | Biological yield |
| CV | Coefficient of variance |
| DA | Dasht-e-Azadegan |
| dS | deciSiemens |
| EC | Electrical conductivity |
| ESP | Exchangeable sodium percentage |
| GY | Grain yield |
| HI | Harvest Index |
| KRB | Karkheh river basin |
| K/S | Kernels/spike |
| KW | Kernel weight |
| LKRB | Lower Karkheh river basin |
| PLH | Plant Height |
| RSC | Residual sodium carbonate |
| SAR | Sodium absorption ratio |
| SL | Stem length |

# Chapter 1.

# Present status of salt-affected and waterlogged soils in Dasht-e-Azadegan and management strategies for their sustainable utilization

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## Introduction

Salt-prone land and water resources are major impediments to the optimal utilization of crop production systems in many arid and semi-arid regions of the world, including Iran (Alizadeh et al. 2004; Moghaddam and Koocheki 2004). The salinization of land and water resources has been the consequence of both anthropogenic activities (causing human-induced or secondary salinity and/or sodicity) and naturally occurring phenomena (causing primary fossil salinity and/or sodicity) (Ghassemi et al. 1995). The main cropping systems in the country are based on irrigated agriculture where at least 50% area (4.1 Mha) fall under different types of salt-affected soils (Cheraghi 2004). Therefore, the dependency on irrigated agriculture is at stake in areas where salt-prone land and degradation of water resources has increased over time.

Human-induced salinization of land and water resources has occurred mostly in unique topographic conditions of semi-closed or closed intermountain basins where irrigated agriculture has been practiced for centuries. The slightly and moderately salt-affected soils are mostly formed on the piedmonts at the foot of the Elburz (Alborz) Mountains in the northern part of the country. The soils with severe to extreme salinity are mostly located in the Central plateau, the Khuzestan and southern coastal plains, and the Caspian coastal plain (Koocheki and Moghaddam 2004). The extent and characteristics of salt-affected soils in Iran has been investigated by several researchers (Dewan and Famouri 1964; Mahjoory 1979; Abtahi et al. 1979; Matsumoto and Cho 1985; Banie 2001).

Owing to abundant water resources, fertile lands and sufficient extraterrestrial energy, Khuzestan province in southwest Iran is potentially one of the most suitable regions for agricultural production. However, salinization of land and water resources has become a serious threat to efficient use of these invaluable resources. It is estimated that out of the total 6.7 Mha of the province, 1.2-1.5 Mha (18-22% of total area) are faced with the dual problems of soil salinization and water logging (Anonymous 2000).

The Karkheh river basin (KRB) is one of the major river basins in the Khuzestan province, consisting of two main sub-basins namely Karkheh Olia (upstream) and Karkheh Sofla (downstream). The KRB is, most notably, the eastern flank of the 'cradle of civilization' (ancient Mesopotamia) and a boundary between the Arab and Persian cultures. This major river system of western Iran has unique agricultural and hydrological aspects; but also much in common with other catchments around the world, e.g. rural poverty and land degradation, low water and agricultural productivity, a dry climate, and growing upstream-downstream competition for water. Agriculture in the upstream basin is mainly rain fed, while the downstream basin is mostly irrigated. The drainage outlet of the KRB, which also is a basin outlet, is the Hoor-Al-Azim swamp in southwest Iran and on the Iran-Iraq border (Fig. 1.1). At present, there are very limited modern irrigation and drainage networks under operation within the KRB and agriculture is yet to be fully developed. However, the government has started constructing irrigation and drainage networks with the goal of improving the traditional irrigation systems, e.g. in the Dasht-e-Azadegan (DA) plain in southern parts of the lower KRB (LKRB). It is in this area where this project was carried out. This chapter describes this area (Dasht-e-Azadegan) in terms of its geology, soils, climate, and

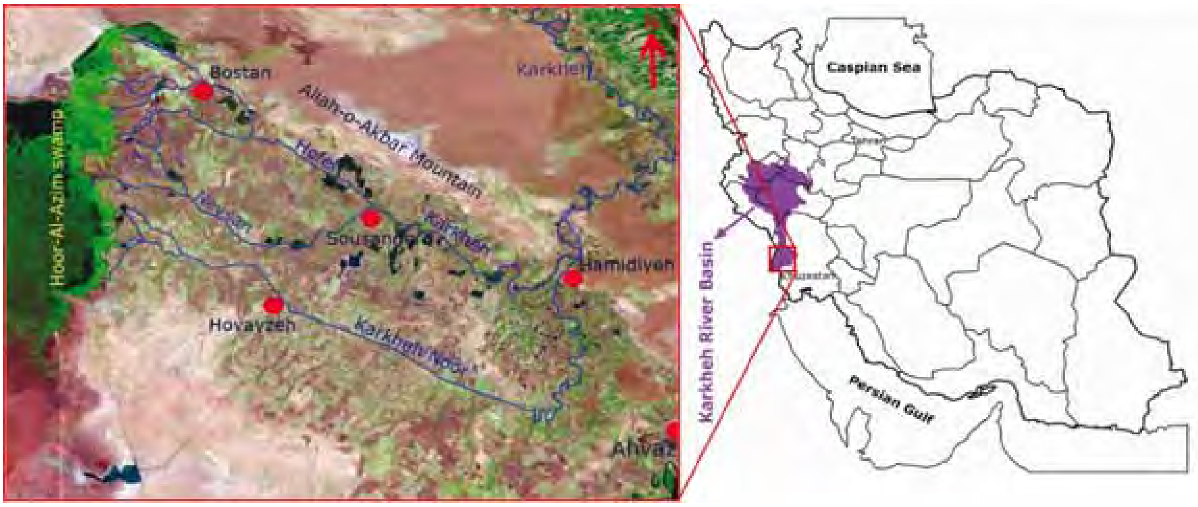


*Fig. 1.1. Karkheh River Basin (KRB) and Dasht-e-Azadegan (DA) region*

water resources. It also reviews salinity and waterlogging problems based on previous studies carried out in the region. Lastly, general recommendations for effective use of soil and water resources for crop production and environmental are given.

## Geology

Azadegan plain is a deep structural hole covered by Quaternary sediments. The deepest part of this cavern is in the west and northwest of the region and around Hoor-Al-Azim. The outer edge of the plain is in the east and northeast, where the bedrocks have been uplifted to form the Mishodagh and Allaoakbar mountains. The deepest layers of the plain are composed of the Kachsaran, Mishan, and Aghajari (Fars group) formation, from deep to shallow. These formations were overlain by conglomerate rocks (Bakhtiari formation). The semi-deep portion of the hole was filled by recent sediment, which covers Bakhtiari conglomerates.

The whole of sedimentary deposits in the Azadegan plain were laid down during the Quaternary period. Sediment ranges in thickness from zero at the foot of the mountains to 100 m in the west and northern west of the plain in the vicinity of Hoor-al-Azim. Information about the upper strata of plain reveals that there are many varieties and diverse features as compared to the deeper part of plain. There, it can be seen that thin lens-like sand features in a clay-silty background appear on a limited scale. These features are accompanied by transverse layers, indicative of a different deltaic formation. These events show that the river tributary beds have undergone frequent changes of position at times near the Holocene epoch. Furthermore, fine sediments such as silt and clay particles and to a lesser extent chemical sediments, organic matter, and vegetative material provide evidence of vast Quaternary marshes in the plain, particularly on the west side of the plain, where marshes along the western border of Iran can be seen. Sedimentary deposits of the Holocene epoch covering the surface of the plain include alluvial, fluvial, and aeolian sediments. The alluvial and fluvial sediments of plain are products of the geodynamic action of the Karkheh river tributaries.

## Soils

The soils of the area are alluvial soils formed originally by the floods of the river. These alluvial areas are flat and soil permeability is low, with little slope and poor natural drainage. Azadegan plain is a flood plain with very weak topography. The maximum elevation of 12 m a.s.l. is around Sosangerd and the Sosangerd-Hoveizeh highway. The lowest elevation is on the northwest side of the plain; adjacent to Hoor-Al-Azim (3-4 m a.s.l.). Azadegan plain is the terminal basin and all of tributaries of the Karkheh river end in this plain. Therefore, the plain is the scene of constant accumulation of the river sediment.

The low precipitation has developed the aridic soil moisture regime throughout the region. The moisture control section, in normal years, is dry in all parts for more than half of the cumulative days per year, when the soil temperature at a depth of 50 cm from the soil surface is above 5°C; and it is moist in some or all parts for less than 90 consecutive days when the soil temperature at a depth of 50 cm is above 8°C. These conditions cause low availability of water for cropping and as a result, soils are classified only in the Aridisol and Entisol orders based on development status of diagnostic horizons (Soil Survey Staff 2003).

As a result of the hot climate, the mean annual soil temperature is 22°C or higher, and the difference between mean summer and mean winter soil temperatures is more than 6°C, either at a depth of 50 cm from the soil surface or at a densic, lithic, or paralithic contact, whichever is shallower, so the soil temperature regime is considered to be hyperthermic in all series.

The carbonatic nature of the parent material, in addition to the low precipitation of the region has enhanced accumulation of secondary lime minerals in the soil mineralogy control section so that the carbonatic or mixed (calcareous) mineralogy classes are common in the region. Based on the USDA Soil Taxonomy (Soil Survey Staff 2003), soils are mainly classified as orders of the Entisols and Aridisols. The young (recently formed) Entisols of the region belong to two suborders. Fluvents are characterized by either 0.2% or more organic carbon of the Holocene age at a depth of 125 cm below the mineral soil surface or an irregular decrease in content of organic carbon from a depth of 25 cm to a depth of 125 cm, or to a densic, lithic, or paralithic contact if shallower. These soils have wide distribution in the region so that seven soil series belong to this suborder. The Kout soil series, which is classified as Salorthidic Torrifluvents, is a typical Solonchak profile. Fluvaquents also are identified in the lowland physiographic region of the plain. Redoximorphic features (brown mottling in a pale green soil matrix) in Fluvaquents (Sarhangiyeh, Shahatt-e-Abbas and Machriyeh series) represent hydric conditions (seasonally saturated) in young, flood plain soils. The coarse-textured soils are extended around rivers in Susangerd city so the Psaments can be identified just in this region. Psaments, which occur only in the Susangerd soil series of the region, have good drainage and have less than 35% (by volume) rock fragments and a texture of loamy fine sand or coarser in all layers.

Medium- to coarse-textured soils exist in areas around the Karkheh river and its tributaries, which have experienced frequent flooding in previous times. Soil series in this area show a distinct stratification, including sequences of different-size textured ranges from coarse to medium textured and in these areas the slope is gently perpendicular to the river (natural levees). For Aridisols also just two suborders of cambids and salids had been identified in the region. Cambids, which are Aridisols with cambic diagnostic horizons, formed under submerged conditions in this region and so they belong to the Aquicambids that cover Fenikhi, Yazd-e-No and Luliyeh series. In this sub-order, the soil profile is either irrigated and has aquic conditions for some time in normal years in one or more layers within 100 cm of the soil surface; or is saturated with water in one or more layers within 100 cm of the soil surface for 1 month or more in normal years. Aridisols with the Salic diagnostic horizon that have a upper boundary of horizon within 100 cm of soil surface are classified as Salids. These soils are identified in Jarahyeh and Abohomayzeh soil series. Table 1.1 gives a classification of the main soil series in Dasht-e-Azadegan (Mahab-e-Ghods 1992).

## Climate

The existing statistics indicate that the weather is hot in summer with a mild and short winter. Annual mean temperature of the region is 23.1ºC. The maximum daily temperature in the warmest months of the year (July and August) is 43.02ºC and the minimum daily temperature in the coldest month of the year (January) is 5ºC. The average precipitation in the area is 175 mm according to statistics of the past 10 years. The wettest month of the year is October, with 44.1 mm and the driest months are May to late September when there is almost no precipitation. Annual mean evaporation in this area is 2004.9 mm. The maximum evaporation of 303.6 mm is in July and the minimum of 42.7 mm occurs in January. Based on the climate data for the last 10 years at Sosangerd and Howeyzeh stations, as well as the bioclimatic map of the Mediterranean region, and despite the existent of 260 dry days in a year, Dasht-e-Azadegan has not been classified as Accentuated Sub-Desertic Area. The total rainfall in Sosangerd and Bostan is 180 and 200 mm, respectively. There is a weather station in Bostan. The agricultural services centers also are equipped with rain gauges. In Table 1.2 some of the factors influential in climate and evaporation of the Dasht-e-Azadegan region are presented (Mahab-e-Ghods, 1992).

## Crops

Current crops in Dasht-e-Azadegan include cereals such as wheat, barley, rice, and ground cereals; vegetables such as melon, watermelon, tomato, cucumber, eggplant, okra, lettuce, cabbage, carrot, radish, onion, etc; grains such as beans; plants used as fodder for livestock such as alfalfa, barely, corn, and sudan grass. More than 78% of agricultural production in Dasht-e-Azadegan region is dominated by grains (Table 1.3), mainly wheat and barley (Mahab-e-Ghods, 1992).

## Water resources

The only source of water for the Dasht-e-Azadegan is the Karkheh river with its tributaries. The river originates from Zagross mountain ranges and is fed by snow melt. The average monthly discharge of the river for the period of 1987 to 1998 is shown in Fig. 1.2 (Mahab-e-Ghods 1992). There is a distinct flood period during winter and early spring. As explained later these floods are the main cause of salinity and waterlogging in the region, because large quantities of salts are deposited in the soils as pure water is evaporated during the hot summers. Since the construction of the Karkheh reservoir dam, the adverse effects of these floods

*Table 1.1. Classification of the main soil series of Dasht-e-Azadegan (Mahab-e-Ghods1992)*

| Physiography | Soil series | Area | | USDA soil taxonomy | | |
|---|---|---|---|---|---|---|
| | | ha | % of total | Family | Sub group | Order |
| River alluvial plain | Hofel | 1460 | 1.6 | Coarse loamy, carbonatic, hyperthermic | Typic Torrifluvents | Entisols |
| | Karami | 15760 | 18.2 | Fine loamy, mixed (calcareous), hyperthermic | Typic Torrifluvents | Entisols |
| | Fenikhi | 10640 | 11.6 | Fine, mixed, hyperthermic | Fluventic Aquicambids | Aridisols |
| | Yazd-e-Now | 8100 | 8.9 | Fine loamy, mixed, hyperthermic | Fluventic Aquicambids | Aridisols |
| | Abu-Homayzeh | 7990 | 8.7 | Fine loamy, carbonatic, hyperthermic | Typic Haplosalids | Aridisols |
| | Ahmad-Abad | 17440 | 19.1 | Fine, mixed (calcareous), hyperthermic | Typic Torrifluvents | Entisols |
| | Kout | 1290 | 1.4 | Fine, mixed (calcareous), hyperthermic | Salortidic Torrifluvents | Entisols |
| | Sousangerd | 170 | 0.2 | Mixed, hyperthermic | Typic Torripsamments | Entisols |
| | Karkheh | 7730 | 8.5 | Fine, mixed, hyperthermic | Typic Solorcthids | Aridisols |
| | Golbahar | 810 | 0.9 | Coarse, loamy, mixed, hyperthermic | Typic Salorthids | Aridisols |
| | Hovayzeh | 3490 | 3.8 | Fine loamy mixed (calcareous), hyperthermic | Typic Torrifluvents | Entisols |
| | Sariyeh | 2300 | 2.5 | Fine mixed (calcareous), hyperthermic | Vertic Torrifluvents | Entisols |
| | Hamidiyeh | 1080 | 1.2 | Fine loamy mixed (calcareous), hyperthermic | Typic Torrifluvents | Entisols |
| Lowland | Sarhangiyeh | 4100 | 4.5 | Fine, mixed (calcareous), hyperthermic | Typic Fluvaquents | Entisols |
| | Shat-e-Abbas | 380 | 0.4 | Coarse loamy, carbonatic, hyperthermic | Typic Fluvaquents | Entisols |
| | Machriyeh | 1950 | 2.1 | Fine loamy, mixed (calcareous), hyperthermic | Typic Fluvaquents | Entisols |
| | Jarrahiyeh | 2890 | 3.2 | Fine loamy, mixed, hyperthermic | Typic Haplosalids | Aridisols |
| | Louliyeh | 1620 | 1.8 | Fine, mixed, hyperthermic | Fluventic Aquicambids | Aridisols |
| **Plateaux** | Kout | 230 | 0.2 | Fine, mixed (calcareous), hyperthermic | Typic Fluvaquents | Entisols |
| | **Sum** | **89430** | **97.8** | | | |
| | Miscellaneous | 2040 | 2.2 | | | |
| | Total | 91470 | 100 | Fine, mixed, hyperthermic | | |

*Table 1.2. Metrological parameters of Dasht-e-Azadegan plain (Hamidiyeh station)*

| **Month** | **Temperature (°C)** | | | **Precipitation (mm)** | **ET (mm)** |
|---|---|---|---|---|---|
| | **Average Min.** | **Average Max.** | **Average** | | |
| January | 5 | 16.4 | 10.7 | 41.3 | 42.7 |
| February | 6.9 | 19.7 | 13.3 | 24.1 | 62.5 |
| March | 11 | 24.8 | 17.9 | 23.3 | 105 |
| April | 15.2 | 30 | 22.6 | 17.7 | 150 |
| May | 19.6 | 36.6 | 28.1 | 6.5 | 234 |
| June | 22 | 41.8 | 31.9 | 0.0 | 299.2 |
| July | 23.7 | 43.2 | 33.5 | 0.2 | 303.6 |
| August | 22.8 | 43.2 | 33 | 0.0 | 279.8 |
| September | 19.2 | 41.2 | 30.2 | 0.7 | 235 |
| October | 14.8 | 35.1 | 25 | 4.2 | 155.5 |
| November | 10.1 | 26.6 | 18.3 | 11.5 | 88.1 |
| December | 6.7 | 19.1 | 12.9 | 45.5 | 49.5 |
| Average | 14.8 | 31.5 | 23.1 | 175 | 2004.9 |

*Table 1.3. Agricultural production in Dasht-e-Azadegan plain (cropping season 2003-2004)*

| **Crop** | **Planted area** | | **Yield (kg/ha)** |
|---|---|---|---|
| | **ha** | **%** | |
| Cereal | 67417 | 90.25 | 2682 |
| Pulses | 626 | 0.84 | 1856 |
| Industrial crops | 1149 | 1.54 | 757 |
| Vegetable | 1218 | 1.63 | 38266 |
| Summer crops | 2836 | 3.80 | 28812 |
| Forages | 1456 | 1.94 | 26540 |
| **Total** | **74702** | **100** | - |

*Table 1.4. Karkheh river water quality.*

| **$EC_{iw}$ dS/m** | **pH** | **meq/L** | | | | | | | **SAR** | **RSC meq/L** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **$HCO^{3-}$** | **$Cl^-$** | **$SO_4^{2-}$** | **$Ca^{2+}$** | **$Mg^{2+}$** | **$Na^+$** | **$K^+$** | | |
| 1.48 | 7.95 | 2.51 | 6.49 | 4.33 | 4.25 | 3.3 | 6.51 | 0.13 | 3.35 | 1.23 |

have been reduced considerably. The dam was completed on the Karkheh river in 1999 and became operational in 2001. The main objectives of the dam are to produce hydropower energy (1000 GW/h/year), flood water control, and

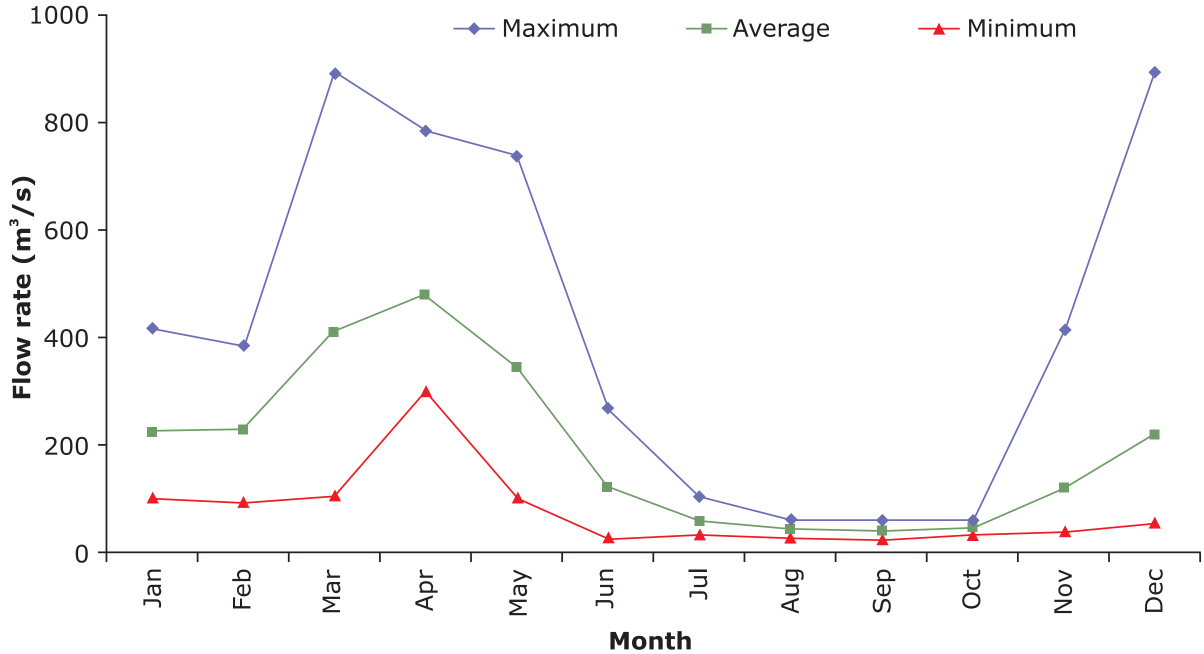


*Fig. 1.2. Karkheh river monthly discharge at Hamidiyeh gauging station, 1987-1998*

a regulated flow of water for irrigation of more than 340,000 ha of land downstream. These arable lands are located in different plains situated in the lower parts of the KRB (Mahab-e-Ghods 1992). The quality of Karkheh river water, as a surface resource, is generally good (Table 1.4), though it varies seasonally and also along the river towards to the outlet (Fig. 1.3), which reaches up to 2.4 dS/m near the Hoor-Al-Azim swamp.

