CGIAR Challenge Program on
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ASSESSMENT AND IMPROVEMENT OF WHEAT AND MAIZE WATER PRODUCTIVITIES IN LOWER KARKHEH RIVER BASIN

Editors: M. Moayeri, H. Dehghanisanij, A. F. Nato, H. Siadat, F. Abbasi and T. Oweis

Improving On-Farm Agricultural Water Productivity in the Karkheh River Basin Project (CPWF - PN8)

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Research Report no. 9

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Abbreviations

AREEO	Agricultural Research, Education, and Extension Organization
AERI	Agricultural Engineering Research Institute
CGIAR	Consultative Group on International Agricultural Research
CPWF	Challenge Program of Water and Food
CWP	Crop water productivities
EC	Electrical Conductivity
ET	Evapotranspiration
FAO	Food and Agriculture Organization
ICARDA	International Center for Agricultural Research in the Dry Areas
KRB	Karkheh River Basin
PAW	Productivity of total Applied Water
SASC	Sorkheh Agricultural Center
SCS	Soil Conservation System
SI	Supplemental Irrigation
WANA	West Asia and North Africa
WP	Water Productivity
WUE	Water Use Efficiency

Executive Summary

This report on '*Assessment and Improvement of Wheat and Maize Water Productivity in Lower Karkheh River Basin*' helps researchers and scientists interested in sustainable water development to improve the Water Productivity (WP) of wheat and maize in irrigated lands of the Karkheh dam downstream.

The Karkheh River Basin (KRB) is an important agricultural zone, located in the south-west of Iran where two major agricultural production systems prevail, a rainfed system upstream of the newly built Karkheh dam, and a fully irrigated system downstream of the dam. The quality of the river water is good (electrical conductivity (EC) ranging between 0.9 dS/m and 1.7 dS/m, depending on the different seasons and locations along the river). The area is suitable for a wide range of crops, such as wheat, maize, alfalfa, and off-season vegetable crops. The agricultural water resources of the KRB consist of both surface and groundwater. Given the high potential of agricultural land and the possibility of using high quality water from the dams; the rationalization of these areas could have significant effects on the economy of the region and the country. The average irrigation efficiency (the ratio of amount of water used for evapotranspiration to the amount of water diverted from the reservoir) in the lower KRB is 30% and average WP is 0.5 kg/m^3 – lower than the country averages of 37% and 0.8 kg/m^3 (Keshavarz *et al.,* 2005).

Based on the results of this two-year study, the average irrigation and rain WP, water application efficiency (WAE) and maize crop water productivity (CWP) were 0.38 kg/m^3, 38.6 % and 1.01 kg/m^3, respectively. Several practices were examined to improve maize water productivity. Inside-furrow planting (T_5) had less water losses compared to the common planting and irrigation method (T_1) thus, having a grain yield higher than (T_1). It was also found that by the application of a planting and irrigation management method according to (T_5), it is possible to reduce water consumption by up to 31%. The (T_5) method also caused a significant increase in IWP and CWP compared to (T_1). In the range of moisture stress of this study, by providing 75 percent of the crop water requirement, the predicted IWP will be 1.3 kg/m^3 of water consumed by the plant. Variable alternate furrow irrigation method cannot be recommended due to high irrigation water consumption resulting from water influx from wet furrows into the neighboring dry furrows. Double row planting on 75 cm ridges (T_3) had higher dry matter, grain yield, and IWP compared to the farmers' practice (T_1), but had less IWP than (T_5). According to this study, proper surface irrigation management methods and furrow planting could increase irrigation water productivity (IWP) to values 45% higher than the prevailing farmers' practice i.e. the control treatment. In addition, using drip irrigation increased irrigation water productivity (IWP) by three fold.

The observations in the study indicate that the factors behind low WP include: 1) poor farmer knowledge of irrigation management, 2) bad crop management practices, 3) plant nutrient deficiency, 4) high water and soil salinity, 5) large wetland areas, and 6) poor functioning of drainage systems. However, researchers who conducted the study clarified that by improving research, as well as farm and irrigation management skills, the average irrigation WP for wheat in the studied area would increase from 0.84 kg/m^3 to 1.1 kg/m^3.

The study concludes with recommendations like replacing current corn varieties in the region with high-yielding ones, planting corn seeds at the bottom of the furrows to give a 20% to 30% decrease in the amount of irrigation water consumed, planting at the bottom of the furrows to reduce the amount of irrigation water consumed and to increase irrigation water productivity.

Chapter 1.

Introduction and description of the project site

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1.1 Introduction

Global agriculture in the 21st century faces two major challenges: total food production needs to increase to feed a still-growing world population, and this increase needs to be accomplished under increasing scarcity of water resources. Falkenmark and Rockström (2004) estimated that, to adequately feed 9.3 billion people in 2050, consumptive water use (i.e. transpired water) by all food and fodder crops needs to increase from its present estimated level of 7000 km^3/year to 12,586 km^3/year. However, fresh water resources are increasingly scarce because of increased competition among a multitude of users (Pimentel *et al.*, 2004; Rijsberman, 2006). The challenge to produce more food under increasing water scarcity has led to the notion that crop water productivity (WP) needs to increase (Kijne *et al.*, 2002; 2003).

In West Asia and North Africa (WANA) region, water resources are generally scarce, and agriculture's share of these resources is declining due to competition from the domestic and industrial sectors. In this region, a typical Mediterranean climate prevails, with rain falling mainly during the winter (and a lesser amount during the warmer spring period). This rainy season is followed by a hot, dry summer. Rainfed crop production under this climate thus depends strongly on both the amount and distribution of rain. In the WANA region, the amount of rainfall is low and generally poorly distributed, so periods of soil-water deficiency occur during the grain-filling stage of wheat (*Triticum aestivum* L.) almost every year (Oweis *et al.*, 1992). As a result, crop yield and water use efficiency (WUE) are generally low and variable. The production of 1 kg of wheat grain under fully-irrigated conditions requires between 1and 2 m^3 of irrigation water (Perrier and Salkini 1991); in rainfed areas it requires between 1 and 3 m^3 of rainwater (Cooper *et al*., 1987a; Perrier and Salkini 1991). Since water is the major limiting factor for agriculture in the WANA region, improving WUE is vital for meeting the increasing food demand (Cooper *et al*., 1987b). Supplemental irrigation (SI) is defined as the application of a limited amount of water to rainfed crops when precipitation fails to provide the essential soil moisture for normal plant growth. This practice has shown potential to alleviate the adverse effects of unfavorable rain patterns and thus improve and stabilize crop yields (Perrier and Salkini, 1991; Oweis *et al.*, 1998; Zhang and Oweis, 1999). Early studies by ICARDA showed that applying two or three irrigations (of between 80 mm and 200 mm) to wheat increased grain yield by from 36% to 450%, and produced similar or even higher grain yields than under fully irrigated conditions (Perrier and Salkini, 1991; Oweis, 1994).

In the water-scarce areas of WANA, water, not land, is the most limiting factor to wheat production. Satisfying crop water requirements, although maximizes production from the land unit, does not necessarily maximize the return per unit volume of water applied. Improving WP can contribute to water savings, which can be used to irrigate additional land with higher total production and/or improve the sustainability of the existing water resources. It is assumed that maximum WUE may be achieved at irrigation levels below those that satisfy full crop irrigation requirements.

The concept of efficiency with respect to the use of water resources in agriculture has been somewhat confusing (Oweis *et al*., 1999), although some agricultural specialists continue to use yield per unit area as the indicator of production efficiency. In recent decades, because of increasing limitations of water resources, higher demand for food, and environmental problems, the views of agricultural authorities and scientists have been inclined to increasing yield per unit volume of water used. In this regard, Molden (1997) introduced the concept of WP.

For better understanding of WP, Molden *et al*. (2003) have defined it at different scales – plant, field, project, and water basin – and indicated that high WP at one scale is not necessarily high on another scale. In situations where economic efficiency is considered, the determination of WP becomes more complicated. WP varies from region to region and from field to field and depends on several factors, including planting pattern, cultivar, rotation, climate, irrigation method and management, the land and its characteristics, and tillage practices. The WP increases with increasing crop yield and/or by decreasing the non-beneficial loss of water (such as evaporation and runoff).

For the worldwide CGIAR Challenge Program on Water and Food, in addition to improving WP, social affairs and environmental conditions should also improve.
The challenge of increasing water use efficiency requires development of scientific and technical activities and the establishment of new opportunities such as:

- Development of new genotypes of plants which are drought-tolerant
- Integrated management of water resources in a basin and its environment
- Effeicnt water management in agricultural units.