There are limited irrigation networks in the region (mainly pumping from river to the canal). The main canals and drains are constructed or under completion (main irrigation and drainage canals in Kout and Hamoodi are under construction). But unfortunately there are no secondary or tertiary canals or lateral drains. At present, despite the construction and operation of main drains, the system is not functioning properly in all areas. This is mainly due to technical and excavation problems (i.e. improper slope of drainage lines) and also due to problems concerning the outlets. Gravitational drainage to outlet is not feasible and pumping is required.

## Salinity and waterlogging

The main problems limiting agricultural production in this region are waterlogging and salinity. As indicated before, saline-sodic soils constitute a vast area of Dasht-e-Azadegan. Soil studies show that around 99% of the area of the region has been faced with either high or low salinity or sodicity for a long time (Table 1.5). Generally, natural and man-made factors are involved in the soil quality of the region.

Based on the field studies, the soils of the Dasht-e-Azadegan region are divided into two types of saline soils and saline-sodic soils. The smaller portion of the region, referring to the Fenikhi soil


*Fig. 1.3. Water quality changes along the main branches of the Karkheh river*

series, is covered by saline soils with electrical conductivity (EC) > 4 dS/m, exchangeable sodium percentage (ESP) < 15% and pH of less than 8.5. In contrast, most of the DA region has saline-sodic soils with EC > 4 dS/m, ESP > 15% and pH of less than 8.5. The Abu-Homayzeh, Ahmad Abad, Karkheh, Karami and Yazd-e-Now soil series belong to the saline-sodic soil class. It is expected that the high values of sodium to calcium plus magnesium ratio would be relatively dominant. The sodium absorption ration (SAR) values varied from 6 to 66 and more, out of which most of the samples had an SAR of more than 13. Table 1.5 shows the extent of saline lands with salinity and alkalinity rates (Mahab-e-Ghods 1993).

Saline-sodic soils have some different properties from both saline and sodic soils. If attempts are made to leach out the soluble salts of saline-sodic soils with good quality water, the exchangeable Na+ levels and also pH would increase and therefore, the soil would take on the adverse characteristics of sodic soils. Therefore, attention must first be given to reducing the levels of exchangeable Na+ ions and then to the problem of excess soluble salts.

The situation in Dasht-e-Azadegan seems to be different. Based on the results of leaching experiments and a number of other observations, it is unlikely that the problem of sodicity will be encountered in leaching of these soils without any other treatment. The result of a leaching experiment in the Hofel soil series is given in Table 1.6. Soil salinity and sodicity of the profile to a depth of 150 cm before leaching (zero depth of application) and with application of water in 0.25-m depth increments up to 1 m is given (Mahab-e-Ghods 1993). After leaching, soil salinity and SAR are both reduced. A regular practice by the farmers is that after the fallow period during summer, the soil is leached generously with one or two applications of water to reduce the accumulated salt in the seed bed. If there were a danger of sodic soil development, this regular practice would result in such soils, but they are not actually observed. Also, as shown by the data in Table 1.4, the SAR of irrigation water is low, which is favorable for leaching these soils.

Leaching experiments of the Karkheh soil series show an interesting feature (Table 1.7). Soil salinity in the lower depths (below 50 cm) remains the same even after 75 cm of water is applied, indicating that water is not moving through these layers and bypass flow is occurring due to deep cracks. This may have great

*Table 1.5. Extent of saline lands with salinity and alkalinity classes (Mahab-e-Ghods 1993)*

| Soil series | S0[1] | S1[2] | S1A13 | S2[4] | S2A1[5] | S2A2[6] | S3A2[7] | S3A3[8] | S3A2 / S2A2[9] | S4A3[10] | S4A4[11] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Hofel | - | - | | | | | | 1460 (1.6) | | | |
| Karami | | 3289 (3.6) | 276 (0.3) | | | 5816 (6.4) | 5988 (6.5) | | 391 (0.4) | | |
| Fenikhi | | 2450 (2.7) | | | | 4830 (5.3) | 3360 (3.6) | | | | |
| Yazd-e-Now | | | | | | 2240 (2.5) | 5860 (6.4) | | | | |
| Abu-Homayzeh | | | | | | | | | | 1180 (1.3) | 6810 (7.4) |
| Ahmad-Abad | | 568 (0.6) | 2002 (2.2) | | 2491 (2.7) | 4659 (5.1) | 2917 (3.2) | 4803 (5.3) | | | |
| Kout | | | | | | | | | | | 1290 (1.4) |
| Sousangerd | 70 (0.1) | 100 (0.1) | | | | | | | | | |
| Karkheh | | | | | | | | | | 7610 (8.4) | 120 (0.1) |
| Golbahar | | | | | | | | | | 810 (0.9) | |
| Hovayzeh | | 429 (0.5) | 427 (0.5) | | 49 (0.1) | 986 (1.0) | 142 (0.2) | 1457 (1.5) | | | |
| Sariyeh | | 449 (0.5) | 31 (0.0) | | | 1037 (1.1) | 783 (0.9) | | | | |
| Hamidiyeh | | | 193 (0.2) | | | 887 (1.0) | | | | | |
| Sarhangiyeh | | 4100 (4.5) | | | | | | | | | |

*Table 1.5. (continued)*

| Soil series | S0[1] | S1[2] | S1A13 | S2[4] | S2A1[5] | S2A2[6] | S3A2[7] | S3A3[8] | S3A2 / S2A2[9] | S4A3[10] | S4A4[11] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Shat-e-Abbas | | | | | | 380 (0.4) | | | | | |
| Machriyeh | | 285 (0.3) | | 1150 (1.3) | 515 (0.5) | | | | | | |
| Jarrahiyeh | | | | | | | | | | | 2890 (3.2) |
| Louliyeh | | | | | | | 1620 (1.8) | | | | |
| Kout | | | | | | | | | | | 230 (0.2) |
| Sum | 70 (0.1) | 11670 (12.8) | 2929 (3.2) | 1150 (1.3) | 3055 (3.3) | 20835 (22.8) | 20670 (22.6) | 7720 (8.4) | 391 (0.4) | 9600 (10.6) | 11340 (12.3 |
| Miscellaneous Total | *Electrical conductivities (EC) are in dS/m, ESP is exchangeable sodium percentage, and numbers on the parenthesis are areas in percent | | | | | | | | | | |

1- EC<4, ESP<10
2- EC=4-8, ESP<10
3- EC=4-8, ESP=10-15
4- EC=8-16, ESP<10
5- EC=8-16, ESP=10-15
6- EC=8-16, ESP=15-30
7- EC=16-32, ESP=15-30
8- EC=16-32, ESP=30-50
9- EC=8-32, ESP=15-30
10- EC>32, ESP=30-50
11- EC>50, ESP>50

implications in terms of water loss during irrigation episodes, where inefficient surface irrigation is practiced in the area. Improvement of leaching efficiency and irrigation application efficiency should require further research in these soils.

## Major causes of soil salinity

Major factors causing soil salinization in the lower Karkheh basin can be classified as follows (Ghobadian 1969; Cheraghi et al. 2008):

- High groundwater table
- Salt-containing layers
- Inadequate drainage facilities
- High evaporation
- Salt intrusion by wind
- Sediment transport during flood periods.

### *High groundwater level*

High water tables are the major factor in soil salinization in Khuzestan province. The salt concentration in groundwater is extremely high, exceeding 100 g/L in many cases. It should be mentioned that groundwater could cause salinity in cases where its level is higher than a certain depth. This specific depth of groundwater is called the critical depth, which varies between 2.5 and 3.5m. It means that soil salinization due to capillaries and its accumulation in the plow layer will be expected if the distance between the soil surface and

*Table 1.6. Soil analyses before and after salt leaching from the Hofel soil series (Mahab-e-Ghods 1993)**

| Applied water (cm) | Soil depth (cm) | $EC_e$ (dS/m) | SAR |
|---|---|---|---|
| 0 | 0-25<br>25-50<br>50-75<br>75-100<br>100-150 | 28<br>25.5<br>24.2<br>24.2<br>26.4 | 23.4<br>16.6<br>21.5<br>16.8<br>15.5 |
| 25 | 0-25<br>25-50<br>50-75<br>75-100<br>100-150 | 18.5<br>25.3<br>23.6<br>22.9<br>7.3 | 17.2<br>-<br>15.6<br>16.5<br>18.4 |
| 50 | 0-25<br>25-50<br>50-75<br>75-100<br>100-150 | 8.3<br>15.8<br>22.9<br>26.4<br>5.1 | 9.9<br>-<br>17.2<br>19.3<br>19.9 |
| 75 | 0-25<br>25-50<br>50-75<br>75-100<br>100-150 | 7.6<br>10.8<br>24.5<br>24.8<br>8.9 | 5.8<br>9.2<br>17.6<br>20.9<br>20.8 |
| 100 | 0-25<br>25-50<br>50-75<br>75-100<br>100-150 | 8.3<br>10.1<br>11.1<br>19.3<br>- | 12<br>11.6<br>14.5<br>13.5<br>19.3 |

*Characteristics of the soil profile: soil texture, silty loam; soil salinity-sodicity class, S3A2; water table depth, 0.5 m; hydraulic conductivity (K), 0.98 m/d; depth of impermeable layer, > 4 m; salinity class of applied water, C3S1 (EC=1.75 dS/m, SAR= 1.8 , pH= 7.6)

the water table is smaller than the above-mentioned depth. In arid and semi-arid regions such as the Khuzestan province, where upward water flux due to high evaporation is considerable, even fresh groundwater causes soil salinization because of high groundwater levels. Investigations have shown that in most parts of Khuzestan, the groundwater level is higher than the critical depth. This case is especially true for the regions where extended agriculture has developed. It is observed that in non-arable lands, the groundwater level is usually deeper than the critical depth, but near villages where agricultural practices are more intensified, the problem is more severe. In LKRB, the groundwater level in non-arable land (or specific locations which had not been cultivated during the Iran-Iraq war 1979-1989) varies between 4 and 7 m, while its level is about 1.2-3.0 m in cultivated land. This difference shows the significance of agricultural return flow effects.

A high groundwater level for extended periods, especially in the hot season, causes specific morphological characteristics in the soil profile, which

*Table 1.7. Result of soil analyses before and after salt leaching in the Karkheh soil series (Mahab-e-Ghods 1993).*

| Applied water (cm) | Soil depth (cm) | $EC_e$ (dS/m) | SAR |
|---|---|---|---|
| 0 | 0-25<br>25-50<br>50-75<br>75-100<br>100-150 | 61<br>59<br>54<br>56<br>52 | 66<br>53<br>50<br>60<br>61 |
| 25 | 0-25<br>25-50<br>50-75<br>75-100<br>100-150 | 9<br>22<br>58<br>62<br>64 | 62<br>51<br>58<br>53<br>54 |
| 50 | 0-25<br>25-50<br>50-75<br>75-100<br>100-150 | 3.4<br>19<br>55<br>65<br>64 | 6<br>31<br>50<br>44<br>36 |
| 75 | 0-25<br>25-50<br>50-75<br>75-100<br>100-150 | 3<br>10<br>54<br>61<br>58 | 8<br>23<br>42<br>48<br>45 |
| 100 | 0-5<br>0-25<br>25-50<br>50-75<br>75-100<br>100-150 | 3<br>3<br>5<br>54<br>59<br>47 | 7<br>4<br>10<br>41<br>37<br>36 |

are the results of periodic oxidation-reduction conditions due to variations in the groundwater level. These specific symptoms are more pronounced in the presence of organic carbon and sesquioxides. One of the most popular signs of this kind is mottling (segregation of subdominant color different from surrounding region's color). In the Ahmadabad soil series (west of Dasht-e-Azadegan), which is heavy textured and has a hard massive structure, gley spots are observed in some profiles below 1m depth. In the Abohomayzeh soil series, weak gley spots and mottling can be observed. West of the Bostan-Pol-e-Ramazam road and near Shatt-e-Abbas, with Machriyeh, Jarrahieh, and Lulieh soil series, which are generally flooded during early winter up to late spring, the soil is usually waterlogged half of the year. Therefore, the soil moisture regime at the moisture control section of these profiles is aquic with diagnostic symptoms of mottling and gley spots.

### *Salt-containing layers*

A salt containing layer is a horizon or a layer of geological material in which salt content is not only high but also higher than the rest of the soil profile. If these layers are located at a depth less than

0.5m below the soil surface, especially in heavy textured soils, topsoil salinization occurs, as in the case of Khuzestan.

In the Dasht-e-Azadegan plain, despite the high calcium carbonate and calcium sulfate content of the soil, no calcic or gypsic diagnostic horizons were identified. However, accumulation of hygroscopic salts such as $CaCl_2$, $MgCl_2$, $MgSO_4$ and KCl in combination with NaCl can be observed on both sides of the river banks. High temperature differences between river, lateral canals and irrigated land cause moisture diffusion and evaporation that in turn leaves huge amounts of salt on the soil surface. Salic diagnostic horizons have been identified only in Abohomayzeh, Kout and Jarahyeh soil series. In Abohomayzeh and Jarahyeh series, soil surface is highly dispersed.

### *Inadequate drainage facilities*

Most of Khuzestan's soils are heavy textured and have a slight slope and therefore, the importance of adequate drainage facilities is obvious. However, in many cases little attention has been paid to this problem. Drains, which had been dogged, are generally the main drains and are deep. Although these drains can partly absorb the drainage water of the surrounding area, their effective radius is small. Natural drains, which discharge to the main outlet of the region (Hoor-Al-Azim), are not functioning well due to technical and environmental problems and due to the very low slope of land. Problems associated with inadequate drainage are more serious in low lands and areas with low slope.

The west side of Dasht-e-Azadegan is usually flooded during winter and spring. During summer, salts, which have been leached into the sub-soil, tend to rise and accumulate on the soil surface due to the high evaporation. The surface of these soils is often cracked during the hot and dry season, which is related to the high clay content of these soils. As a result, infiltration rates are low.

### *High evaporation*

One of the factors that accelerates soil salinization under high groundwater conditions is high evaporative demand, which causes upward flux of salt-containing water to the topsoil continuously, or at least in the warm season. The critical depth of the groundwater table that will cause soil salinization is highly dependent on evaporation rate as well as the soil type. For example in Khuzestan such depth had been reported to be range between 2.5 and 3.5 m, based on soil type and evaporation demand. Periods of 260 dry days in Hamidiyeh, and 290 dry days in Ahvaz, are climatic characteristics of the region. In Hamidiyeh, annual precipitation is 245 mm, while annual evaporation is 2205 mm, or an evaporation to precipitation ratio exceeding nine. Surface evaporation is one of the most important meteorological factors in the region significantly affecting the soil genesis processes. High evaporation leads to a capillary rise of soluble salts and their accumulation at the soil surface.

### *Salt intrusion by wind*

The dominant directions of winds in this region are west, northwest, and southeast, which occur as dust storms. They carry huge quantities of sediments that are mostly deposited on the surface of the plains. It has been estimated that in each storm event 5-50 kg salts/ha are deposited on the soil surface, which accumulates to 200-1000 kg/ha annually. It is suggested that the deposited salts originate from the coastal lands of both sides of the Persian Gulf and of the Gulf of Oman. They represent salt intrusion by wind erosion. These salt deposits are translocated within the region. It has been estimated for Khuzestan province that 10-50 t salts/ha are translocated from one point to another. It should be mentioned that the risk of accumulation of these salts is more serious around the villages (Ghobadian 1969).

### *Sediment transport in the flood periods*

The origin of most of the soil series in Dasht-e-Azadegan derives from the sediments of Karkheh river and its tributaries, except for the lowlands. Hence, the salt content of sediments from Karkheh river affects the salinity and sodicity of these soils. After flood periods, a large part of the region is submerged. During the dry season, water drawing back from land of higher elevation leads to the formation of small swamps (hour) and permanent ponds in the lowlands. Typical examples are the small swamps around the Hour-Al-Hoveyzeh. In 1968, about 3000-4000 $km^2$ of Khuzestan province were covered with floodwater. The sediment deposited about 1.5 million tonnes of salt on the soil surface (Ghobadian 1969).

### *Amelioration and management strategies*

Availability of drainage facilities is fundamental to improve the quality of salt-affected soils. It reduces the adverse effects of shallow water tables and waterlogging, and hence, improves crop production. There is no doubt that one of most important needs for the study area is to complete an adequate drainage network for the entire irrigated area. Encouraging efforts has been initiated, but the drainage system is incomplete. Lateral connections are lacking, and the drainage system covers only a limited area under irrigation. It is noted that agricultural management practices cannot serve as a substitute for adequate drainage of salt-affected and waterlogged soils. Most efforts in improved management to reduce the impact of salinity are suggested to have a rather temporary effect. To avoid the further salinization of agricultural soils, the communities and agricultural agencies are called to apply sound management practices until adequate drainage is installed.

One of the most important pre-requisites to enable permanent crop production in this region is the development of a network to monitor the effect of different management practices on the salt content of groundwater, as well as the salt and water balance of the root zone. These regular measurements will provide the data basis required to suggest the best methods to prevent restoration of salinity in the root zone and groundwater. On the other hand, water and salt balance studies on the watershed scale will increase our ability to predict the role of any hydrological unit in the fate and behavior of catchments. Cheraghi (2008) monitored salinity and depth to a shallow water table with observation wells during November 2003 to April 2004 in Dasht-e-Azadegan. There was a large variation in salinity of groundwater ranging between 4 and 100 dS/m. No trend was found in the way in which salinity changed throughout the study area. Salinity variation could be partly explained because of variation in soil textures. Salinity of groundwater in light-textured soils was less than that of heavier textured soils. Salinity was also lower in the vicinity of the river tributary rather than further away from the river. The depth to water table was lowest in April as a result of deep percolation from winter rain, over-irrigation of fields, river flooding, and seepage from earth channels. The depth to water table reached its maximum in September due to high evaporation during the hot dry summer. This pattern seems to repeat itself throughout the years, hence accumulating salt in the soil.