The WP index is one of the basic factors in determining the efficient use of water for agricultural production. This index indicates the amount of yield per unit of water used per unit area. The meaning of a unit of water used is not always the same. In some cases, it is defined as the unit volume of water evaporated or transpired, while in other cases, it is defined as the unit volume of water conveyed from a water source (e.g. a dam) to the field.The simplest definition of WP is the yield per unit volume of water used. Another definition indicates the income per unit volume of water used. The role of water use in gross value of production or gross domestic product has a different meaning to that in WUE (Heidari *et al.*, 2006).

Iran is located in the northern hemisphere between latitudes 25° and 40° N and longitudes 44° and 63° E, in one of the driest regions of the world. Mean annual precipitation is 252 mm, which is less than one-third of the world's mean (1050 mm). With the high evaporation potential of the country (between 1500 mm/year and 2000 mm/year), nearly 70% of the precipitation evaporates before use (Keshavarz *et al.*, 2005). It is estimated that there are 51 million ha (Mha) of cultivable land in Iran, of which 37 Mha are arable lands. Just 14 Mha are used for agricultural production (Agricultural Statistics, 2004) and of these, only 8.1 Mha are irrigated because of limited water resources. However, of the available 93 billion m^3 of surface and ground water, approximately 84 billion m^3 (93%) is used annually by the agricultural sector (Dehghanisanij *et al*., 2006). The irrigated area of the country has been estimated at 8.1 Mha by the Ministry of Jihad-e-Agriculture (Agricultural Statistics, 2004), and uses nearly 10,375 m^3/ha of water annually. Most of this area is planted to wheat and barley, which account for half of this water in seasonal evaporation and transpiration. The figures indicate a lack of efficient irrigation management. There is no comprehensive information provided for the efficiency of water consumption in Iran, particularly for different basins, and few case studies have been conducted in different regions of the country.

The Karkheh River basin (KRB) is an important agricultural zone, located in southwest Iran. In the KRB, two major agricultural production systems prevail, a rainfed system upstream of the newly built Karkheh dam, and a fully irrigated system downstream of the dam. The river water quality is good (Electrical Conductivity (EC) is between 0.9 dS/m and 1.7 dS/m), although it varies both seasonally and along the river. The area is suitable for a wide range of crops, such as wheat, maize, alfalfa, and off-season vegetable crops. The total area of KRB is 5.2 Mha, of which only 1.07 Mha is irrigable and 0.9 Mha is suitable for dryland farming. Of the total cultivated area, more than 70% is under cereals (wheat and barley). The agricultural water resources of the KRB consist of both surface and groundwater.

1.2 Objectives

In the southern part of the KRB, although the potential for irrigated farming is high and there is a drainage system, the weak irrigation management, salinity of water and soil, large wetlands areas, and improper functioning of drains are considered limiting factors in improving WP. In the northern part of the KRB, which is studied in this research, the farmers have little knowledge of irrigation and agriculture management and there has been inadequate research in this field. Given the high potential of agricultural land and the possibility of using high quality water from the dams, wise use of these areas could have significant effects on the economy of the region and the country.

Average irrigation efficiency (the ratio of amount of water used for evapotranspiration to the amount of water diverted from the reservoir) in the lower KRB is 30% and average WP is 0.5 kg/m^3 – lower than the country averages of 37% and 0.8 kg/m^3 (Keshavarz *et al*., 2005). Different factors cause WP to be low in the region. They include low irrigation efficiency and poor tillage and irrigation management, which have caused salinity and unsustainable agriculture in lower lands of the basin.

Evaluation of irrigation efficiency and WP provide good information on water use status and agricultural products that help in developing suitable management tools to increase WP. This research has been designed to assess the WP of wheat and maize in irrigated lands of the Karkheh Dam downstream and to study the factors affecting WP, improve irrigation efficiency, and develop better agricultural practices that improve WP. The objectives of this project were defined as:

- Determine WP for important crops (maize and wheat) at the site
- Recognize those factors that cause WP to be low at the experimental site
- Study crop yield versusWP relationships for maize and wheat
- Introduce maize and wheat varieties with higher WP
- Improve farmers' knowledge of water issues and irrigation management at the farm level
- Plant representative fields according to known factors, in relation to WUE

and the results of experimental designs from the experimental at the site.

1.3 Description of the lower Karkheh river basin

The Karkheh River ranks third in size after the Karoon and Dez Rivers in Iran, irrigating about 50,000 km^2 with a flow rate of 176 m^3/s. It enters Khuzestan Province (in southwestern Iran) and the research site is in the northwest of the province. Karkheh dam was constructed to provide irrigation water, hydroelectric energy generation, flood control, and environmental needs.

According to climatic conditions and other conditions of exploitation of water and soil resources, the Karkheh Dam downstream is divided into three areas:

- Irrigated lands under Dasht-e Abbas tunnel, including Dasht-e Abbas, Ein Khosh, Fakeh, and Mussian
- Lands of upper Karkheh (upper part of Karkheh Dam downstream), including the Plains of Evan, Dusalgh, Araiez, and Bagheh
- Lands of lower Karkheh (lower part of Karkheh Dam downstream), including the fields of Azadegan Plain, south of Karkheh Noor, Chamran, Hamidieh, Ghods, and Kossar.

The required water for the upper Karkheh lands is supplied via the regulating dam of Paieh Pol, located at 1.5 km upstream of the Karkheh River bridge.

1.3.1 Climate

According to climatic classification, Khouzestan is arid and semi-arid with most of the precipitation falling in the winter and none in the hot months of the summer. The climate is characteristic by long and hot summers and mild and short winters. Most of the time, the temperature is high and rarely drops below zero. But sometimes in the winter the region is affected by the very cold northern currents from the high pressure centers of Siberia and the temperature drops and frost occurs for short periods. The climate system affecting the area consists of tropical sea air currents. This current mostly enters Iran from the west and southwestern parts, sometimes from the Indian Ocean affecting the southeastern parts, and from the coasts of the Oman Sea. It can provide humidity for systems affecting the central and western parts of Iran. Air currents from the polar sea, which affect the research site, have abundant humidity and, after passing over the Mediterranean Sea and South Atlantic Ocean, enter the country from the north and northwestern parts and cause high precipitation in the foothills of the Zagros Mountains. Most of the activities of these air currents are in the winter, but in spring and autumn they also cause showers, thunder, and lightning. Climatic parameters in agricultural studies that affect tillage, calendar, and estimates of required water for agronomic and orchard crops, and the temperature periods required for crops during the growing season include the following elements:

Precipitation

The precipitation of the region (including the research site) results mainly from the low pressure systems of the Mediterranean region and North Africa which pass over Egypt and north of Sudan towards Saudi Arabia. The mean precipitation amount at different fields of the KRB is presented in Table 1.1. Evan field with mean annual precipitation of 300 mm has the lowest precipitation of the fields studies while the south Karkheh Noor lands and the development of Karkheh Noor, with a mean precipitation of 140 mm, has the highest. The mean annual precipitation of the upper, lower, and tunnel of water translocation fields are 235 mm, 266 mm, and 165 mm, respectively.

Temperature
The region has mild winters and hot and dry summers. In the upper parts of KRB, January is the coldest month of the year and July and August are the warmest months. In the lower parts, January is the coldest month of the year and August the warmest. The mean maximum and minimum temperatures for the different plains of KRB are presented in Table 1.2.

Frost
The mean monthly numbers of days of frost in the region are presented in Table 1.3. The number of frost days in the region is small. Frost days are determined from the records of the weather station or stations in proximity of the research site.

Relative humidity
The mean minimum relative humidity for the different plains of KRB are shown in Table 1.4 The relative humidity data have been estimated statistically using information from the synoptic and weather stations of the Iranian Meteorological Organization.

Wind
Measurements of wind velocity and directions are made by synoptic stations of the Iranian Meteorological Organization and the monthly wind speed (at 2 m height) data are shown in Table 1.5.

1.3.2 Drainage requirements of lands in the northern parts of lower KRB (Paieh pol fields)

Paieh pol fields (northern parts of Karkheh Dam command area) include foothill and river alluvial lands. In these plains, soil texture is mainly medium to heavy with mild to medium gradients.
In these land sections, just 10% have serious drainage problems and 12% have moderate drainage problems. The limiting factors in these lands are the low water conductivity of the soil and the limiting layers at different depths. In addition to Evan fields, salinity problems, sodium soils, and unsuitable drainage exist in parts of the Dusalgh, Araiez and Bagheh Plains.
The most important causes of drainage problems in the abovementioned regions are:

- Lack of outlet channels and the shallow slopes of lands in some parts
- Heavy texture soil of river alluvial origin and low percolation capability of soil layers
- Low water conductivity of soils
- Presence of limiting layers (semi-permeable and hard layer) at surface.