Appropriate irrigation schedules based on soil-moisture depletion or climatic data would prevent excess losses of irrigation water into the subsoil or groundwater. Land leveling could improve water distribution and limit waterlogging problems. Further attention should be paid to the irrigation system. To increase the efficiency of water use the irrigation water must be applied uniformly. Some of these issues were tested in the field as part of this project and the results are given in Chapter III.

Generally speaking, the agricultural cropping systems and practices in the subject area are suboptimal and should be improved. At present, the crop varieties used by farmers are not adapted to the prevailing soil conditions. Significant improvements in production could be realized by introducing salt-tolerant varieties. As was discussed earlier, 90% of the cultivated area is allocated to wheat. The two varieties grown, Chamran and Verinak, give average yields of 2 t/ha. Testing high-yielding varieties, available in the country, in the area may introduce a more suitable variety for the area. Some varieties that are bred for salinity tolerance such as Kavir, Bam, Sistan, etc. were tested as part the CPWF projects for improving water productivity in the area and the results are presented in Chapters IV and V of this report.

Another important factor limiting crop production is the accumulation of salt in the top soil that mainly occurs during the fallow period when the soil is uncultivated. Leaching of salts before sowing can reduce the adverse effects of salt on crop establishment. Other suitable practices are trash mulching and suitable crop rotations.

## Conclusions

KRB is one of the major river basins in the Khuzestan province consisting of two main sub-basins namely Karkheh Olia (upstream) and Karkheh Sofla (downstream). Agriculture in the upstream basin is mainly rain fed, while the downstream basin is mostly irrigated. Dasht-e-Azadegan plain is the terminal basin of the Karkheh river so all of its tributaries end in this basin. The main problems limiting agricultural production in this region are salinity and waterlogging. Saline-sodic soils constitute a vast area of Dasht-e-Azadegan. About 99% of the area of the region has been faced with salinity or sodicity for a long time. The salinization of land and water resources has been the consequence of both anthropogenic activities (causing human-induced or secondary salinity and/or sodicity) and naturally occurring phenomena (causing primary fossil salinity and/or sodicity). Major factors causing soil salinization in the lower Karkheh basin are the high groundwater table, salt-containing layers, inadequate drainage facilities, high evaporation, salt intrusion by wind and sediment transport during flood periods.

The management strategies for sustainable utilization of salt-affected soils in Dasht-e-Azadegan should consider: installation of a drainage network for the entire irrigated area, leaching of salts to reduce the adverse effects of salt on crop establishment, appropriate irrigation scheduling and water distribution systems, introduction and use of salt tolerant crops, improvement of the agricultural cropping systems and practices, and development of a network for monitoring the effect of different management practices on the salt content of groundwater as well as salt and water balance of the root zone.

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# Chapter 2.

## Management practices for improving water productivity in the Dasht-e-Azadegan

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## Introduction

In the LKRB, because of the differences in factors affecting agricultural water productivity in the north and the south parts, two distinct regions can be identified. In the northern part soil and water quality is not greatly affected by external factors. In this area it seems that improving farmers' skills and application of appropriate farming systems can improve water productivity greatly. Limitations in water supply and excess irrigation water losses (mainly in earthen canals) also causes lower water productivity of crops. Therefore, demonstration of new farming systems, e.g., pressurized irrigation, land preparation methods (raised bed, double-row cropping, etc.), could be a useful method for water productivity improvement. Based on reports (Khuzestan Water and Power Authority 2004), in the next 10 years, when most of the irrigation projects will be completed, there will be more uncertainty in water supplies in the Khuzestan province (including LKRB). The report recommends that the water productivity (WP) of the province has to be increased through using pressurized irrigation systems, participation of stakeholders, and capacity buildings of water users.

Heydari 2010 concluded that for the improvement of WP in the field scale in Iran, some of the high priority issues include: enhancement of farmers' knowledge on soil-water-plant relationships, improvement of farming systems and farm mechanization, proper design and execution of water saving technologies, land leveling and consolidation, and technical and training supports. Overall, in this area, successful introduction and implementation of new farming systems and technologies in accordance with agricultural extension services can be an effective way to improve water productivity. However the problem in this area is large farm size and low-population communities. The low numbers in the communities is mainly due to migration of the people to the cities, especially during war. This has caused poor supervision and management of the farms, due to lack of effective presence of the farmers or land owners, and also shortage of the labor required for the farm and irrigation activities.

In the southern part of LKRB, mainly the Dasht-e-Azadegan plain, available data and surveys show that the problem of soil salinity is magnified due to lack of farmers' knowledge, skills and unavailability of new and improved farming practices. In general, the main cause of soil salinity in the LKRB is the high water table, often less than 2.0 m, usually 1.2-3.0 m below the soil surface (Hajrasuliha 1970). If left alone, the problem is likely to worsen with the current plans for expansion of irrigation networks (unpublished, N. Heydari 2007).

In the southern parts it seems that in addition to factors limiting water productivity (e.g. farmer skills, new farming systems, etc.) the major limiting factors are waterlogging, and soil and groundwater salinity. With the expansion of irrigation networks with no consideration to salinity management and drainage, this problem in future will worsen. At present, despite construction and operation of main drains in the area, they are not properly functioning. This is mainly due to some design problems (non-uniform slope of drain canals,) and also the problems concerning suitable outlets. Gravity drainage to outlet is not possible and pumping is needed. Environmental concerns regarding drainage to the Hawr-Al-Azim wetlands are another problem. It is thought that the government is studying a plan to construct a main drain and carry drained water to Persian Gulf by gravity (unpublished, N. Heydari 2007). However, research topics (both on-farm and experimental) related to water table management and salinity control are expected to do much to improve the productivity of agriculture in this area.

However, in the LKRB (mainly the Dasht-e-Azadegan plain) heavy soil texture and recharge from upstream areas produces natural conditions for waterlogging, and is further induced by low irrigation efficiency of irrigated agriculture in the region. Wheat is the main crop cultivated in this area. Irrigation management practices are traditional and the region suffers from poor water management. This has lead to waterlogging and soil salinity, and hence low water productivity and non-sustainable agricultural production in

*Fig. 2.1. Poor irrigation management in the farmers' fields*

*Fig. 2.2. Poor water distribution because of improper land leveling*

the Dasht-e-Azadegan plain .Therefore, sound irrigation management solutions that can be adopted and adapted by the farmers are necessary and will help to improvement agricultural WP and livelihood resilience of the communities living in this poor area.

Based on a review of 84 references on WP during the past 25 years, Zwart and Bastiaanssen (2004) found that the average WP of wheat is 1.09 kg/m$^3$. The range of WP is wide and varies between 0.6 and 1.7 kg/m$^3$. Fahong et al. (2004), by comparing basin and furrow irrigation on wheat, concluded that cultivation of wheat on a basin surface with flood irrigation causes surface sealing, irrigation efficiency reduction, and fertilizer losses. They found that furrow irrigation of wheat led to a 17% reduction in water consumption, increased irrigation efficiency (21-30%), increased fertilizer efficiency, and reduced crop disease.

Wheat is the main cultivated crop in the LKRB. Its average yield is 1500 kg/ha (Agricultural Statistics 2004). Irrigation management practices are traditional and the region suffers from poor water management, which is partly due to lack of modern irrigation infrastructure and improved on-farm activities (Figs.2.1 2.2). Therefore, sound and adoptive solutions are necessary to ameliorate this condition.

## Materials and methods

Research was conducted in a farmer's field in the Dasht-e-Azadegan region during the cropping seasons of 2006-07 and 2007-08. The farm is located at 31°26'39.6''N and 48°17'45.2''E.

Soil texture was silty clay loam to silt-loam, average soil pH was 7.8, and average soil salinity at a depth of 0-30 cm was on average 15 dS/m. Table 2.1

*Table 2.1. Some physical and chemical properties of the soil in the selected field (years 2006-07 2007-08 (only for EC)*

| Soil depth (cm) | Sampling date | Particle-size analysis (%) | | | | EC (2006-07) | pH | OC | P | K | Fe | Zn | Cu | Mn | EC (2007-08) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sand | Silt | Clay | Texture | (dS/m) | | (%) | (ppm) | (ppm) | (ppm) | (ppm) | (ppm) | (ppm) | (dS/m) |
| 0-30 | | 14 | 48 | 38 | | 3.4 | 7.6 | 0.4 | 3.5 | 166 | 3.9 | 1.1 | 0.8 | 6.8 | nm |
| | Aug. 06 | 24 | 48 | 28 | | 18 | 7.7 | 0.4 | 3.4 | 166 | 3.7 | 1.8 | 0.6 | 5.2 | nm |
| | | 18 | 42 | 40 | | 12 | 7.7 | 0.3 | 8.3 | 166 | 3.9 | 1.1 | 0.5 | 3.6 | nm |
| | 4 Dec. 06 | | | | | 8.8 | nm | nm | nm | nm | nm | nm | nm | nm | 18.2 |
| | 21 Dec. 06 | | | | | 4.1 | nm | nm | nm | nm | nm | nm | nm | nm | nm |
| | 21 Dec. 06 | | | | | 9.9 | nm | nm | nm | nm | nm | nm | nm | nm | 6.2 |
| | 1 Feb. 07 | | | | | 3.7 | nm | nm | nm | nm | nm | nm | nm | nm | 3.8 |
| | 1. Feb. 07 | | | | | 8.9 | nm | nm | nm | nm | nm | nm | nm | nm | 4.9 |
| | 15 Feb. 07 | | | | | 4.3 | nm | nm | nm | nm | nm | nm | nm | nm | 5.6 |
| | 15 Feb. 07 | | | | | 9.4 | nm | nm | nm | nm | nm | nm | nm | nm | 8.4 |
| Average | | 19 | 46 | 35 | Silty clay loam | 8.3 | 7.7 | 0.4 | 5.1 | 166 | 3.8 | 1.3 | 0.6 | 5.2 | |
| 30-60 | | 14 | 50 | 36 | | 3.5 | 7.9 | 0.16 | 2.7 | 115 | 2.4 | 0.15 | 0.5 | 1.6 | nm |
| | Aug. 06 | 22 | 52 | 26 | | 8.8 | 7.9 | 0.13 | 1.7 | 89 | 2.2 | 0.14 | 0.3 | 1.1 | nm |
| | | 30 | 50 | 20 | | 14.7 | 8 | 0.11 | 2.2 | 62 | 2.8 | 0.1 | 0.3 | 0.9 | nm |
| | 4 Dec. 06 | | | | | 5.9 | nm | nm | nm | nm | nm | nm | nm | nm | nm |
| | 21 Dec. 06 | | | | | 4.4 | nm | nm | nm | nm | nm | nm | nm | nm | nm |
| | 21 Dec. 06 | | | | | 6.7 | nm | nm | nm | nm | nm | nm | nm | nm | nm |
| | 1 Feb. 07 | | | | | 3.6 | nm | nm | nm | nm | nm | nm | nm | nm | nm |
| | 1. Feb. 07 | | | | | 6.1 | nm | nm | nm | nm | nm | nm | nm | nm | nm |
| | 15 Feb. 07 | | | | | 4.5 | nm | nm | nm | nm | nm | nm | nm | nm | nm |
| | 15 Feb. 07 | | | | | 9.5 | nm | nm | nm | nm | nm | nm | nm | nm | nm |
| Average | | 22 | 51 | 27 | Silty clay loam | 6.8 | 7.9 | 0.13 | 2.2 | 89 | 2.5 | 0.13 | 0.4 | 1.2 | |
| 60-90 | | 22 | 56 | 22 | | 4.5 | 7.8 | 0.18 | 1.7 | 62 | 3.2 | 0.1 | 0.3 | 1.3 | nm |
| | Aug. 06 | 28 | 52 | 20 | | 12.6 | 7.9 | 0.1 | 1.3 | 53 | 2.9 | 0.1 | 0.8 | 1.6 | nm |
| | | 28 | 52 | 20 | | 17 | 8 | 0.12 | 2.3 | 62 | 3.5 | 0.16 | 0.3 | 1.6 | nm |
| | 4 Dec. 06 | | | | | 5.3 | nm | nm | nm | nm | nm | nm | nm | nm | nm |
| | 21 Dec. 06 | | | | | 5 | nm | nm | nm | nm | nm | nm | nm | nm | nm |
| | 21 Dec. 06 | | | | | 6.6 | nm | nm | nm | nm | nm | nm | nm | nm | nm |
| | 1 Feb. 07 | | | | | 3.5 | nm | nm | nm | nm | nm | nm | nm | nm | nm |
| | 1. Feb. 07 | | | | | 4.7 | nm | nm | nm | nm | nm | nm | nm | nm | nm |
| Average | | 26 | 53 | 21 | Silt loam | 7.4 | 7.9 | 0.13 | 1.8 | 59 | 3.2 | 0.12 | 0.5 | 1.5 | |

nm, not measured

presents some physical and chemical properties of the soil in the selected field (years 2006-07 2007-08 (just for EC)) and Table 2.2 summarizes some of the soil's physical and chemical characteristics just prior to the first irrigation. However, the soil salinity values in the region vary greatly, both temporally and spatially, therefore different values of soil ECs were measured during different times and locations in the field, and are listed in these tables.

The source of irrigation water was the Karkheh river. The ECs of groundwater and irrigation water were 11.3 and 1.4 dS $m^{-1}$, respectively. Groundwater depth at the beginning of the growing season, before starting rainfall and irrigation recharges, was 237 cm. In winter, following recharge from irrigation, it increased to 3598 cm from the soil surface. In Table 2.3 and in Figs. 2.3, 2.4 and 2.5, groundwater and drainage water qualities, and variation of groundwater depth in the cropping seasons in the selected field are provided. As it can be seen from Fig. 2.3, there is a wide range of variation in water table depth. The reason is water logging, which produces increased soil salinity at certain periods in the LKRB. Wheat is planted in early November in DA, late November is the first irrigation for land preparation and harvest time is in late May. Deep percolation losses of irrigation during this period cause the water table to rise, usually in February. Therefore, depending to the recharge from irrigated areas during the peak consumption period, and due to heavy soil texture and inadequate drainage capacity of the soil, the water table fluctuates very rapidly and to a large extent.

The dimensions of the border and the basin of the treatments were selected as 160 m x 10 m (for T1, T2, T3) and 40 m x 10 m (for T4, T5, T6). These dimensions were optimal sizes and were based on Statistics and Census Sector recommendations. The traditional method of irrigation (control) was similar to a combination of basin and border irrigation. Farmers choose the borders' length according to their farm dimensions (usually 100-400 m) and then divide borders into several basins of 30-70 m length, depending on the field topography. They fill the first basin and then transfer water to the second one, and so on. The width of the borders was usually between 5 m and 14 m (Figs. 2.6, 2.7).

The Chamran wheat variety was sown in all the treatments. The seed rate was 250 kg in treatments sown by centrifugal broadcaster and managed under optimized irrigation (T1, T4). In other treatments a seed drill (TAKA) or a three-row bed seeder (Hamedani) sowed seeds at a rate of 180 kg/

*Table 2.2. A summary of some soil's physical and chemical characteristics prior to the first irrigation*.*

| Soil depth (cm) | Year 2006-07 | | | | | | | | | Year 2007-08 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | EC (dS/m) | pH | OC (%) | P (ppm) | K (ppm) | Fe (ppm) | Zn (ppm) | Cu (ppm) | Mn (ppm) | EC (dS/m) | pH | OC (%) | P (ppm) | K (ppm) | Fe (ppm) | Zn (ppm) | Cu (ppm) | Mn (ppm) |
| 0-30 | 11.1 | 7.7 | 0.4 | 5.1 | 166 | 3.8 | 1.3 | 0.6 | 5.2 | 18.8 | 7.8 | 0.37 | 3.4 | 165 | 3.7 | 1.8 | 0.6 | 5.2 |
| 30-60 | 9.0 | 7.9 | 0.1 | 2.2 | 88.7 | 2.5 | 0.1 | 0.4 | 1.2 | 16.7 | 8.0 | 0.15 | 1.7 | 89 | 2.2 | 0.1 | 0.3 | 1.1 |
| 60-90 | 11.4 | 7.9 | 0.1 | 1.8 | 59.0 | 3.2 | 0.1 | 0.5 | 1.5 | 19.1 | 7.9 | 0.1 | 1.3 | 53 | 2.9 | 0.1 | 0.8 | 1.6 |

*$EC_e$ = 15 dS/m; depth to water table = 237 cm; $EC_{GW}$ = 11.3 dS/m; $EC_{ir}$ = 1.4 dS/m; $EC_e$ = 18.2 dS/m
Depth to water table = 190 cm; $EC_{GW}$ =38.5 dS/m; $EC_{ir}$ = 1.5 dS/m

*Table 2.3. Groundwater and drainage water quality in selected fields (2006-07; 2007-08).*

| Type of water* | Sampling date (2006-07) | EC (dS/m) | | pH | Ions (meq/L) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2006-07 | 2007-08 | | Ca | Mg | Na | Cl | $HCO_3$ |
| GW | 4 Dec. 06 | 13.2 | nm | 7.2 | 22 | 36 | 82 | 113 | 12.5 |
| GW | 21 Dec. 06 | 11.3 | nm | 7.2 | 22 | 30 | 49 | 72 | 8 |
| GW | 26 Dec. 06 | 6.1 | nm | 7.3 | 26 | 75 | 22.5 | 20 | 7 |
| GW | 26 Dec. 06 | 44 | 38.5 | 7.1 | 60 | 130 | 210 | 400 | 20 |
| GW | 22 Jan. 07 | 39 | nm | 7.2 | 80 | 90 | 240 | 425 | nm |
| GW | 22 Jan. 07 | 0.85 | nm | 7 | 140 | 260 | 260 | 1150 | nm |
| GW | 22 Jan. 07 | 10.8 | nm | 7.3 | 32 | 16 | 56 | 53 | nm |
| GW | 9 Feb. 07 | 27.2 | 39.1 | 7.2 | nm | nm | nm | nm | nm |
| GW | 26 Feb. 07 | 23.4 | nm | 7.3 | nm | nm | nm | nm | nm |
| GW | 26 Feb. 07 | 62.1 | nm | 7.1 | nm | nm | nm | nm | nm |
| GW | 26 Feb. 07 | 5.2 | nm | 7.4 | nm | nm | nm | nm | nm |
| GW | 18 Mar. 07 | 20 | 23.3 | 6.6 | nm | nm | nm | nm | nm |
| GW | 18 Mar. 07 | 54 | nm | 6 | nm | nm | nm | nm | nm |
| GW | 8 April 07 | 36.7 | nm | 6.5 | nm | nm | nm | nm | nm |
| GW | 8 April 07 | 79 | nm | 6.3 | nm | nm | nm | nm | nm |
| GW | 8 April 07 | 10 | nm | 7 | nm | nm | nm | nm | nm |
| DG | 9 Feb. 07 | 17.3 | nm | 7.5 | nm | nm | nm | nm | nm |
| DG | 29 Nov 06 | 13.9 | nm | 7.8 | 14 | 36 | 91 | 123 | 22.5 |

*GW = groundwater; DG = drained water; nm = not measured.

ha. In the control treatment (Tc), which was sown by centrifugal broadcaster and managed by the farmer, the seed rate was 350 kg/ha. Other farming practices were the same for all treatments (Figs. 2.8, 2.9).

Crop yield and yield components were measured through sampling from fields before harvest. The yield samples were taken by 1 $m^2$ sampling frames. The amount of irrigation water applied was measured by Washington State College flumes. There was no difference between the farmer and modified management treatments in terms of interval and number of irrigation. In fact, the difference was in how to manage water flow on the land and the method of irrigation, both of which directly affected water consumption.
The research treatments were as follows:
T1 = border irrigation + sowing by centrifugal broadcaster followed by one disc pass
T2 = border irrigation + sowing by seed drill machine (Taka type)
T3 = border irrigation + sowing by three-row bed seeder (Hamedani type)
T4 = basin irrigation + sowing by centrifugal broadcaster followed by one pass of a disc
T5 = basin irrigation + sowing by seed drill machine (Taka type)
T6 = basin irrigation + sowing by three-row bed seeder (Hamedani type)
Tc = irrigation and sowing managed by traditional farming method (as control).