The areas needing drainage and the priorities of these drainage needs of Paieh pol (upper Karkheh lands), by fields, are presented in Table 1.6.

Table 1.1. Monthly and annual mean precipitation (mm) in some agricultural plains/regions in lower part of Karkheh Dam (1981–2001).

Plain/ region	Mar-Apr	Apr-May	May-Jun	Jun-Jul	Jul-Aug	Aug-Sep	Sep-Oct	Oct-Nov	Nov-Dec	Dec-Jan	Jan-Feb	Feb-Mar	Annual
Evan	38.5	12.5	0.5	0	0	0.2	5.7	24.6	54.3	63.8	54.2	45.7	300
Dosalag	23.8	7.6	0	0	0	0	8.1	28.6	47.9	60.1	40.2	33.6	250
Arayez	21.4	4.9	0.2	0	0.1	0.1	4.5	24.8	35.8	42	34.1	32.1	200
Abbas	35.4	12	0.3	0	0	0	2.4	17.3	56	56.4	51.8	48.3	280
Dehloran	34	20.9	0.4	0	0	0	3.3	25.3	41.2	53.6	56.4	44.7	280
Mosiyan	33.5	15.8	0.4	0	0	0	2.7	20.5	47.1	53.1	52.1	44.9	270
Kosar	81.1	6.4	0.5	0	0	0	5.9	26.7	45.5	48.7	32.1	31	215
Bageh	23	5	0.3	0	0.1	0.1	3	23.9	33.8	36.1	32.4	32.3	190
Gods	18	6.6	0.9	0	0	0	2.8	16.4	29.5	34.8	28.4	22.6	160
Azadegan	17.9	3.8	0.4	0	0.1	0.1	3.2	20	26.2	29.7	25.3	23.4	150
Ein Khosh	33.5	11.4	0.3	0	0	0	2.3	16.4	53	53.4	49.1	45.7	265
Fakeh	27.3	7.3	0.1	0	0.1	0	6.2	27.8	47.1	54.5	41.7	37.9	250
Zamzam	19.6	7.3	0.9	0	0	0	3.1	17.9	32.3	38.1	31.1	24.8	175
Hamidieh network and Elhaghieh lands	14.1	5.3	0.6	0	0	0	4.2	19.9	30.9	34.7	24.3	20.9	155
Southern lands of Karkheh Noor	16.7	3.5	0.4	0	0.1	0.1	3	18.7	24.4	27.7	23.6	21.8	140
Shahid Chamran lands	15.3	3.8	0.4	0	0	0.1	4	21.1	28.3	34.1	23.6	21.9	150
Lands north of Hofel	19.1	4	0.5	0	0.1	0.1	3.4	21.3	27.9	1.7	27	24.9	160
Development lands of south Karkheh Noor	16.7	3.5	0.4	0	0.1	0.1	3	18.7	24.4	27.7	23.6	21.8	140
North of Hamidieh	19.3	6.9	0.5	0	0	0	4.7	24.3	43.4	46.3	33	31.5	210

Table 1.2. Mean maximum and minimum temperature (°C) in some agricultural plains in lower part of Karkheh Dam (1981–2001).

Plain	**Max/ Min**	**Mar- Apr**	**Apr.- May**	**May- Jun**	**Jun- Jul**	**Jul- Aug**	**Aug- Sep**	**Sep- Oct**	**Oct- Nov**	**Nov- Dec**	**Dec- Jan**	**Jan- Feb**	**Feb- Mar**
Evan	Max	29.1	36.8	43.6	46.4	46.1	42.8	37.1	28.9	22.4	19.2	19.3	23
	Min	14.3	19.8	24.6	27.1	27.7	25.3	20.2	14.8	10.3	8	8	10.1
Dosalag	Max	28.1	35.4	42	45.2	45.2	42.6	36.8	28.8	21.4	17.6	18.6	22.6
	Min	12.4	17.7	21.6	23.9	24.1	21.2	17	12.2	7.6	5.3	5.7	8
Arayez	Max	29	36.1	42	45.1	45.3	42.8	37.3	29.4	21.8	18	19	22.8
	Min	13.5	18.4	21.9	24.2	24.4	21.4	17.3	12.4	8.2	6.1	6.4	9.1
Abbas	Max	28.8	36.5	43.2	46.1	45.8	42.9	37.3	29.6	23.1	19.4	18.8	22.4
	Min	12.4	17	22.2	25.6	26	22.9	18	13.2	9.2	7.4	7.4	9.1
Dehloran	Max	27.6	35.2	41.5	45.2	45.8	42.8	36.4	28.2	21.1	17.3	17.8	20.8
	Min	16	22.4	27.6	30.6	30.8	28.1	23.1	16.8	11.4	8.5	8.5	10.7
Mosiyan	Max	28.2	35.9	42.4	45.7	45.8	42.9	36.8	28.9	22.2	18.3	18.3	21.6
	Min	14.2	19.8	24.9	28.1	28.4	25.5	20.6	15	10.3	8	7.9	9.9
Kosar	Max	29.6	36.5	42.2	45	45.2	42.8	37.4	29.5	33	18.4	19.4	23.5
	Min	14	18.8	22.3	24.6	24.9	22.2	18	13.2	8.8	6.6	7	19.6
Bageh	Max	29.4	35.8	41.3	44.1	44.4	42.3	37.5	30.2	22.8	18.9	19.6	23.6
	Min	13	17.4	21	23.4	23.4	20.6	16.5	11.7	8.2	6	6.3	9
Ghods	Max	29.7	36.1	41.3	43.8	44.2	42.2	37.4	30	22.6	18.9	19.7	23.8
	Min	13.0	17.4	20.6	22.7	22.8	20.3	16.6	12.1	8.6	6.2	6.4	9
Azadegan	Max	28.8	34.8	40.3	43	43.3	41.7	37.1	29.3	21.7	17.9	19.1	23.4
	Min	13.6	18	21.2	23.2	23.1	20.4	16.6	11.7	8.2	5.9	6.5	9.5

Table 1.3. Monthly and annual mean number of frost days in some agricultural regions in lower KRB (1981–2001).

Region	Jan	Feb	Mar	Apr-Oct	Nov	Dec	Annual
Ahvaz	0.8	0.2	0.0	0.0	0.0	0.3	1.3
Bostan	2.1	1.9	0.0	0.0	0.3	0.7	5.0
Dezful	2.4	0.9	0.3	0.0	0.0	0.8	4.4
Safi Abad	1.0	0.7	0.0	0.0	0.0	0.2	1.9
Dehloran	0.1	0.5	0.0	0.0	0.0	0.0	0.6
Mollasani	2.0	1.3	0.0	0.0	1.0	1.0	5.0
Karoon agro-industry	2.0	2.0	0.0	0.0	0.0	1.0	5.0
Sardasht	1.0	0.0	0.0	0.0	0.0	0.0	1.0
Mazoo	1.0	0.0	0.0	0.0	0.0	0.0	1.0
Shushtar	1.0	1.0	0.0	0.0	0.0	1.0	3.0
Haft Tapeh	2.0	1.0	0.0	0.0	0.0	1.0	4.0
Azadegan	5.0	1.0	0.0	0.0	1.0	2.0	9.0
Andimeshk	1.0	0.0	0.0	0.0	0.0	1.0	2.0
Water and electricity organization of Dezful	1.0	0.0	0.0	0.0	0.0	1.0	2.0
Hamidiyeh	0.0	0.0	0.0	0.0	0.0	1.0	1.0
Hoveyzeh	2.0	1.0	0.0	0.0	0.0	1.0	4.0
Galeh no Askar	3.0	1.0	0.0	0.0	0.0	2.0	6.0
Ben Sydan	3.0	1.0	0.0	0.0	0.0	1.0	5.0
Shamoon	2.0	1.0	0.0	0.0	0.0	1.0	4.0
Shush	2.0	1.0	0.0	0.0	0.0	1.0	5.0

Table 1.4. Mean minimum relative humidity (%) in some agricultural plains/regions in lower part of Karkheh Dam (1981–2001).