This research examined the reuse of drainage water for irrigation. In the first year this was done in small experimental plots. In the second year it was done in large plots beside the field. Table 2.4 shows soil salinity and pH values. Tables 2.5 and 2.6 list the soil moisture

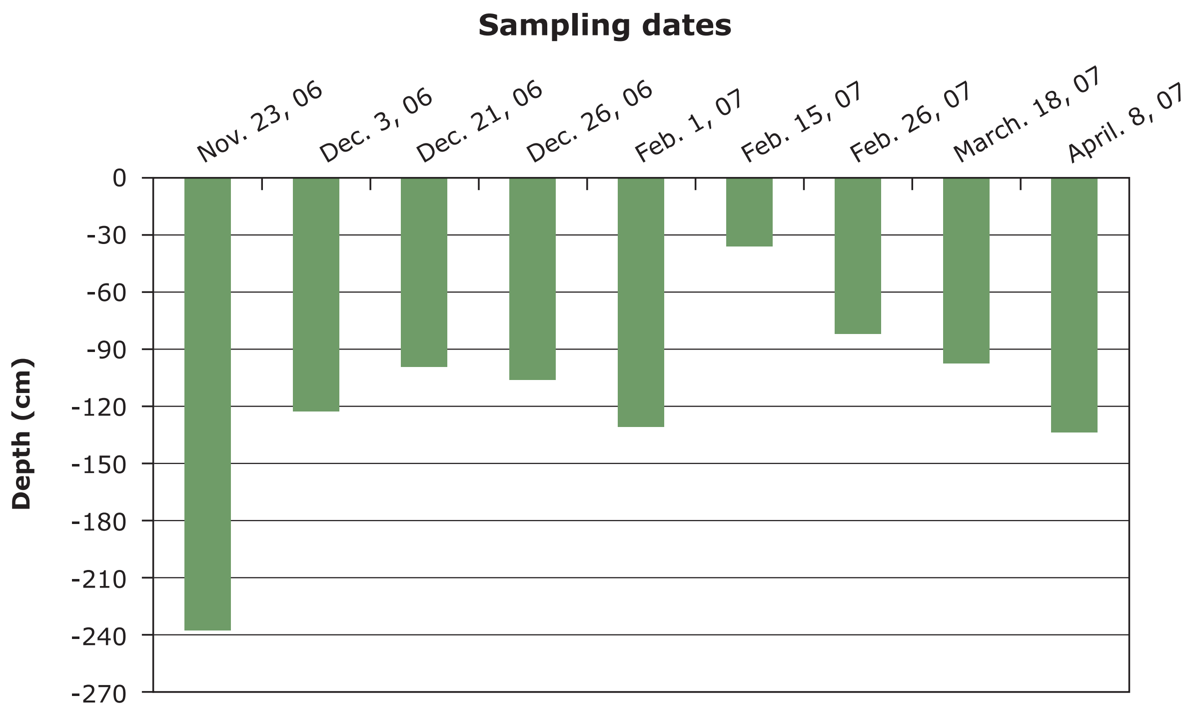


*Fig. 2.3. Variation of groundwater depth (average of three points) during 2006-07*

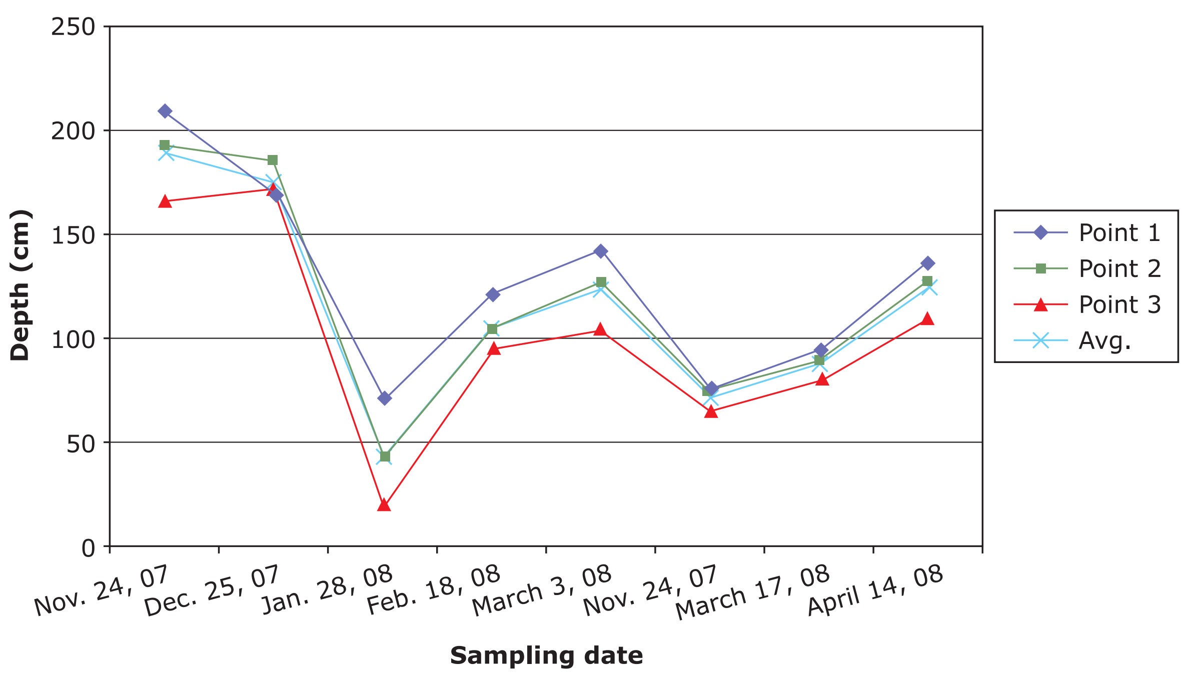


*Fig. 2.4. Variation of the groundwater depth (average of three points) during 2007-08*

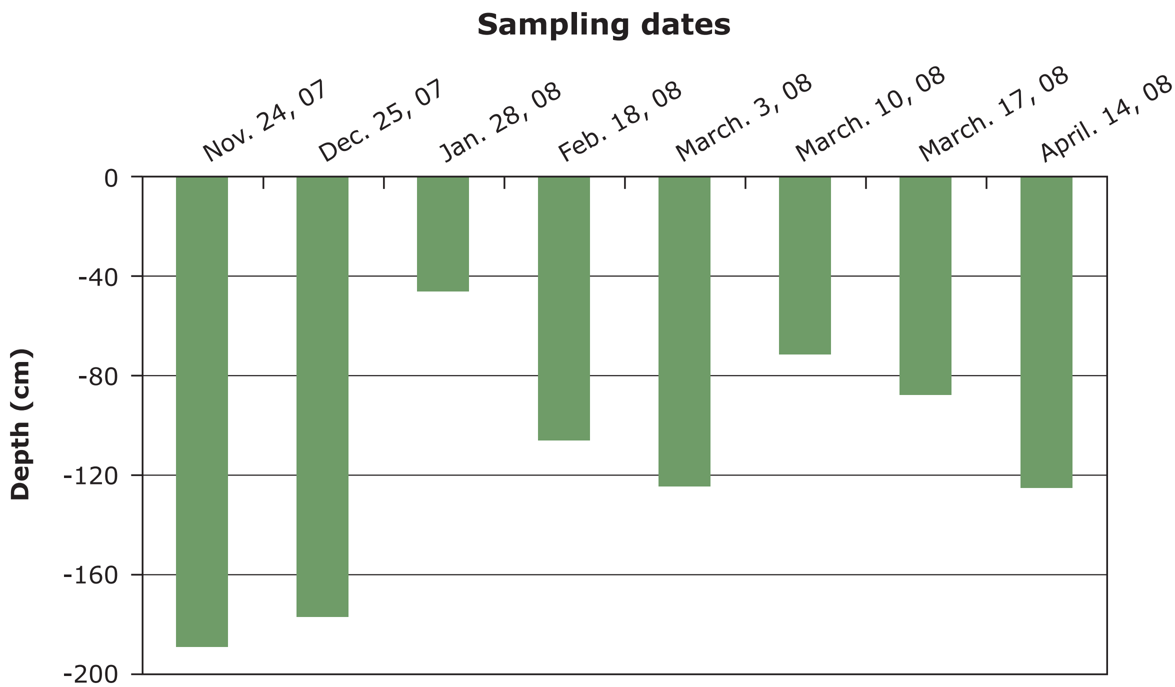


*Fig. 2.5. Variation in groundwater depth (average of three points) during 2007-08*

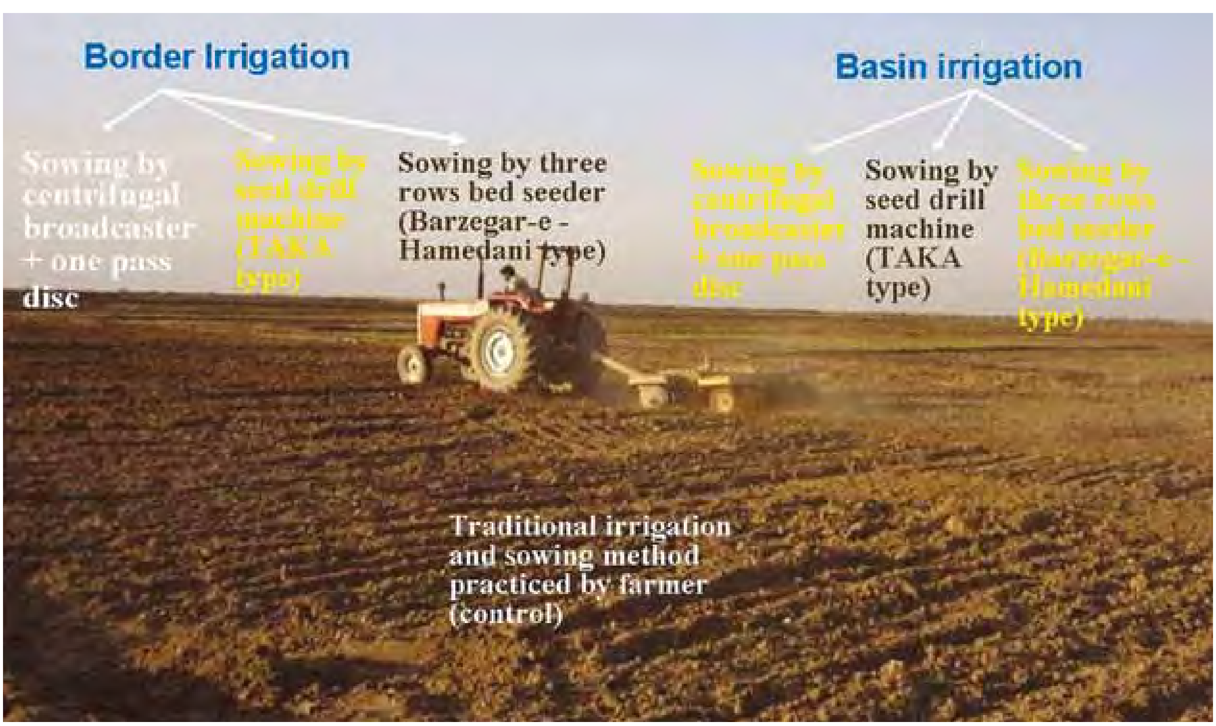


*Fig. 2.6. Different combinations of the treatments and land preparation*

*Fig. 2.7. Measurement of flow to the irrigation border*

*Fig. 2.8. Barzegar-e Hamedani seed planter*

*Fig. 2.9. Taka type seed planter*

condition, and the quality and depth of the drain water used for irrigation.

## Results and discussion

The main objective was to find cost effective and short-term solutions to the salinity and waterlogging problems and hence to increase wheat water productivity in the Dasht-e-Azadegan region. The following targets were identified:

- Recognition of simple management practices for reducing soil salinity hazards and improving agricultural water productivity.
- Comparing WP under different irrigation methods i.e., traditional vs. improved border-basin irrigation method.
- Investigating the effect of different cultivation/sowing methods on wheat WP.

In this experiment, the different water quality treatments were applied in a cyclic way, i.e. drain and fresh irrigation canal water, in irrigation intervals (Figs. 2.10, 2.11). However, due to technical and logistical problems, the research

*Table 2.4. Soil salinity and acidic values (year 2006-07)*

| Treatments | Soil layer (cm) | Sampling date | $EC_e$ (dS/m) | pH |
|---|---|---|---|---|
| T1* | 0-30 | 14 Feb. 07 | 4 | 7.9 |
| | 30-60 | | 30 | 7.9 |
| T2 | 0-30 | 3 Dec. 06 | 3.6 | 7.9 |
| | 30-60 | | 5.7 | 7.9 |
| | 60-90 | | 9.1 | 7.8 |
| T2 | 0-30 | 20 Dec. 06 | 4.5 | 7.7 |
| | 30-60 | | 4.5 | 7.8 |
| | 60-90 | | 4.5 | 7.9 |
| T3 | 0-30 | 3 Dec. 06 | 7.8 | 8.0 |
| | 30-60 | | 4.1 | 8.0 |
| | 60-90 | | 4.5 | 7.9 |
| T3 | 0-30 | 20 Dec. 06 | 8.2 | 7.6 |
| | 30-60 | | 4.9 | 7.8 |
| | 60-90 | | 4.8 | 7.9 |

*T1 = saline-saline-fresh water;
T2 = fresh-fresh-saline water;
T3 = fresh-saline-fresh water

*Table 2.5. Soil moisture in of the field during the year 2006-07*

| Experimental treatments | Sampling date | Soil moisture content (%) Soil layer (cm) | | |
|---|---|---|---|---|
| | | 0-30 | 30-60 | 60-90 |
| T1* | 14 Feb. 07 | 21.58 | 21.86 | nm |
| | 25 Feb 07 | 20.2 | 21.2 | nm |
| | 7 April 07 | 16.5 | 17.0 | nm |
| T2 | 3 Dec 06 | 21.89 | 20.22 | 17.30 |
| | 20 Dec 06 | 25.19 | 16.30 | 16.59 |
| | 14 Feb. 07 | 23.0 | 21.4 | nm |
| | 7 April 07 | 12.2 | 14.8 | nm |
| T3 | 3 Dec 06 | 19.51 | 17.15 | 21.00 |
| | 20 Dec 06 | 20.09 | 19.16 | 20.34 |
| | 14 Feb. 07 | 22.4 | 24.0 | nm |
| | 7 April 07 | 15.3 | 18.6 | nm |
| Tc | 14 Feb. 07 | 23.72 | 20.61 | nm |
| | 25 Feb 07 | 21.2 | 20.8 | nm |
| | 7 April 07 | 13.2 | 13.5 | nm |

*T1 = saline-saline-fresh water; T2 = fresh-fresh-saline water; T3 = fresh-saline-fresh water; Tc = fresh-fresh-fresh water; nm = no measurement

*Table 2.6. Quality and depth of drainage water used in the treatments as saline water*

| Year 2006-07 | | Year 2007-08 | | |
|---|---|---|---|---|
| **Irrigation date** | **EC of drain water (dS/m)** | **Irrigation date** | **EC of drain water (dS/m)** | **Depth of water applied (mm)** |
| 28 Nov. 06 | 13.9 | 31 Dec. 07 | 18.3 | 61 |
| 8 Feb. 07 | 17.3 | 7 March 08 | 25.4 | 59 |
| 3 March 07 | 18.7 | 15 April 08 | 27.2 | 63 |

*Table 2.7. The research treatments for the 2 years of the reuse experiments*

| 2006-07 | | 2007-08 | |
|---|---|---|---|
| **Treat-ment** | **Explanation** | **Treat-ment** | **Explanation** |
| **T1** | Application of drain water in initial stage and after seed sowing | **T1** | Cyclic application of water (saline-saline-fresh-fresh) |
| **T2** | Application of drain water in final growth period | **T2** | Cyclic application of water (fresh-fresh-saline-saline) |
| **T3** | Cyclic application of drain water during growth period | **T3** | Cyclic application of water (fresh-saline-fresh-saline) |
| **Tc** | Control (canal fresh water) | **Tc** | Control (fresh-fresh-fresh-fresh) |

*Fig. 2.10. Reuse of drain water treatments*

*Fig. 2.11. Irrigation of reuse treatment plots by drain water*

treatments for the 2 years of the experiment were different as shown in Table 2.7.

Table 2.8 shows the dates and amounts of water applied in the field under two irrigation management regimes, i.e., the traditional and the modified methods, for the 2 years of experiments are provided. There are considerable reductions in water consumption and savings in the volume of applied irrigation water.

Crop yields under different treatments were also determined. Water productivity of wheat (in kg/$m^3$) was calculated using yield and applied water data. Tables 2.9 and 2.10 provide the amounts of applied water, obtained yields and WP values of the different treatments for the 2 years of experiments. The WPs values were also calculated by considering the amount of effective rainfall (75% of total rain) during the growth period (Table 2.11).

Border irrigation with centrifugal and Hamedani sowing methods (T1, T3) provided the highest water productivities in years 2006-07 and 2007-08, being 1.60 and1.88 kg/m$^3$ respectively. Among the applied irrigation methods, the modified border irrigation had the maximum WP, 1.36 and 1.74 kg/m$^3$ in 2006-07 2007-08 respectively, while the farmer-managed treatment (traditional border-basin irrigation method under centrifugal sowing with 350 kg seed) provided the minimum WP of 0.61 and 0.81 kg/m$^3$ (Tables 2.9 2.10).

Agronomic measurements and data analysis were also conducted on the experimental treatments. Tables 2.12 and 2.13 give the measurements of some agronomics factors of the different experimental treatments.

Statistical analysis showed that the experimental treatments improved germination, yield and seed consumption in comparison to the control. Tables 2.13-17 show the results for the 2006-07 and 2007-08 seasons.

There was no significant difference ($\alpha$=0.05) in yield between applied treatments and control treatment in the first year (2006-07). This indicates that the treatments were more efficient in water saving than yield improvements. However, in the second year of experiments, because of a severe drought in the area, the treatments had much

*Table 2.8. The amounts and dates of irrigation under the two irrigation managements (years 2006-07, 2007-08)*

| **Irrigation management option** | **Irrigation water consumed (m$^3$/ha)** | | | | **Sum (m$^3$/ha)** |
|---|---|---|---|---|---|
| | | **1st irrigation** | **2nd irrigation** | **3rd irrigation** | |
| Farmer management | Volume | 1196 | 1081 | 928 | 3205 |
| | Date | 24 Nov. 06 | 8 Feb. 07 | 4 March 07 | |
| | Volume | 1196 | 1220 | - | 2416 |
| | Date | 31 Dec. 07 | 7 March 08 | - | |
| Modified irrigation management (border and basin) | Volume | 704 | 685 | 657 | 2046 |
| | Date | 24 Nov. 06 | 8 Feb. 07 | 4 March 07 | |
| | Reduction to farmer management (%) | 41.1 | 36.6 | 29.2 | Avg.=35.6 |
| | Volume | 695 | 790 | - | 1485 |
| | Date | 31 Dec. 07 | 7 March 08 | - | |
| | Reduction to farmer management (%) | 40.4 | 35.2 | - | Avg.=37.8 |

*Table 2.9. Amount of applied water, yield and water productivities under different irrigation management treatments (year 2006-07)*

| Irrigation method | Sowing method | Water applied ($m^3$/ha) 1st irrig. | 2nd irrig. | 3rd irrig. | Sum of applied water ($m^3$/ha) | Yield (kg/ha) | WP (kg/$m^3$) | Avg. WP of irrigation method (kg/$m^3$) |
|---|---|---|---|---|---|---|---|---|
| Modified border | Centrifugal | 513 | 547 | 558 | 1618 | 2590 | 1.60 | 1.36 |
| | Taka | 579 | 545 | 650 | 1774 | 2434 | 1.37 | |
| | Hamedani | 529 | 590 | 610 | 1729 | 1901 | 1.10 | |
| Modified basin | Centrifugal | 844 | 827 | 723 | 2394 | 2730 | 1.14 | 1.04 |
| | Taka | 927 | 795 | 695 | 2417 | 2521 | 1.04 | |
| | Hamedani | 830 | 808 | 706 | 2344 | 2198 | 0.94 | |
| Average | | 704 | 685 | 657 | | 2396 | 1.20 | |
| Basin-border (farmer) | Centrifugal | 1196 | 1081 | 928 | 3205 | 1953 | 0.61 | 0.61 |

more effect on water savings and hence better yields were obtained in comparison to control and the difference was significant. Although the consumption of seed used in the Taka and Hamedani sowing methods was 50% less, the seed germination percentage was higher than that with the centrifugal method.