Plain/region	Mar-April	Apr-May	May-Jun	Jun-Jul	Jul-Aug	Aug-Sep	Sep-Oct	Oct-Nov	Nov-Dec	Dec-Jan	Jan-Feb	Feb-Mar	Annual
Evan	59.9	39.2	32.9	34.1	36.6	40.1	3.49	59.8	69.9	73.3	71.8	65.8	59.9
Dosalag	34	27	17	17	19.5	20.5	28	40.9	56	60	52.5	43	34
Arayez	38.8	30.8	31.3	30.3	34.9	29.9	34.4	44.8	58.9	61.8	52.5	46.3	38.8
Abbas	70.9	45.2	48.4	53.9	51.7	50	55.6	69	74.5	77.1	78.6	77.4	62.7
Dehloran	26	19	15	13	12	13	22	34	48	50	40	38	25.1
Mosiyan	48.5	32.1	31.7	33.4	31.9	31.5	38.8	51.5	61.3	63.6	59.3	57.7	48.5
Kosar	31.3	25.3	15.9	20.3	27.7	24.7	30.5	39.7	55.2	60.5	51.1	41.2	31.3
Bageh	41.6	29.8	36.9	35.5	40.9	32.9	36.6	46.1	59.9	62.3	52.8	48.4	41.6
Gods	35	27	23	25	26.5	29	33	43	58	61	52.5	42	35
Azadegan	29.5	22.5	20	20.5	22	24	28.5	38.5	53.5	56.5	44.5	37.5	29.5
Ein Khosh	70.9	45.2	48.4	53.9	51.7	50	55.6	69	74.5	77.1	78.6	77.4	62.7
Fakeh	41.7	29.6	25.1	26.5	27.2	27.3	33.4	46.3	59.4	62.5	55.7	49.8	41.7
Zamzam	35	27	23	25	26.5	29	33	43	58	61	52.5	42	32
Hamidieh	42	37.3	27.8	24.8	44	37	46	56	83	92.5	76.8	60.5	42
Southern lands of Karkheh Noor	36	29	23	23	23	22	30	43	61	63	55	42	37.5
Shahid Chamran lands	28.7	23.9	18.6	18.3	26	25	30.8	38.7	54.8	59.8	49.4	37.8	28.7
Lands north of Hofel	32	25.3	21.3	20.9	27	25	29.2	39	86.2	60.2	49.8	41.5	32
Development lands of south Karkheh Noor	36	29	23	23	23	22	30	43	61	63	55	42	37.5
Haghabeh Baran north of Hamidieh	37.3	29.1	28.9	28.4	36.7	30.4	35.7	44.1	58.6	63.3	54.9	46.1	37.3

Table 1.5. Mean value of wind velocity (m/sec) at 2 m height in some agricultural plains/regions in lower part of Karkheh Dam (1981–2001).

Plain/region	**Mar-Apr**	**Apr-May**	**May-Jun**	**Jun-Jul**	**Jul-Aug**	**Aug-Sep**	**Sep-Oct**	**Oct-Nov**	**Nov-Dec**	**Dec-Jan**	**Jan-Feb**	**Feb-Mar**
Evan	1.3	1.6	1.6	1.5	1.3	1.1	0.9	0.8	0.7	0.8	0.9	1.1
Dosalag	1	1.1	1.2	1.1	0.9	0.7	0.6	0.5	0.5	0.5	0.6	0.8
Arayez	1.9	2	2.1	2.1	2	1.6	1.3	1.3	1.3	1.2	1.3	1.7
Abbas	1.5	1.8	1.8	1.7	1.5	1.3	1.1	0.9	0.9	1	1.1	1.3
Dehloran	1.9	2.1	2.2	2	1.8	1.6	1.4	1.4	1.3	1.3	1.5	1.6
Mosiyan	1.9	1	2.2	2	1.8	1.6	1.4	1.4	1.3	1.3	1.5	1.6
Kosar	2.1	2.23	2.7	2.6	2.3	1.9	1.6	1.4	1.4	1.5	1.6	1.9
Bageh	2.7	2.8	3.1	3.1	3	2.4	2	2.1	2.1	2	2.1	2.5
Gods	2.4	2.6	2.9	2.9	2.7	2.2	1.8	1.8	1.7	1.7	1.8	2.2
Azadegan	2.4	2.6	2.9	2.9	2.7	2.2	1.8	1.8	1.7	1.7	1.8	2.2
Ein Khosh	1.4	1.6	1.7	1.6	1.4	1.2	1	0.9	0.8	0.9	1.1	1.2
Fakeh	1.9	2	2.1	2.1	2	1.6	1.3	1.3	1.3	1.2	1.3	1.7
Zamzam	2.4	2.6	2.9	2.9	2.7	2.2	1.8	1.8	1.7	1.7	1.8	2.2
Hamidieh network and Elhaghieh lands	2.1	2.3	2.7	2.6	2.3	1.9	1.6	1.4	1.4	1.5	1.6	1.9
Southern lands of Karkheh Noor	2.7	2.8	3.1	3.1	3	2.4	2	2.1	2.1	2	2.1	2.5
Shahid Chamran lands	2.1	2.3	2.7	2.6	2.3	1.9	1.6	1.4	1.4	1.5	1.6	1.9
Lands north of Hofel ds	2.7	2.8	3.1	3.1	3	2.4	2	2.1	2.1	2	2.1	2.5
Development lands of south Karkheh Noor	2.4	2.6	2.9	2.9	2.7	2.2	1.8	1.8	1.7	1.7	1.8	2.2
Haghabeh Baran north of Hamidieh	2.1	2.3	2.7	2.6	2.3	1.9	1.6	1.4	1.4	1.5	1.6	1.9