As explained earlier, in the reuse experiments the objective was to examine the effects of using available drain water for crop production and to find out the WP in this situation. However, the main objective was to find a solution for ameliorating drainage problems by lowering the water table and at the same time to use this water for crop production and hence save more water.

Tables 2.18 and 2.19 detail the grain yield obtained under different water quality treatments (actually different cyclical applications of saline drain and fresh water) for the 2 years of the experiments.

To assess the soil salinity changes before and after irrigation with drainage water, soil samples were taken from the soil profile (Table 2.20).

## Conclusions and recommendations

In the LKRB on the Dasht-e-Azadegan plain, heavy soil texture and lateral subsurface flows from upstream irrigated areas provide the conditions for waterlogging that is aggravated by the low irrigation efficiency of irrigated agriculture in the region. Waterlogging and soil salinity are the major constraints. Wheat is the main crop in the LKRB with an average yield of 1.5 t/ha. Irrigation management practices are traditional and the region suffers from poor water management, which is partly due to lack of modern irrigation infrastructure and

*Table 2.10. Amount of applied water, yield and water productivities under different irrigation management treatments (year 2007-08)*

| **Irrigation method** | **Sowing method** | **Yield (kg/ha)** | **Applied water ($m^3$/ha)** | **WP (kg/$m^3$)** | **WP (Avg. of irrigation treatment - kg/$m^3$)** |
|---|---|---|---|---|---|
| Basin-border (farmer) | Centrifugal | 1940 | 2388 | 0.81 | 0.81 |
| Modified border | Centrifugal | 2144 | 1348 | 1.59 | 1.74 |
| | Taka | 2471 | 1414 | 1.75 | |
| | Hamedani | 2400 | 1277 | 1.88 | |
| Modified basin | Centrifugal | 2251 | 1663 | 1.35 | 1.53 |
| | Taka | 2606 | 1633 | 1.60 | |
| | Hamedani | 2564 | 1576 | 1.63 | |

*Table 2.11. Values of water productivity of different treatments with the inclusion of rainfall**

| **Irrigation method** | **Sowing method** | **WP** (kg/$m^3$)** | | **WP* (Avg. of irrigation treatment - kg/$m^3$)** | |
|---|---|---|---|---|---|
| | | **2006-07** | **2007-08** | **2006-07** | **2007-08** |
| Basin-border (farmer) | Centrifugal | 0.40 | 0.65 | **0.40** | **0.65** |
| Modified border | Centrifugal | 0.80 | 1.10 | **0.70** | **1.20** |
| | Taka | 0.70 | 1.25 | | |
| | Hamedani | 0.55 | 1.30 | | |
| Modified basin | Centrifugal | 0.65 | 1.00 | **0.60** | **1.15** |
| | Taka | 0.60 | 1.20 | | |
| | Hamedani | 0.55 | 1.20 | | |

*Based on rainfall data, the total amounts of rainfall during the growing season for the years 2006-07 and 2007-08 were 228 mm and 72 mm respectively. Considering 75% of the total rain as effective rainfall, these values will be 1710, 540 $m^3$/ha respectively. The values were added to the volume of applied water to each farm for calculating the modified WPs.
**Adjusted with the amount of effective rainfall during cropping season.

on-farm improvement activities. Sound, adaptable irrigation methods that can be adopted by farmers are needed to improve agricultural WP and livelihood resilience of communities.

There is no doubt that the construction and/or completion of modern irrigation and drainage networks is the main solution. However, this is costly and time-consuming solution and may not be possible in the short term. Therefore, low-cost and short-term solutions to water management practices in the region must be developed. This could be achieved through research activities related to the water-table management, soil salinity control, irrigation water management, selection of suitable crop varieties, and improved agronomic practices. These will help to improve agricultural WP and farmers'

*Table 2.12. Seed consumption, number of shrub and sprouting percentage of the treatments (year 2006-07)*

| **Irrigation method** | **Sowing method** | **Seed consumption rate (kg/ha)** | **Shrubs in m² (No.)** | **Sprouting percentage (%)** | **Yield (kg /ha)** | |
|---|---|---|---|---|---|---|
| | | | | | Planting treatment | Irrigation treatment |
| Basin-border (farmer) | Centrifugal (350 kg/ha) | 350 | 247 | 34 | 1953 | 1953 |
| Modified border | Centrifugal (250 kg/ha) | 250 | 341 | 56 | 2590 ns | 2308 |
| | Taka (180 kg/ha) | 180 | 262 | 60 | 2434 ns | |
| | Hamadani (180 kg/ha) | 180 | 286 | 65 | 1901 ns | |
| Modified basin | Centrifugal (250 kg/ha) | 250 | 387 | 63 | 2730 ns | 2483 |
| | Taka (180 kg/ ha) | 180 | 332 | 75 | 2521 ns | |
| | Hamadani (180 kg/ ha) | 180 | 353 | 80 | 2198 ns | |

ns, not significant

*Table 2.13. Seed consumption, number of shrubs and sprouting percentage of the treatments (year 2007-08)*

| **Irrigation method** | **Sowing method** | **Seed consumption rate (kg/ha)** | **Number of shrub in m²** | **Sprouting percentage (%)** | **Yield (kg /ha)** | |
|---|---|---|---|---|---|---|
| | | | | | Planting treatment | Irrigation treatment |
| Basin-border (farmer) | Centrifugal | 350 | 270 | 31 | 1940 | 1940 |
| Modified border | Centrifugal | 250 | 290 | 47 | 2144 ns | 2338 |
| | Taka | 180 | 302 | 61 | 2471 ns | |
| | Hamadani | 180 | 316 | 64 | 2400 ns | |
| Modified | Centrifugal | 250 | 320 | 52 | 2251 ns | 2474 |
| | Taka | 180 | 321 | 65 | 2606 ns | |
| | Hamadani | 180 | 352 | 71 | 2564 ns | |

ns, not significant

*Table 2.14. A comparison between sowing method of the farmer (control) and the modified irrigation method regarding seed consumption rate and agronomic indexes (year 2007-08)*

| Irrigation method | Sowing method | Seed consumption rate (kg/ha) | Number of shrubs ($m^2$) | Sprouting percentage (%) | Yield (kg /ha) Planting treatment |
|---|---|---|---|---|---|
| Basin-border (farmer) | Centrifugal | 350 | 305 | 35 | 1940 |
| Modified border | Centrifugal | 250 | 335$^{ns}$ | 54$^{**}$ | 2198$^{ns}$ |
| | Taka | 180 | 344$^{**}$ | 70$^{**}$ | 2538$^{**}$ |
| | Hamedani | 180 | 336$^{**}$ | 68$^{**}$ | 2482$^{**}$ |

ns, not significant; **, highly significant

*Table 2.15. Results of t-test for the pair comparison of differences between grain yields of different levels of irrigation and sowing methods treatments (year 2007-08)*

| Basin irrigation | | | Border irrigation | | | Irrigation method | |
|---|---|---|---|---|---|---|---|
| Hamedani (2564) | Taka (2606) | Centrifugal (2251) | Hamedani (2400) | Taka (2471) | Centrifugal (2144) | **Sowing method** | |
| | | | | | - | Centrifugal (2144) | Border irrigation |
| | | | | - | -1.5$^{ns}$ | Taka (2471) | |
| | | | - | 0.3$^{ns}$ | -1.1$^{ns}$ | Hamedani (2400) | |
| | | - | 0.6$^{ns}$ | 0.9$^{ns}$ | -0.5$^{ns}$ | Centrifugal (2251) | Basin irrigation |
| | - | -1.4$^{ns}$ | -0.9$^{ns}$ | -0.6$^{ns}$ | -2.1$^{ns}$ | Taka (2606) | |
| - | 0.2$^{ns}$ | -1.2$^{ns}$ | -0.7$^{ns}$ | -0.4$^{ns}$ | -1.7$^{ns}$ | Hamedani (2564) | |
| -2.8$^{**}$ | -3.2$^{**}$ | -1.4$^{ns}$ | -2.3$^{*}$ | -2.7$^{**}$ | -1.1$^{ns}$ | Centrifugal (Farmer) (1940) | Basin-border (farmer) |

ns, not significant; *, **, significant at 5% and 1%, respectively

*Table 2.16. Results of t-test for the pair comparison of differences between sprouting percentage of different levels of irrigation and sowing methods treatments (year 2007-08)*

| **Basin irrigation** | | | **Border irrigation** | | | **Irrigation method** | |
|---|---|---|---|---|---|---|---|
| Hamedani (71) | Taka (65) | Centrifugal (52) | Hamedani (64) | Taka (61) | Centrifugal (47) | **Sowing method** | |
| | | | | | - | Centrifugal (47) | Border irrigation |
| | | | | - | $-4.3^{**}$ | Taka (61) | |
| | | | - | $-0.7^{ns}$ | $-4.1^{**}$ | Hamedani (64) | |
| | | - | $2.8^{**}$ | $2.8^{*}$ | $-1.5^{ns}$ | Centrifugal (52) | Basin irrigation |
| | - | $-3.6^{**}$ | $-0.2^{ns}$ | $-1.2^{**}$ | $-5.1^{**}$ | Taka (65) | |
| - | $-1.2^{ns}$ | $-3.9^{**}$ | $-1.3^{ns}$ | $-2.1^{*}$ | $-5.0^{**}$ | Hamedani (71) | |
| $-8.3^{**}$ | $-10.0^{**}$ | $-6.3^{ns}$ | $-8.1^{**}$ | $-10.0^{**}$ | $-5.1^{**}$ | Centrifugal (Farmer) (31) | Basin-border (farmer) |

ns, not significant; *, **, significant at 5% and 1%, respectively

*Table 2.17: Results of t-test for the pair comparison of differences between number of shrubs/m$^2$ of different levels of irrigation and sowing methods treatments (year 2007-08)*

| **Basin irrigation** | | | **Border irrigation** | | | **Irrigation method** | |
|---|---|---|---|---|---|---|---|
| Hamedani (352) | Taka (321) | Centrifugal (320) | Hamedani (316) | Taka (302) | Centrifugal (290) | **Sowing method** | |
| | | | | | - | Centrifugal (290) | Border irrigation |
| | | | | - | $-0.7^{ns}$ | Taka (302) | |
| | | | - | $-0.7^{ns}$ | $-1.2^{ns}$ | Hamedani (316) | |
| | | - | $0.2^{ns}$ | $-0.9^{ns}$ | $-1.4^{ns}$ | Centrifugal (320) | Basin irrigation |
| | - | $-0.1^{ns}$ | $-0.2^{ns}$ | $-1.1^{ns}$ | $-1.6^{ns}$ | Taka (321) | |
| - | $-1.2^{ns}$ | $-1.2^{ns}$ | $-1.3^{ns}$ | $-2.1^{*}$ | $-2.4^{*}$ | Hamedani (352) | |
| $-3.0^{**}$ | $-2.3^{*}$ | $-2.1^{*}$ | $-1.9^{ns}$ | $-1.6^{ns}$ | $-0.9^{ns}$ | Centrifugal (Farmer) (270) | Basin-border (farmer) |

ns, not significant; *, **, significant at 5% and 1%, respectively

*Table 2.18. Grain yield (kg/ha) (2006-07)*

| Treatment/replication | T1* | T2 | T3 | Tc | Average |
|---|---|---|---|---|---|
| R1 | 3523 | 3358 | 3466 | 3963 | 3577.5 |
| R2 | 3025 | 3880 | 3026 | 4088 | 3504.8 |
| R3 | 3355 | 3528 | 3045 | 3839 | 3441.8 |
| Average | 3301 | 3589 | 3179 | 3963 | - |
| Change from control (%) | 16.7 | 9.5 | 19.8 | - | - |

*T1, saline-saline-fresh water; T2, fresh-fresh-saline water; T3, fresh-saline-fresh water, Tc: fresh-fresh-fresh water.

*Table 2.19 :Grain yields under different treatments (year 2007-08)*

| Water treatment | | Grain yield | |
|---|---|---|---|
| | | kg/ha | t/ha |
| I1 | Fresh-fresh-fresh (control) | 2698.4 | 2.70 |
| I2 | Fresh-fresh-saline | 2117.8 | 2.12 |
| I3 | Fresh-saline-saline | 1710.1 | 1.71 |
| I4 | Saline-saline-saline | 1501.3 | 1.50 |

*Table 2.20. Soil salinity and acidity before and after drain water irrigation, 2007-08*

| Before irrigation | | After irrigation* | |
|---|---|---|---|
| EC (dS/m) | pH | EC (dS/m) | pH |
| 6.3 | 7 | 4 | 7.2 |
| 4.8 | 7.2 | 8.5 | 7.2 |
| 7.9 | 7.2 | 10.8 | 7.6 |
| 8.5 | 7.3 | 11.5 | 7.1 |

*The last irrigation was on 15 April 2008

livelihood in this region without requiring heavy investments.

The main objective of this research was to find cost effective and short-term solutions for the irrigation challenges in the area and to improve the WP of wheat in the salt-prone areas of lower KRB. Improved basin and border irrigation methods can both be recommended for this area. However, basin irrigation method is more suited to local conditions because:

- It requires less stringent land leveling and uniform slope across the irrigation plot, so requires less on-farm improvement to the existing conditions
- It is more adoptive to farm micro relief caused by common cultivation practices
- It requires less labor (considering the labor shortages in the area)
- It requires less control over flow, considering the high flow variation
- Considering the high levels of salinity

and its variation in different farms, the basin method provides pre-cultivation leaching opportunities, a common practice for reducing soil salinity prior to sowing ("Makhar" water).

Water productivity of irrigated wheat under saline-waterlogged conditions is low in the Karkheh River Basin, but it can be improved with simple irrigation management techniques. Improving traditional surface irrigation methods in the saline and waterlogged areas can help ameliorate the situation and improve crop water productivity.

It should be noted that yields under different treatments were not potential yields, but were obtained under existing farmer agronomic practices. Research treatments only focused on water-saving measures. Higher WPs could be expected under different treatments, if water management and agronomic practices were applied together.

The results of reuse experiments indicated the feasibility of the option of using drainage water as irrigation water, especially with the cyclic application of water during different growth stages without considerable yield losses. Reuse will help to improve WP levels of the wheat crop, especially in scarce water and drought conditions.

Waterlogging followed by increased soil salinity occurs in certain periods of the year. For example, under wheat cultivation, early November is the planting date in DA. Late November is the first irrigation for land preparation and harvest is in late May. Deep percolation losses of irrigation during this period cause the water table to rise. The rise peaks in February. Therefore, reuse of drainage water, considering that there are few feasible options for gravity disposal of drainage water, will also, indirectly, help to improve WP by lowering the water table and hence the salinity of the soil profile.

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# Chapter 3.

# Comparison of the yield of local wheat cultivars in the saline areas of the lower Karkheh river basin

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## Introduction

Salinity and waterlogging are common occurrences in the lower reaches of several river basins throughout the world, affecting agricultural production and the livelihoods of the affected communities (Wichelns and Oster 2006). The same applies to the lower Karkheh River Basin (LKRB) of Iran.

Wheat, barley, and vegetable crops are currently produced in the LKRB. However, more than 78% of agricultural production in this area (Dasht-e-Azadegan) is from cereals (Mahab-e Ghods 1992). Due to the severity of salinity and waterlogging stresses, together with the hot climate, the average yield of wheat is less than 2 t/ha in the region. Values of water productivity for wheat and barley (the main crops in the area) are less than 0.5 kg/$m^3$.

The efforts being made to overcome salinity and waterlogging problems consist of engineering solutions such as the installation of a drainage system to manage the drainage effluent generated by the irrigated agriculture. However, this is an expensive, long-term strategy and the areas under salt-affected and waterlogged soils are expanding because of inappropriate on-farm water and soil management. Alternatively, selection and cultivation of high-yielding, salt-tolerant varieties of different crops could be used as an interim strategy to fulfill the needs of the communities relying on these soils for their livelihoods (Rhoades et al. 1992).

Many crops are known to be salt-tolerant (Maas and Hoffman 1977). Some of them also show intra-specific variation in response to salinity (Epstein 1985; Norylyn and Epstein 1984; Parida and Das 2004). There is evidence that suggests considerable intra-specific diversity among wheat genotypes with regard to their ability to withstand ambient salinity (Kingsbury and Epstein 1984; 1986). Previous studies carried out elsewhere have shown that some varieties of wheat are more salt-tolerant than others and could be used as genetic resources for further selection and cultivation on salt-affected and waterlogged areas (Tanveer-ul-Haq et al. 2003; Pervaiz et al. 2003). The study of response of crop cultivars to salinity under naturally saline condition is not feasible due to extreme variability in soil salinity both spatially and temporarily (Pervaiz et al. 2003). To avoid this problem, the comparative differences for salt tolerance among cultivars must be studied in small plots with significant replications.

Many efforts have been made to release salt-tolerant wheat varieties. For example, field screening for salt tolerance in Pakistan led to the release of the salt-tolerant Kharchia-Rata wheat line. Sakha-8(Egypt), LU-26S and SARC-1 are other wheat varieties from Pakistan that have shown salt tolerance (Shannon 1997). Elsewhere in Iran, efforts have been made to develop and release salt-tolerant wheat varieties. In this respect, varieties such as Roshan, Kavir, Bam (a double haploid line), Sistan, and Akbari have been released for salt-affected areas (Anonymous 2007). The objective of this study was to evaluate growth response of these new varieties along with local wheat cultivars in the salt-affected areas of LKRB

## Materials and methods

This study was conducted at Dasht-e-Azadegan in Khuzestan province during 2005-2008. Dasht-e-Azadegan is located in the LKRB and lies between 31o04′35″ to 31o51′39″N and 47o46′34″ to 48o35′12″E.

The crops were grown in 4.0 × 7.0 m plots with each plot containing 18 rows of each variety. The rows were spaced 0.2 m apart. Prior to sowing date triple super phosphate was mixed into the top 0.25 m of soil at a rate of 115 kg P/ha. To assure adequate nitrogen fertility throughout the experiment, urea was added at the rate of 150 kg N/ha. Herbicides were applied to control weeds whenever necessary.

Five commercial varieties selected for saline conditions, referred to as new varieties, and two local cultivars were sown in the plots in November each year. The new varieties were Roshan (a tall variety), Kavir (a semi-dwarf variety, released in 1996), Bam, Akbari, and Sistan (semi-dwarf varieties, released in 2006). The local wheat cultivars were Chamran and Verinak. In total, the experimental design consisted of seven wheat genotypes replicated three times in a randomized complete block design.

During the growing season, all plots were irrigated at the same time with the same amount of irrigation water. Three soil cores per block were taken to a depth of 0.9 m four times during the growing season. The pre-experiment average soil salinities (electrical conductivity of soil saturated paste extract, ECe) for the 0.9 m soil depth were 7.1, 7.0 and 12.9 dS/m in 2005, 2006 and 2007, respectively. Irrigation water for the experimental fields was taken directly from the Karkheh river. The electrical conductivity of river water was less than 1.5 dS/m.

To determine grain and straw yield of each genotype, a 3 $m^2$ area was harvested from the center of each plot. The data collected were subjected to variance analysis using SAS software.

## Results and discussion

### *Soil analysis*

The mineral composition of the soils in the experimental field in Dasht-e-Azadegan is presented in Table 3.1. The analyses of soil samples revealed that the soils were medium to heavy textured and saline-sodic throughout the 0.9 m profile. One can conclude that this high sodium adsorption ratio, in addition to the fine size of soil particles, may cause reduction in infiltration rate and hydraulic conductivity. Low level of organic matter as revealed by low nitrogen content is the most obvious fertility constraint.

### *Root zone salinity*

Irrigation was applied five times during the growing season with water diverted from the Karkheh river. The relatively good quality of irrigation water leached the salts, which were deposited in the root zone during the fallow season as a result of high evaporative demand and high water table. The average soil salinity for the 0.9 m soil depth during growing season was 7.2, 5.5 and 9.1 dS/m in 2005, 2006 and 2007, respectively. Therefore, crops were affected by salinity during the growing season in addition to other environmental factors.

### *Grain yield*

Comparison of mean grain yields for 3 years showed that Sistan and Verinak produced the highest and lowest grain yield, respectively. The mean grain yield of Sistan, Kavir, Bam, Chamran, Roshan, Akbari, and Verinak were 4.72, 4.47, 4.42, 4.26, 4.06, 3.93 and 3.25 t/ha, respectively (Fig. 3.1). There were significant differences among local cultivars vs. new varieties (Table 3.2). New varieties produced more grain yield than the local cultivars by 15%. Generally, Sistan, Kavir, and Bam produced more grain yield than the other varieties. Among new varieties,

*Table 3.1. Physicochemical properties of soil during 2005-08*

| | Depth | Texture | $EC_e$ | SAR | $K^+$ | $Na^+$ | $Mg^{2+}$ | $Ca^{2+}$ | $SO_4^{2+}$ | $Cl^-$ | $HCO^{3-}$ | K (average) | P (average) | Total N | OC | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (cm) | | (dS/m) | | | | | | | | | (ppm) | (ppm) | % | % | |
| **2005-06** | 0-30 | L | 13.09 | 16.63 | 0.89 | 91.06 | 28.56 | 31.44 | 61.53 | 81 | 2.5 | 102 | 10.16 | 0.019 | 0.22 | |
| | 30-60 | SL | 9.81 | 14.46 | 0.46 | 70.28 | 17.72 | 29.52 | 65.08 | 40 | 2.5 | 78 | - | 0.011 | 0.13 | |
| | 60-90 | L | 9.57 | 16.00 | 0.44 | 71.9 | 14.4 | 26 | 70.12 | 30 | 2.55 | 84 | 10.42 | - | - | |
| **2006-07** | 0-30 | L | 14.46 | 15.22 | 1.03 | 88.99 | 26.96 | 41.44 | 47.05 | 107 | 2.5 | 150 | 14.81 | 0.029 | 0.34 | 7.15 |
| | 30-60 | L | 9.88 | 16.05 | 0.53 | 73.53 | 15.24 | 26.76 | 64.81 | 39.00 | 2.5 | 96 | 5.93 | - | - | 7.26 |
| | 60-90 | Si. L | 10.88 | 21.60 | 0.42 | 90.92 | 9.60 | 25.84 | 79.10 | 36.5 | 2.5 | 115 | 7.3 | - | - | 7.32 |
| **2007-08** | 0-30 | L | 13.08 | 18.61 | 1.02 | 100.1 | 21.56 | 36.36 | 80.60 | 78.75 | 3.00 | 177 | 20.48 | 0.02 | 0.23 | 7.9 |
| | 30-60 | Sl.C.L | 11.14 | 17.82 | 0.66 | 85.82 | 18.40 | 28.00 | 85.65 | 50.70 | 2.05 | 217 | 12.99 | 0.03 | 0.31 | 7.8 |
| | 60-90 | Sl.C.L | 10.55 | 22.76 | 0.32 | 81.18 | 10.28 | 15.16 | 71.28 | 48.25 | 2.50 | 185 | 4.30 | 0.02 | 0.20 | 7.8 |

Roshan and Akbari produced lower grain yield.

Grain yields of the new varieties were significantly correlated with number of kernels per spike (Table 3.3). On the other hand, the correlation coefficient between spike length and number of kernels per spike were positive and significant ($P < 0.01$). Therefore, number of kernels per spike was the main yield component that caused yield improvement in the new varieties. A higher number of kernels could be attributed to lower floret mortality (Bremner and Davidson 1978). Shearman et al. (2005) concluded that the more assimilate allocated during spike development results in a higher percentage of floret survival and therefore more kernels are formed per spike.

The new varieties as well as local cultivars produced the same mean kernel weight (Fig. 3.2). Mean kernel weight of the varieties ranged from 35.6 to 41.1 mg. Generally, mean kernel weight is a genetic trait and is not affected by environmental stresses (Shearman et al.

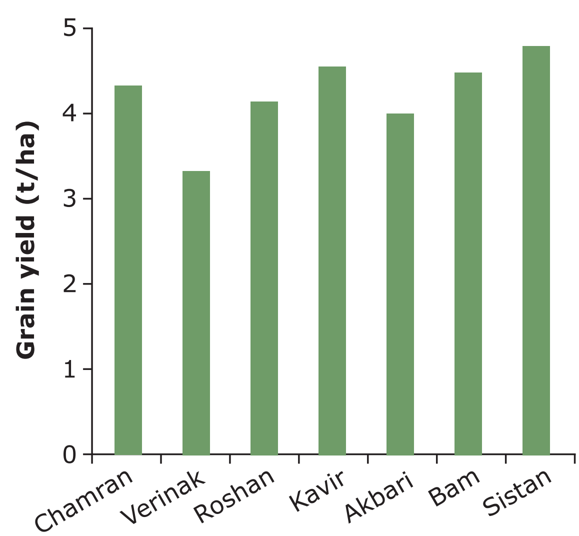


*Fig. 3.1. Comparison of mean grain yield of local cultivars and new varieties, regardless of the years*

*Table 3.2. Orthogonal contrasts of mean grain yield for local cultivars and new varieties during 2005-2008*

| Contrast | Sum squares of error |
|---|---|
| Grain yield of local vs. new varieties | 41,000.620* |
| Grain yield of Bam, Sistan, and Kavir vs. other varieties | 67,411.260** |
| Grain yield of Bam, Sistan, and Kavir vs. Roshan and Akbari | 31,601.120* |

*, **Significant at the 0.05 and 0.01 probability levels, respectively.

*Table 3.3. Correlation coefficients among morphological traits, yield and yield components of new varieties*

| | Grain yield | Spike length | Kernel per spike | Kernel weight | Number of spikes | Biological yield | Harvest index |
|---|---|---|---|---|---|---|---|
| Grain yield | 1 | | | | | | |
| Spike length | 0.6349* | 1 | | | | | |
| Kernel per spike | 0.5457* | 0.7496** | 1 | | | | |
| Kernel weight | 0.4758ns | 0.4531ns | -0.0058ns | 1 | | | |
| Number of Spike | 0.0567ns | -0.4911ns | -0.7477** | 0.0713ns | 1 | | |
| Biological yield | 0.7898** | 0.1759ns | 0.2642ns | 0.1247ns | 0.2984ns | 1 | |
| Harvest index | 0.0281ns | 0.4841ns | 0.2870ns | 0.2943ns | -0.4080ns | -0.6223* | 1 |

*, **Significant at the 0.05 and 0.01 probability levels; ns, not significant

2005; Hay and Walker 1989). However, severe stresses like high levels of salinity (Shannon 1997) and lodging (Hay and Walker 1989) can markedly reduce mean kernel weight.

### *Biological yield and harvest index*

Results of this study show greater biological yields for the new varieties than the local cultivars (Fig. 3.3). The mean biological yields of local cultivars and new varieties were 10.17 and 12.32 t/ha, respectively. Biological yield is also highly correlated with grain yield for new varieties (Table 3.3).

There was no relationship observed between grain yield of the new varieties and harvest index (Table 3.3). The mean harvest index of the new varieties as well as local cultivars varied in the range of 0.35-0.40 (Fig. 3.4). However, varieties had different values from one year to another. This finding is in agreement with the observation made by Prihar and Stewart (1990), who found that for a given cultivar, different climates may result in different harvest index values.

According to the results, increase in grain yield of the new varieties was more attributable to the increase in the number of kernels per spike and biological yield rather than harvest index. It seems that yield improvement for wheat could be obtained without further increase in harvest index (Musick and Porter 1990). The same results were obtained by Waddington et al. (1986). They concluded that grain yield of high-yielding wheat genotypes was associated with increase in biological yield and the number of kernel per spike.

### *Morphological traits*

Roshan and Verinak had the highest and lowest stem heights, respectively (Table 3.4). Other genotypes had the same stem

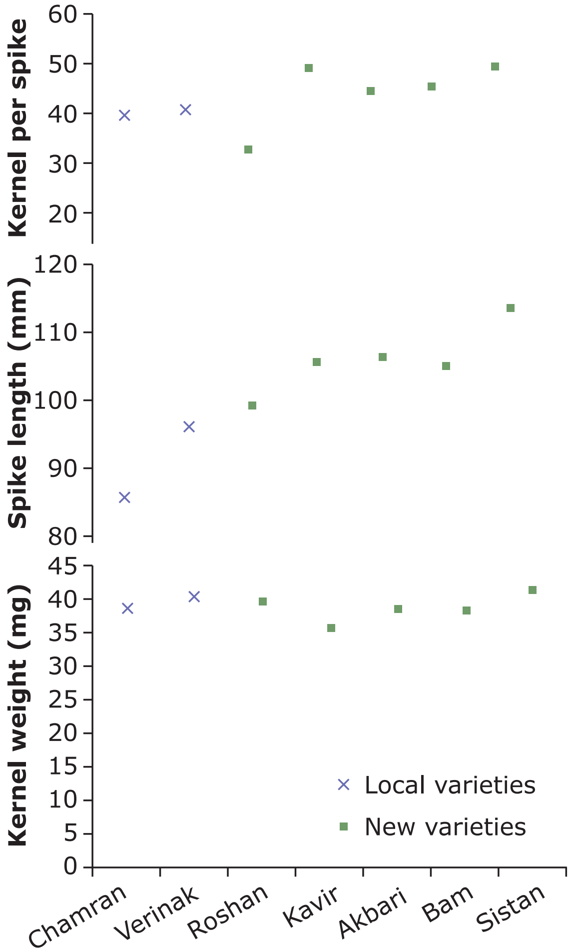


*Fig. 3.2. Comparison of the number of kernels per spike, spike length and kernel weight of local cultivars and new varieties*

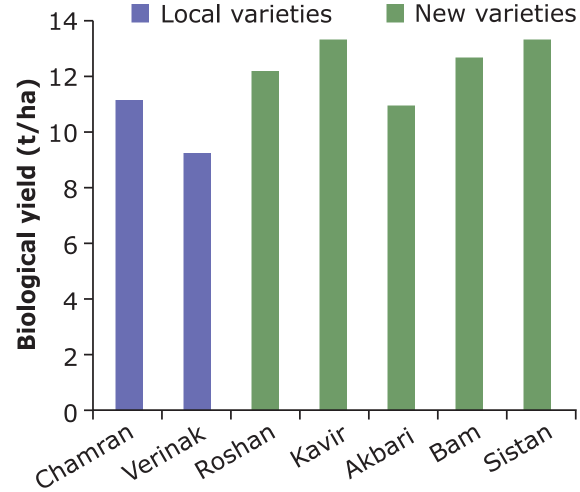


*Fig. 3.3. Comparison of mean biological yield of local cultivars and new varieties*

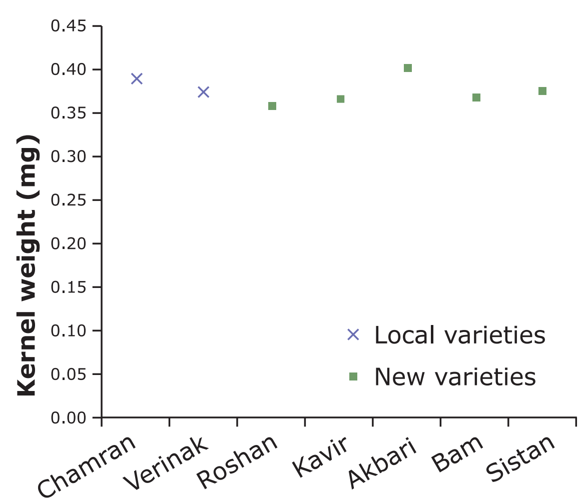


*Fig. 3.4. Comparison of mean harvest index of local cultivars and new varieties*

height (average = 78.7 cm). Roshan is an old variety with a long, weak stem, which even in these conditions lodged and its grain yield was markedly reduced. The highest spike length was observed for Sistan (Table 3.4). However, the differences among spike length of Sistan, Kavir, and Bam were not significant. Chamran and Verinak had the lowest spike length.

From the present study it appears that all genotypes had the same main stem leaf number, and equal times for initiation of emergence, tillering, and stem elongation stages, except for Verinak. In spite of this, Kavir, Bam, and Sistan showed higher yield than the others (Fig. 3.1). There are many genetic factors that affect grain yield under saline conditions, such as number of tillers and leaf area duration index (Hay and Walker 1998). As shown in Table 3.5, new varieties produced more

*Table 3.4. Comparison of wheat genotype stem height and spike length means (field 2)*

| Genotypes | Stem height (cm) | Spike length (mm) |
|---|---|---|
| Kavir | $81.25^{b}$ | $109.00^{ab}$ |
| Roshan | $110.00^{a}$ | $101.10^{b}$ |
| Bam | $78.25^{b}$ | $106.90^{ab}$ |
| Akbari | $76.75^{b}$ | $105.10^{b}$ |
| Sistan | $80.00^{b}$ | $115.50^{a}$ |
| Chamran | $77.25^{b}$ | $87.70^{c}$ |
| Verinak | $67.50^{c}$ | $98.80^{b}$ |

*Table 3.5. Phonological and morphological characteristics of wheat genotypes*

| Genotypes | Main stem leaf no. | Days until emergence | Days until tillering | Days until stem elongation | Average tiller no. | Average fertile tiller | Lodging (%) |
|---|---|---|---|---|---|---|---|
| Kavir | 4.10 | 9 | 28 | 56 | 2.88 | 2.00 | 0 |
| Roshan | 3.33 | 8 | 26 | 67 | 4.10 | 2.20 | 25 |
| Bam | 4.01 | 6 | 23 | 61 | 3.53 | 2.00 | 0 |
| Akbari | 3.30 | 6 | 23 | 66 | 3.70 | 2.20 | 0 |
| Sistan | 4.00 | 9 | 27 | 66 | 4.03 | 2.20 | 0 |
| Chamran | 4.30 | 8 | 25 | 54 | 2.18 | 1.10 | 0 |
| Verinak | 3.80 | 5 | 21 | 46 | 2.00 | 1.00 | 0 |

tillers than the local varieties. Roshan produced more tillers during the growing season (Table 3.5), but it lodged at the end of the season and its grain yield was markedly reduced.

The other very important factor affecting grain yield under stressed conditions is the leaf area duration index or grain-filling period. Varieties like Bam, Kavir, and Sistan had the highest ground cover and grain -filling period (field observation). This allows for more mobilization of soluble carbohydrates from other parts of the plant to developing grains. A short grain-filling period could be a factor causing low yield in varieties like Verinak.

## Conclusions

Crop production in the lower areas of LKRB is impaired by highly salinized soil and water resources, and waterlogged conditions. The long term solution to the problem is through control of the saline groundwater level, which is a time consuming and expensive task. In the short term, however, production could be improved through the selection of suitable crop species or varieties for the area. Based on the results of this study, wheat varieties like Bam, Sistan, and Kavir were found to be more productive than Roshan, Akbari, and local cultivars and could be considered as potential substitutes for present varieties under saline (also waterlogged) conditions of LKRB. This experiment also showed that the number of kernels per spike was the main yield component that caused yield improvement in new varieties. However, more grain yields for the new varieties were associated with an increase in biological yield rather than harvest index.

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# Chapter 4.

# Comparison of yield of local barley cultivars in saline areas in the lower Karkheh river basin

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## Introduction

Barley is the most important cereal crop after wheat, maize, and rice. Due to broad ecological adaptation, it is grown in regions with climates unfavorable for the production of other major cereals. The major production areas of barley include Western Europe, North America, the former USSR, and China (Poehlman 1985). Barley, after wheat, is the most important and widely adapted food cereal in Dasht-e-Azadegan . Due to the severity of salinity and waterlogging in the region, the average yield is generally less than 2 t/ha.

Several approaches are available for controlling salinity and waterlogging. Natural or artificial drainage systems are the prime approaches for successful crop production in saline/waterlogged soils (Rhoades et al. 1992). Another applicable approach for use of saline soil is the selection of appropriate crop cultivars (Rhoades et al. 1992; Minhas and Sharma 2004). Varieties of crops differ considerably in their ability to tolerate salinity and these differences can be used for selecting the varieties, which produce significant yield under saline conditions.

Barley is one of the most salt-tolerant crop species. However, there are wide variations among its genotypes under saline conditions. Experiments on determining the relative yield responses of commercial barley cultivars under NaCl salinity showed that some varieties were more salt tolerant than the others (Suhayda et al. 1992).

Investigations have shown that some barley varieties developed primarily for higher yield in saline regions of Pakistan, India, Egypt and the United States showed higher salt-tolerance than varieties developed for non-saline areas (Minhas and Sharma 2004; Kingsbury and Epstein 1986). However, Royo and Aragues (1999) concluded that barley genotypes with the highest yield in non-saline conditions were also most productive at medium and high salinities. These differences led to extensive screening for salt-tolerance among thousands of barley accessions of the world collection (Kingsbury and Epstein 1984).

The objective of this study was to compare grain yield of some barley genotypes under saline conditions of the lower areas of Karkheh river basin (LKRB) and to introduce the most productive and salt-tolerant varieties for the area.

## Materials and methods

A field experiment was conducted in Dasht-e-Azadegan, Khuzestan province, during 2005-2008. The treatments included two barley cultivars (Afzal and Reyhan) and four barley lines (Karon × Kavir, M80-9, M-81-19 and On-4). The experimental design was randomized complete blocks with three replications.

Genotypes were sown in the plots in November each year. Barley rows were spaced 0.2 m apart with sowing density of 350 seeds/m$^2$. Each plot was 4.0 x 6.5 m, so that 18 rows of each genotype were sown in every plot.

All plots were fertilized with 25 kg N/ha of urea and 85 kg P/ha of triple superphosphate before planting. At tillering and stem elongation, 50 kg N/ha of urea was used as a top dressing to each plot. Herbicides were applied to control weeds whenever necessary.

All plants received an adequate amount of water during the growing season. Irrigation water for the experiments was taken directly from the Karkheh river. The electrical conductivity of river water was always below 1.5 dS/m during the experiment. At harvest, a 3 $m^2$ area was harvested from the center of each plot. Data were analyzed using analysis of variance techniques. Duncan's Multiple Range test was used to differentiate among measured yields across the genotypes.

## Results and discussion

### *Soil analysis*

Soil characteristics of the experimental fields are presented in Table 4.1. Soil samples from all depths are classified as saline sodic soils. The high sodium adsorption ratio, in addition to the fine size of soil particles, may lead to the problem of infiltration and waterlogging. Poor organic matter and as a result low nitrogen content were the most obvious fertility aspects of the soils of the two fields.

### *Root zone salinity*

Irrigation was applied four times during the growing season with water diverted from the Karkheh river. The relatively good quality of irrigation water leached the salts, which were deposited in the root zone during the fallow season as a result of high evaporative demand and high watertable. The average soil salinity at 0.9 m soil depth during the growing season is presented in Fig. 4.1. As shown, crops were affected by salinity during the growing season.

### *Grain yield and its components*

Combined analysis of variance showed that On-4 and Afzal produced the highest and lowest grain yields regardless of the year. The mean grain yields of On-4, Reyhan, M80-9, M81-19, Karon x Kavir and Afzal were 3.33, 3.12 2.82, 3.01, 2.91 and 1.65 t/ha, respectively. Comparison of mean grain yield in each year showed that barley genotypes produced different grain yields in each year (Table 4.2). The highest grain yield was observed for On-4, except for 2006-2007. Generally, Afzal produced the least grain yield in each year. Other studies on the genetics of barley grain yield show different results depending on such variables as locally adapted or exotic cultivars and the particular environment of the study (Hockett and Nilan 1985).

Grain yield of barley genotypes was highly correlated with stem height and biological yield (Table 4.3, $P < 0.01$). As for grain yield, the highest and lowest plant height was observed for On-4 and Afzal genotypes (Table 4.4). The differences among plant height of On-4, Karon Kavir, and M80-9 were not significant.

Biological yield of the genotypes was not markedly different. However, the highest biological yield was observed for M80-9. The differences among biological yields of M80-9 (6.99 t/ha), Karon Kavir (5.91 t/ha) and On-4 (6.56 t/ha) were not significant. Afzal, with 4.19 t/ha, had the lowest biological yield.

There was no significant correlations among grain yield and stem length, kernel per spike, kernel weight, and harvest index (Table 4.3). Among the genotypes M81-19 and Reyhan had the highest and lowest spike length (Table 4.4). On-4 and Afzal with 48.2 and 36.1 had the highest and lowest numbers of kernel per spike, respectively (Fig. 4.2). The differences among kernel per spike for On-4, Reyhan, and other lines were not significant.

On-4 and M81-19 produced the highest and lowest mean 1000 kernel weight regardless of the years (Fig. 4.3). The differences among mean 1000 kernel weight of On-4, Karon x Kavir, Reyhan and even Afzal were not significant.

There were no significant differences among harvest index of the genotypes

*Table 4.1. Some chemical properties of soils of the experimental site*

| | Depth (cm) | Texture | $EC_e$ (dS/m) | SAR | $K^+$ | $Na^+$ | $Mg^{2+}$ | $Ca^{2+}$ | $SO_4^{2+}$ | $Cl^-$ | $HCO^{3-}$ | K (average) (ppm) | P (average) (ppm) | N % | OC % | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2005-06** | 0-30 | Si.C | 1.85 | 2.83 | 0.26 | 7.34 | 4.6 | 8.8 | 4.91 | 7 | 5 | 129 | 8.57 | 0.023 | 0.27 | |
| | 30-60 | S.L | 2.52 | 2.42 | 0.32 | 9.36 | 7.92 | 22 | 25.35 | 7.5 | 2.5 | 84 | 6.72 | - | - | |
| | 60-90 | S.L | 2.59 | 1.95 | 0.32 | 8.37 | 10.92 | 26.08 | 34.96 | 4.5 | 2.5 | 78 | 6.46 | - | - | |
| **2006-07** | 0-30 | L | 23.6 | 25.05 | 1.22 | 178.6 | 38.16 | 63.44 | 45.4 | 230 | 2.85 | 109 | 11.85 | 0.020 | 0.23 | 7.15 |
| | 30-60 | L | 11.76 | 12.56 | 0.7 | 69.13 | 21.12 | 39.48 | 38.64 | 85 | 2 | 115 | 9.89 | - | - | 7.26 |
| | 60-90 | Si.C.L | 7.11 | 12.61 | 0.43 | 50.88 | 7.16 | 25.4 | 55.54 | 18.65 | 2.25 | 135 | 7.88 | - | - | 7.32 |
| **2007-08** | 0-30 | - | 23 | 21.95 | 1.11 | 159.1 | 44.3 | 60.8 | 52.35 | 222.5 | 0 | 185 | 44.56 | 0.01 | 0.18 | - |
| | 30-60 | - | 15.35 | 18.14 | 0.77 | 102.6 | 26.3 | 37.68 | 59.43 | 115.0 | 0 | 209 | 24.95 | 0.02 | 0.24 | - |
| | 60-90 | - | 7.05 | 21.07 | 0.24 | 58.48 | 7.6 | 7.84 | 40.03 | 31.25 | 0 | 11.6 | 11.56 | 0.001 | - | - |

(data not shown). The mean harvest index of genotypes varied in the range of 0.39 for Afzal to 0.46 for On-4. Harvest index is a measure of the degree to which a crop partitions photo-assimilate into grain (Wych et al. 1985). Riggs et al. (1981) noted that harvest index of spring barley varieties varied from 0.33 to 0.50. However, the harvest index for the varieties in the USA varied from 0.27 to 0.40 from 1920 to 1978 (Wych and Rasmusson 1983).

As shown in Table 4.5, there were noticeable differences among the genotypes with respect to lodging percentage. However the amount of lodging percentage in 2006 and 2007 was lower than 2005 due to reduced plant height, which may have been the result of higher soil salinity of the root-zone.

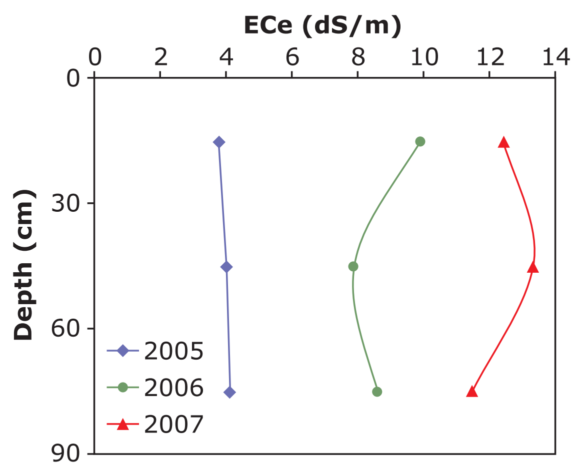


*Fig. 4.1. Average root-zone salinity during 2005-2008*

## Conclusions

Barley as well as wheat is an economic crop grown in Dasht-e-Azadegan, which is facing the dual problem of salinity and waterlogging. Native varieties of barley are commonly cultivated in the area and

*Table 4.2. Yield comparison of barley genotypes during 2005-2008*

| **Genotype** | **2005-2006** | **2006-2007** | **2007-2008** |
|---|---|---|---|
| | (t/ha) | | |
| Reyhan | 3.30$^{a}$ | 3.56$^{a}$ | 2.51$^{ab}$ |
| M80-9 | 2.58$^{b}$ | 2.86$^{ab}$ | 3.03$^{a}$ |
| M81-19 | 3.40$^{a}$ | 3.36$^{a}$ | 2.26$^{bc}$ |
| On-4 | 3.63$^{a}$ | 3.27$^{a}$ | 3.10$^{a}$ |
| Karon × Kavir | 3.16$^{ab}$ | 2.91$^{ab}$ | 2.67$^{ab}$ |
| Afzal | 1.01$^{c}$ | 2.23$^{b}$ | 1.71$^{c}$ |

Means follow by the same letter in each column were not significantly different (Duncan's 5%)

*Table 4.3. Correlation coefficients among yield and yield components of barley genotypes*

| | **GY** | **PLH** | **SL** | **K/S** | **KW** | **BY** | **HI** |
|---|---|---|---|---|---|---|---|
| GY | 1 | | | | | | |
| PLH | 0.7237$^{**}$ | 1 | | | | | |
| SL | -0.2729$^{ns}$ | -0.0895$^{ns}$ | 1 | | | | |
| K/S | 0.4210$^{ns}$ | 0.4574$^{ns}$ | -0.0524$^{ns}$ | 1 | | | |
| KW | 0.3094$^{ns}$ | 0.4574$^{ns}$ | -0.3102$^{ns}$ | 0.328$^{ns}$ | 1 | | |
| BY | 0.9254$^{**}$ | 0.6356$^{**}$ | -0.2949$^{ns}$ | 0.2913$^{ns}$ | 0.2676$^{ns}$ | 1 | |
| HI | 0.3644$^{ns}$ | 0.3911$^{ns}$ | -0.0114$^{ns}$ | 0.4073$^{ns}$ | 0.1437$^{ns}$ | -0.0106$^{ns}$ | 1 |

*Table 4.4. Comparison of stem and spike length of barley genotypes*

| **Genotypes** | **Stem height (cm)** | **Spike length (mm)** |
|---|---|---|
| Reyhan | 66.67$^{bc}$ | 48.63$^{c}$ |
| M80-9 | 75.67$^{ab}$ | 54.20$^{abc}$ |
| M81-19 | 70.00$^{bc}$ | 58.27$^{a}$ |
| On-4 | 86.00$^{a}$ | 51.30$^{bc}$ |
| Karon × Kavir | 78.33$^{ab}$ | 51.70$^{bc}$ |
| Afzal | 60.33$^{c}$ | 56.23$^{ab}$ |

*Table 4.5. Lodging percentage of barley genotypes during 2005-2006 and 2006-2007*

| **Genotypes** | **Lodging (%)** | | | |
|---|---|---|---|---|
| | **2005-2006** | **2006-2007** | | **2007-2008** |
| Karon × Kavir | 10 | 15 | 0 | 5 |
| Afzal | 100 | 60 | 0 | 5 |
| Reyhan | 40 | 10 | 0 | 5 |
| M81-19 | 5 | 0 | 0 | 0 |
| M80-9 | 5 | 5 | 0 | 0 |
| On-4 | 5 | 5 | 0 | 0 |

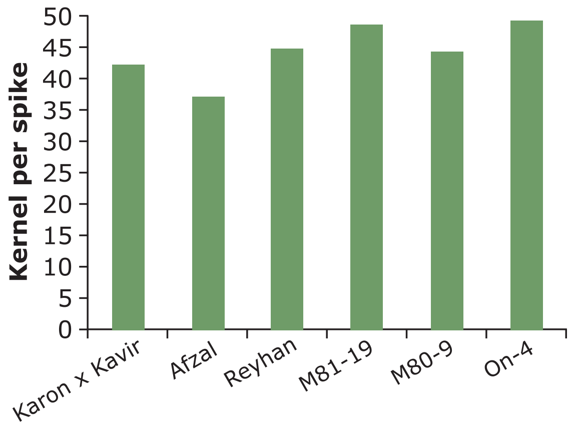


*Fig. 4.2. Comparison of mean kernels per spike of barley genotypes*

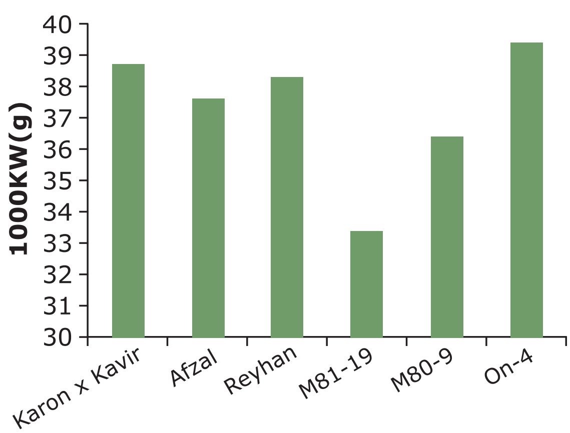


*Fig 4.3. Comparison of mean 1000 kernel weight of barley genotypes*

its production is lower than the averages of the country. It was assumed that introduction of high-yielding varieties could increase production in the region. Results of this study indicate that varieties such as On-4 and M81-19 could be considered as new barley genotypes for the lower parts of the Karkheh river basin.

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## Chapter 5.

# Comparison of yield of local and exotic sorghum cultivars in saline areas of the lower Karkheh river basin

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## Introduction

A wide variety of crops, such as, cereals, cold-season tropical fruits, and fodder crops are grown for local consumption and export in Iran (FAO 2008). The 2004 statistics showed that the total agricultural produce of the country is about 70 million tonnes. The average yields of these crops vary according to the environmental stress and climatic conditions. Salinity and drought are among the most important environmental stresses that limit crop production in Iran (FAO 2008).

On the other hand, existing forage production and natural fodder resources are insufficient to feed the existing livestock numbers in Iran. The strategy for the enhancement of livestock production in the country should therefore be primarily focused on increasing forage and fodder productivity both quantitatively and qualitatively, through introduction of high-yielding variety/lines in sorghum-cultivating areas. It is very important to determine the most suitable variety in any region for increase in yields. Variety selection on the basis of better production could be one of the quickest ways to overcome the existing dry matter deficiency and improve livestock performance in the sector.

Responses of plants to salinity are not the same. Salt tolerance of many agronomic and horticultural crops to a somewhat constant salinity in the root zone, have been determined (Maas and Hoffman, 1977). Salt effects are the combined result of the complex interaction among different morphological, physiological, and biochemical processes (Shannon et al. 1994; Munns 2002; Munns et al. 2006; Munns and Tester 2008; Greenway and Munns 1980; Tester and Davenport 2003). One of the most important prerequisites for improving salt tolerance is the existence of genetic variability in the cultivated species (Shannon 1993). Genetic variation for salt tolerance, as defined by parameters such as survival and yield, has been reported for many crop species, including wheat (Hollington 1998; Steppuhn and Wall 1997; Van Hoorn et al. 1993), barley (Royo and Aragues 1999; Flowers and Hajibagheri 2001; Jaradat et al. 2004), cotton (Gossett et al. 1994) and sorghum (Sunseri et al. 2002; Francois et al. 1984; Maas et al. 1986; Zulfiqar and Asim 2002).

Generally, substantial genotypic differences exist among sorghum cultivars in response to salinity stress (Sunseri et al. 2002; Netondo et al. 2004a, b). The objective of this study was to compare forage sorghum variety performance under saline conditions in the lower part of the Karkhe river basin (Dasht-e-Azadegan, Khuzestan province).to introduce high-yielding varieties of forage sorghum.

## Materials and methods

The experiment was conducted at Dasht-e-Azadegan, Khuzestan province, during spring and summer 2006-2007 for 2 years. The experiment was laid out in a randomized complete blocks design with 3 replications. Treatments were 4 hybrid varieties, namely Speedfeed, Sugargraze, Jumbo, and Nectar, and 4 pure lines, namely $KFS_1$, $KFS_2$, $KFS_3$, and $KFS_4$. Each plot was 6.0 m long and 1.8 m wide and contained 6 rows that were spaced 0.3 m apart. Leaf and stem weight were obtained through destructive sampling on 3 representative plants at harvest time. Plant samples were then dried in the oven at 68ºC for 48 h to estimate dry mass. The same data reported for leaf and stem masses of plant were also used to calculate leaf to stem ratio. Plant height was also recorded on the same plant sample in each variety at each cut. To obtain fresh and dry matter yield, a 2 $m^2$ plot

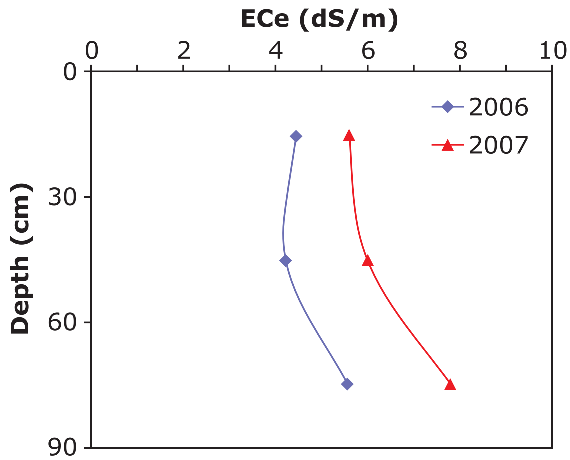

*Fig. 5.1. Means of electrical conductivity of saturated paste extract (ECe) during the growing seasons*

was harvested from the central rows. A sample of 2 kg of fresh matter was further dried in the oven to estimate dry matter yield. For determining of soil salinity, ECe was measured by soil sampling during the growing season. Means of ECe for the two growing seasons are illustrated in Fig. 5.1. All data were analyzed using the SAS statistical package. Means found significant were tested using Duncan's test at the 5% level of probability.

## Results and discussion

### *Fodder yield*

Fresh matter product of sorghum pure lines was found to be significantly different in annual analysis at the 1% level of probability for 2 years (Tables 5.1 and 5.2). $KFS_4$ produced the most fresh matter of 100.67 t/ha in the first year, followed by $KFS_2$ and $KFS_1$, with 92.67 and 86.33 t/ha, respectively, which were not significantly different. A minimum of 66.86 t/ha fresh matter was observed for $KFS_3$ in the first year (Table 5.3). The highest fresh matter obtained from $KFS_4$ could be due to its maximum plant height (Table 5.3). Purushotham and Sidaraju (1998) argued that the tallest plants yield maximum production in sorghum.

In the second year, the maximum fresh matter was measured for $KFS_4$, with 107.72 t/ha again followed by $KFS_2$ (100.15 t/ha) with no significant difference. Finally, the $KFS_3$ and $KFS_1$ lines ordered in the next and last Duncan's group respectively (Table 5.5).

There was no significant effect of year and variety in combined analysis of pure lines, but the interaction effect of year × variety was significant at the 1% level of probability (Table 5.7). The maximum fresh matter yield was obtained for $KFS_4$ with 104.19 t/ha for 2 years, followed by the $KFS_2$, $KFS_1$ and $KFS_3$ lines, respectively with no significant difference (Table 5.8). $KFS_4$ also produced the maximum fodder yield for 2 years and $KFS_2$ was good yielding also, but $KFS_3$ produced acceptable yield for the second year only (Table 5.10).

The fresh matter product of sorghum hybrid varieties was found to be significantly different in annual analysis at the 1% and 5% level of probability in the first and second years respectively (Table 5.1 and 5.2). For hybrid varieties, Speedfeed produced the maximum fresh matter yield of 117 t/ha in the first year and Sugargraze, Nectar, and Jumbo placed in the next and same Duncan's group with 89.33, 81.93 and 70.17 t/ha, respectively (Table 5.4). In the second year, Jumbo produced the highest fodder yield with 130.37 t/ha followed by Speedfeed and Sugargraze, with 124.60 and 120.70 t/ha, respectively, which were not significantly different. The nectar hybrid variety had the lowest fodder yield in the second year (Table 5.6).

There was only a significant effect on year × variety in combined analysis of hybrid varieties (Table 5.7). In comparison to hybrid varieties, Speedfeed, Sugargraze, Jumbo, and Nectar produced 120.80, 105.02, 100.27 and 88.98 t/ha, respectively for 2 years with no significant difference (Table 5.9). However, comparison of means of year × variety showed significant interaction such that Jumbo produced the highest fodder yield in the second year, while producing the lowest in the first year. Sugargraze also had similar behavior to Jumbo. The Nectar hybrid variety was a mediocre yielding variety in the 2 years of the experiment. Accordingly, only Speedfeed was placed in the top Duncan's group rating for 2 years continuously (Table 5.11).

There were no significant differences between the lines group and the hybrids group, if we compare all of the genotypes together with orthogonal coefficients. In this way only Speedfeed would have been significantly different to $KFS_1$ and $KFS_3$ at the 5% level of probability (Table 5.12).

Based on the above, $KFS_4$ and Speedfeed showed highest sustainable fodder yield among the pure lines and hybrid varieties, respectively.

### *Dry matter*

Dry matter production of the pure sorghum lines was found to be significantly different on annual analysis at the 5% and 1% level of probability in the first and second years, respectively (Tables 5.1 and 5.2).

The highest dry matter yield of 23.55 t/ha was measured for $KFS_4$, followed by $KFS_2$ and $KFS_1$, with 22.80 and 20.56 t/ha, respectively in the first year, which were not significantly different. $KFS_3$ produced the least dry matter of 17 t/ha among lines in the first year (Table 5.3).

$KFS_4$ produced the highest dry matter yield of 30.12 t/ha in the second year, again followed by $KFS_3$ (27.68 t/ha) with no significant difference. Dry matter yield of $KFS_2$ (27.39 t/ha) was not significantly different with $KFS_3$, but it was different to $KFS_4$. $KFS_1$ was placed at last through Duncan's group rating, with significant difference (Table 5.5).

Upon combined analysis of the 2 years of the experiment, the effects of year and year × variety was found to be significantly different at the 5% level of probability (Table 5.7). Dry matter production of $KFS_4$, $KFS_3$, and $KFS_2$ in the second year was placed in the top Duncan's group rating in comparison to means of year × variety (Table 5.10). The means of $KFS_4$ and $KFS_2$ in the first year were placed in the next statistical group and $KFS_3$ in first year ordered in the last with 17.03 t/ha (Table 5.10). It is noted

*Table 5.1. Analysis of variances in the first year of the experiment*

| Hybrid/line | SOV | Height | Leaf/stem | DMY/FMY | FMY | DMY |
|---|---|---|---|---|---|---|
| Hybrid | Replication | 43.7$^{ns}$ | 0.009$^{ns}$ | 0.0005$^{ns}$ | 47.51$^{ns}$ | 0.36$^{ns}$ |
| | Variety | 456.0$^{ns}$ | 0.01$^{ns}$ | 0.0003$^{ns}$ | 1187.26$^{**}$ | 74.39$^{**}$ |
| | Error | 185.4 | 0.02 | 0.0008 | 119.25 | 3.48 |
| | % C.V | 9.7 | 12.6 | 11.8 | 12.19 | 8.64 |
| Line | Replication | 572.2$^{*}$ | 0.001$^{ns}$ | 0.0005$^{ns}$ | 926.69$^{*}$ | 43.10$^{*}$ |
| | Variety | 216.3$^{ns}$ | 0.001$^{ns}$ | 0.0005$^{ns}$ | 625.46$^{**}$ | 25.68$^{*}$ |
| | Error | 59.9 | 0.003 | 0.0006 | 59.71 | 3.75 |
| | % CV | 8.3 | 6.1 | 9.6 | 8.92 | 9.23 |

*, **Significant at the 5% and 1% probability levels respectively; ns, not significantly different

*Table 5.2: Analysis of variance in the second year of the experiment*

| Hybrid/line | SOV | Height | Leaf/stem | DMY/FMY | FMY | DMY |
|---|---|---|---|---|---|---|
| Hybrid | Replication | $75.7^{ns}$ | $0.006^{ns}$ | $0.001^{ns}$ | $54.90^{ns}$ | $4.71^{ns}$ |
| | Variety | $635.5^{**}$ | $0.009^{ns}$ | $0.0009^{ns}$ | $687.76^{*}$ | $29.29^{*}$ |
| | Error | 51.8 | 0.003 | 0.0008 | 134.47 | 4.48 |
| | % CV | 5.6 | 4.8 | 10.4 | 9.83 | 6.78 |
| Line | Replication | $136.7^{ns}$ | $0.02^{**}$ | $0.0006^{ns}$ | $110.13^{*}$ | $1.42^{*}$ |
| | Variety | $74.5^{ns}$ | $0.01^{*}$ | $0.0002^{ns}$ | $317.14^{**}$ | $19.88^{**}$ |
| | Error | 76.5 | 0.001 | 0.0001 | 14.43 | 1.64 |
| | % CV | 9.5 | 3.6 | 4.4 | 3.93 | 4.70 |

*, **Significant at the 5% and 1% probability levels respectively; ns, not significantly different

*Table 5.3: Means of pure lines by Duncan's multiple test ($P \leq 0.05$) in the first year*

| Characteristics line | Height (cm) | Leaf/stem | DMY/FMY | FMY (t/ha) | DMY (t/ha) |
|---|---|---|---|---|---|
| $KFS_1$ | $88.7^{a}$ | $0.95^{a}$ | $0.24^{a}$ | $86.33^{a}$ | $20.56^{ab}$ |
| $KFS_2$ | $86.5^{a}$ | $0.93^{a}$ | $0.25^{a}$ | $92.67^{a}$ | $22.80^{a}$ |
| $KFS_3$ | $92.8^{a}$ | $0.93^{a}$ | $0.26^{a}$ | $66.83^{b}$ | $17.03^{b}$ |
| $KFS_4$ | $105.5^{a}$ | $0.90^{a}$ | $0.23^{a}$ | $100.67^{a}$ | $23.55^{a}$ |

*Table 5.4. Means of hybrid varieties by Duncan's multiple test ($P \leq 0.05$) in the first year*

| Characteristics line | Height (cm) | Leaf/stem | DMY/FMY | FMY (t/ha) | DMY (t/ha) |
|---|---|---|---|---|---|
| Speed feed | $157.5^{a}$ | $1.01^{a}$ | $0.24^{a}$ | $117.00^{a}$ | $28.31^{a}$ |
| Sugar graze | $138.9^{a}$ | $1.09^{a}$ | $0.25^{a}$ | $89.33^{b}$ | $22.27^{b}$ |
| Jumbo | $136.4^{a}$ | $1.01^{a}$ | $0.24^{a}$ | $70.17^{b}$ | $17.07^{c}$ |
| Nectar | $128.3^{a}$ | $1.13^{a}$ | $0.23^{a}$ | $81.93^{b}$ | $18.69^{bc}$ |

*Table 5.5. Means of pure-lines by Duncan's multiple test ($P \leq 0.05$) in the second year*

| Characteristics line | Height (cm) | Leaf/stem | DMY/FMY | FMY (t/ha) | DMY (t/ha) |
|---|---|---|---|---|---|
| $KFS_1$ | $85.7^{a}$ | $1.06^{ab}$ | $0.29^{a}$ | $83.20^{c}$ | $23.87^{c}$ |
| $KFS_2$ | $96.3^{a}$ | $1.11^{a}$ | $0.27^{a}$ | $100.15^{ab}$ | $27.39^{b}$ |
| $KFS_3$ | $90.4^{a}$ | $0.99^{b}$ | $0.29^{a}$ | $95.42^{b}$ | $27.68^{ab}$ |
| $KFS_4$ | $95.7^{a}$ | $0.98^{b}$ | $0.28^{a}$ | $107.72^{a}$ | $30.12^{a}$ |

*Table 5.6. Means of hybrid varieties by Duncan's multiple test ($P \leq 0.05$) in the second year*

| Characteristics line | Height (cm) | Leaf/stem | DMY/FMY | FMY (t/ha) | DMY (t/ha) |
|---|---|---|---|---|---|
| Speed feed | $142.2^{a}$ | $1.10^{a}$ | $0.26^{a}$ | $124.60^{a}$ | $32.59^{ab}$ |
| Sugar graze | $117.1^{b}$ | $1.01^{a}$ | $0.25^{a}$ | $120.70^{a}$ | $30.11^{bc}$ |
| Jumbo | $137.0^{a}$ | $1.04^{a}$ | $0.27^{a}$ | $130.37^{a}$ | $34.68^{a}$ |
| Nectar | $112.7^{b}$ | $1.13^{a}$ | $0.29^{a}$ | $96.00^{b}$ | $27.45^{c}$ |

*Table 5.7. Combined analysis of variances for the 2 years of the experiment*

| Hybrid/line | SOV | Height | Leaf/stem | DMY/FMY | FMY | DMY |
|---|---|---|---|---|---|---|
| **Hybrid** | Year | $1018.5^{ns}$ | $0.0009^{ns}$ | $0.004^{ns}$ | $4808.2^{ns}$ | $555.8^{*}$ |
| | Rep × year | $59.7^{ns}$ | $0.007^{ns}$ | $0.0009^{ns}$ | $51.2^{ns}$ | $2.5^{ns}$ |
| | (Ea) | $952.8^{ns}$ | $0.01^{ns}$ | $0.00009^{ns}$ | $1046.0^{ns}$ | $55.5^{ns}$ |
| | Variety | $138.6^{ns}$ | $0.007^{ns}$ | $0.001^{ns}$ | $829.0^{**}$ | $48.1^{**}$ |
| | Year × variety | 118.6 | 0.01 | 0.0008 | 126.9 | 4.0 |
| | Error (Eb) | 8.1 | 9.5 | 11.09 | 10.8 | 7.6 |
| | CV % | | | | | |
| **Line** | Year | $10.5^{ns}$ | $0.07^{ns}$ | $0.008^{ns}$ | $599.5^{ns}$ | $236.6^{*}$ |
| | Rep × year | $354.4^{*}$ | $0.009^{*}$ | $0.0006^{ns}$ | $518.4^{**}$ | $22.3^{**}$ |
| | (Ea) | $191.4^{ns}$ | $0.007^{ns}$ | $0.0004^{ns}$ | $676.2^{ns}$ | $30.1^{ns}$ |
| | Variety | $99.4^{ns}$ | $0.005^{ns}$ | $0.0002^{ns}$ | $266.4^{**}$ | $15.4^{*}$ |
| | Year × variety | 68.2 | 0.002 | 0.0003 | 37.1 | 2.7 |
| | Error (Eb) | 8.9 | 4.9 | 7.2 | 6.6 | 6.8 |
| | CV % | | | | | |

*, **Significant at 5% and 1% probability’ respectively; ns, not significantly different

*Table 5.8. Means of pure lines by Duncan’s multiple test (P ≤ 0.05) based on combined analysis*

| Characteristics line | Height (cm) | Leaf/stem | DMY/FMY | FMY (t/ha) | DMY (t/ha) |
|---|---|---|---|---|---|
| $KFS_1$ | $87.2^{a}$ | $1.00^{a}$ | $0.26^{a}$ | $84.77^{a}$ | $22.21^{a}$ |
| $KFS_2$ | $91.4^{a}$ | $1.02^{a}$ | $0.26^{a}$ | $96.41^{a}$ | $25.09^{a}$ |
| $KFS_3$ | $91.6^{a}$ | $0.96^{a}$ | $0.28^{a}$ | $81.12^{a}$ | $22.35^{a}$ |
| $KFS_4$ | $100.6^{a}$ | $0.94^{a}$ | $0.26^{a}$ | $104.19^{a}$ | $26.83^{a}$ |

*Table 5.9. Means of hybrid varieties by Duncan’s multiple test (P ≤ 0.05) based on combined analysis*

| Characteristics line | Height (cm) | Leaf/stem | DMY/FMY | FMY (t/ha) | DMY (t/ha) |
|---|---|---|---|---|---|
| Speed feed | $149.9^{a}$ | $1.05^{a}$ | $0.25^{a}$ | $120.80^{a}$ | $30.45^{a}$ |
| Sugar graze | $128.0^{a}$ | $1.05^{a}$ | $0.25^{a}$ | $105.02^{a}$ | $26.19^{a}$ |
| Jumbo | $136.7^{a}$ | $1.03^{a}$ | $0.26^{a}$ | $100.27^{a}$ | $25.88^{a}$ |
| Nectar | $120.5^{a}$ | $1.13^{a}$ | $0.26^{a}$ | $88.98^{a}$ | $23.07^{a}$ |

that there was no significant differences among lines in dry matter production based on means of 2 years (Table 5.8).

Dry matter production of the hybrid sorghum varieties was found to be significantly different on annual analysis at the 1% and 5% levels of probability in the first and second years, respectively (Tables 5.1 and 5.2).

Dry matter production of Speedfeed, Sugargraze, and Jumbo hybrid varieties differed significantly from one to another in the first year (Table 5.4). The highest total dry matter of 28.31 t/ha was measured for the Speedfeed variety for the first year. Sugargraze and Nectar were placed in the next Duncan’s group with no significant differences with yields of 22.27 and 18.69 t/ha, in the first year. The minimum dry matter of 17.07 t/ha was measured for the Jumbo variety among hybrid varieties (Table 5.4).

Jumbo produced the highest dry matter of 34.68 t/ha in the second year and Speedfeed produced 32.59 t/ha with no significant differences. Also Sugargraze and Nectar had no statistical differences in the second year (Table 5.6).

There was significant effect of year and year × variety interaction in combined analysis of dry matter of hybrid varieties at the 5% and 1% levels of probability, respectively (Table 5.7). In comparison with means of dry matter of hybrid varieties, Speedfeed produced 30.45 t/ha for 2 years with no significant differences with other varieties (Table 5.9).

In comparison with means of year × variety, Jumbo was placed at the top of Duncan's group in the second year and at the bottom in the first year. The Speedfeed variety had sustainable yield for 2 years among the hybrids (Table 5.11).

Comparison of all the genotypes showed that there were no significant differences between lines and hybrid groups by orthogonal coefficient. In this way, Speedfeed had a significant difference with $KFS_1$ and $KFS_3$ at the 5% level of probability (Table 5.12).

### *Plant height*

The means of plant heights at cut times were considered as plant height annually. The effects of year, variety and year × variety was not significant on plant height of hybrid/lines of sorghum in combined analysis (Table 5.7). There was only a significant effect on plant height of hybrid varieties in the second year based on annual analysis (Table 5.2 and 5.6). The tallest and shortest plant height was measured for Speedfeed and Nectar with 149.9 and 120.5 cm, respectively, with no significant difference for 2 years among hybrid varieties (Table 5.9); values were 100.6 and 87.2 cm for $KFS_4$ and $KFS_1$, respectively among pure lines (Table 5.8). Average plant height of pure lines was 41 cm shorter than hybrid varieties in the 2 years of the experiment.

*Table 5.10. Interaction means of year × variety of fresh and dry matter yield for pure lines by Duncan's multiple test (P ≤ 0.05) based on combined analysis*

| Year | Line | FMY | DMY |
|---|---|---|---|
| 1 | $KFS_1$ | 86.3$^{c}$ | 20.56$^{c}$ |
| | $KFS_2$ | 92.7$^{bc}$ | 22.80$^{bc}$ |
| | $KFS_3$ | 66.8$^{d}$ | 17.03$^{d}$ |
| | $KFS_4$ | 100.7$^{ab}$ | 23.55$^{b}$ |
| 2 | $KFS_1$ | 83.2$^{c}$ | 23.87$^{b}$ |
| | $KFS_2$ | 100.1$^{ab}$ | 27.39$^{a}$ |
| | $KFS_3$ | 95.4$^{b}$ | 27.68$^{a}$ |
| | $KFS_4$ | 107.7$^{a}$ | 30.12$^{a}$ |

*Table 5.11. Interaction means of year × variety of fresh and dry matter yield for hybrid varieties by Duncan's multiple test (P ≤ 0.05) based on combined analysis*

| Year | Hybrid | FMY | DMY |
|---|---|---|---|
| 1 | Speed feed | 117.00$^{a}$ | 28.31$^{c}$ |
| | Sugar graze | 89.33$^{bc}$ | 22.27$^{d}$ |
| | Jumbo | 70.17$^{c}$ | 17.07$^{e}$ |
| | Nectar | 81.93$^{bc}$ | 18.69$^{e}$ |
| 2 | Speed feed | 124.60$^{a}$ | 32.59$^{ab}$ |
| | Sugar graze | 120.70$^{a}$ | 30.11$^{bc}$ |
| | Jumbo | 130.37$^{a}$ | 34.68$^{a}$ |
| | Nectar | 96.00$^{b}$ | 27.45$^{c}$ |

### *Leaf to stem ratio*

There were no significant effects in source of variables of leaf to stem ratio based on combined analysis of hybrid/lines of sorghum (Table 5.7). However, there was a significant effect of leaf to stem ratio of sorghum lines in the second year based on annual analysis (Table 5.2), so that $KFS_2$ had a leaf to stem ratio of 1.11, which was slightly more and significant

*Table 5.12. Contrast comparison with orthogonal coefficient*

| Contrast | df | FMY | | DMY | |
|---|---|---|---|---|---|
| | | Mean Square | Pr>F | Mean Square | Pr>F |
| Speedfeed vs. $KFS_1$ | 1 | 3895.2* | 0.0398 | 203.3* | 0.0399 |
| Speedfeed vs. $KFS_2$ | 1 | 1784.9$^{ns}$ | 0.1318 | 85.9$^{ns}$ | 0.1456 |
| Speedfeed vs. $KFS_3$ | 1 | 4722.3* | 0.0275 | 196.4* | 0.0425 |
| Speedfeed vs. $KFS_4$ | 1 | 827.5$^{ns}$ | 0.2834 | 39.1$^{ns}$ | 0.3056 |
| Speedfeed vs. Sugargraze | 1 | 747.3$^{ns}$ | 0.3061 | 54.4$^{ns}$ | 0.2338 |
| Speedfeed vs. Jumbo | 1 | 1264.8$^{ns}$ | 0.1941 | 62.6$^{ns}$ | 0.2048 |
| Speedfeed vs. Nectar | 1 | 3040.1$^{\dagger}$ | 0.0613 | 163.1$^{\dagger}$ | 0.0586 |
| Hybrids vs. Lines | 1 | 1768.4$^{ns}$ | 0.1333 | 61.9$^{ns}$ | 0.2072 |
| Speedfeed vs. Lines | 1 | 4086.2* | 0.0364 | 191.8* | 0.0443 |
| Sugargraze vs. Lines | 1 | 861.1$^{ns}$ | 0.2747 | 20.4$^{ns}$ | 0.4509 |
| Nectar vs. Lines | 1 | 33.9$^{ns}$ | 0.8209 | 5.3$^{ns}$ | 0.6961 |
| Jumbo vs. Lines | 1 | 358.6$^{ns}$ | 0.4694 | 14.7$^{ns}$ | 0.5195 |
| Speedfeed vs. other hybrids | 1 | 2322.2$^{ns}$ | 0.0927 | 131.2$^{ns}$ | 0.0827 |
| Sugargraze vs. other hybrids | 1 | 12.6$^{ns}$ | 0.8901 | 0.35$^{ns}$ | 0.9200 |
| Jumbo vs. other hybrids | 1 | 97.8$^{ns}$ | 0.7016 | 2.1$^{ns}$ | 0.8028 |
| Nectar vs. other hybrids | 1 | 1751.3$^{ns}$ | 0.1349 | 88.3$^{ns}$ | 0.1408 |
| $KFS_1$ vs. other hybrids | 1 | 376.1$^{ns}$ | 0.4592 | 29.2$^{ns}$ | 0.3717 |
| $KFS_2$ vs. other hybrids | 1 | 183.2$^{ns}$ | 0.6016 | 7.5$^{ns}$ | 0.6426 |
| $KFS_3$ vs. other hybrids | 1 | 881.6$^{ns}$ | 0.2695 | 25.1$^{ns}$ | 0.4058 |
| $KFS_4$ vs. other hybrids | 1 | 1263.8$^{ns}$ | 0.1943 | 58.7$^{ns}$ | 0.2179 |

*Significant at the 5% probability level; ns, not significantly different; †, this comparison was close to significant

than other lines (Table 5.5). Nectar and $KFS_2$ had the highest leaf to stem ratios of 1.13 and 1.02, respectively, for hybrid and pure lines of sorghum varieties based on the means of 2 years (Table 5.8 and 5.9).

***Dry weight to fresh weight ratio***

Dry weight/fresh weight ratio is a measure of water uptake, the ratio being inversely related to water content. There was no significant effect on source of variables of dry/fresh weight ratio in annual and combined analysis of the 2 years (Tables 5.1; 5.2 and 5.7).

## Conclusions

Selection of a variety/line should be based on the highest production both in fresh matter and dry matter yield. Based on the results of this study, $KFS_4$ and $KFS_2$ produced the highest fresh and dry matter yields among lines. For hybrid varieties, Speedfeed showed the highest fresh and dry matter yields.

Comparison of all of the genotypes without considering the genotypic potential (hybrid or pure line) showed that hybrid and pure lines (the means of fresh or dry matter yields) were not significantly different. Therefore, it could be concluded that for the agroecological condition of the area, pure lines could well compete with hybrid varieties of sorghum. $KFS_4$ produced 104.19 and 26.83 t/ha of fresh and dry matter, respectively, which is comparable to those of Sugargraze, Nectar, and Jumbo. Also, since $KFS_2$ is considered to be a salt-tolerant line, it can compete with Jumbo and Nectar hybrids in the agro-climatic conditions of Dasht-e-Azadegan in the Khuzestan province.

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## Benchmark river basins


The CP Water & Food is a research, extension and capacity building program aims at increasing the productivity of water used for agriculture. The CP Water & Food is managed by an 18-member consortium, composed of five CGIAR/Future Harvest Centres, six National Agricultural Research and Extension Systems (NARES) institutions, four Advanced Research Institutes (ARIs) and three international NGOs. The project is implemented at nine river basins (shown above) across the developing world. The Karkheh River Basin (KRB) in western Iran is one of the selected basins. The program's interlocking goals are to allow more food to be produced with the same amount of water that is used in agriculture today, as populations expand over the coming twenty years. And, do this in a way that decreases malnourishment and rural poverty, improves people's health and maintains environmental sustainability.

Improving On-farm Agricultural Water Productivity in the Karkheh River Basin Project (CPWF PN 8)

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