Table 1.6. Areas needing drainage and their priorities in the upper Karkheh lands.

Plain	Evan		Dosalag		Arayez		Bageh		Total	
Drainage needs	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**
First priority (very high)			2,520	14	2,700	10	1,340	19	6,560	10.1
Second priority (high)			3,960	22	3,240	12	987	14	8,187	12.6
Third priority (medium)			1,800	10	9,450	35	423	6	11,673	18
Fourth priority (low)			5,580	31	9720	36	4,300	61	19,600	30
Without drainage needs	13,100	100	4,140	23	1,890	7			19,130	29.3
Total	13,100	100	18,000	100	27,000	100	7,050	100	651,50	100

1.3.3 A glance at present agriculture

The upper fields of KRB, consisting of Evan fields, Dusalgh, Araiez, Bagheh, and the irrigated lands of the translocation tunnel of Karkheh (consisting of Dasht-e Abbas, Dehloran, Mussian, Ein Khosh and Fakkeh), with their surface and groundwater sources make it possible to cultivate irrigated cereals, vegetables, cucurbits, and orchards over a large part of the land and support dry farming of cereals on other parts of the land.

The cultivation practices for different crops have been adopted by native farmers from other parts of Iran, particularly Isfahan and Yazd. Other farmers, taking advantage of the suitable climatic conditions of the region and the available water sources, cultivate leafy vegetables and cucurbits on the irrigated lands. In some parts of the plains, which have no shortage of summer irrigation water, summer crops, including corn, leafy vegetables, cucurbits, and others are grown.

1.3.4 Cropping patterns

The combination of cropping lands is directly related to the potential of each region – in terms of the quality and quantity of water and soil sources, the economic profitability of the crops, the climatic conditions of the region, the growing season, and factors such as machinery and distance from markets. In this area, wheat and barley are the main crops. These crops are planted depending on the availability of the water resources to meet family food needs and for livestock forage. Other crops grown here include vegetables, cucurbits, Sudan grass, sugar beet, rice, maize, sesame, bean, mug bean, canola, and clover. Also there are palm trees and citrus orchards. These crops are planted in the different parts of the area based on the water and soil resources and the farmers' preferences.

Table 1.7 shows the combination of cropping lands in upper fields of KRB and Table 1.8 shows cropping combination in Evan Plain. Of the total 55,613 ha of arable land, 25,682 ha (46.2%) are irrigated and the remaining 29,931 ha (53.8%) are dry lands.

Most of the irrigated farms are planted to wheat – about 20,436 ha (79.6%). Of the 29,931 ha of dry farming lands in the region, nearly14,588 ha (48.7%) are planted to dryland wheat and nearly 4,233 ha (14.2%) are planted to dryland barley. Of the 8,050 ha of land which could be cultivated in the summer, 3,909 ha are planted to corn. Table 1.9 shows the mean amounts of the agricultural products in the upper fields of KRB.

1.3.5 Reference evapotranspiration

For the climatic condition of the region, reference evapotranspiration (ET) values were calculated using the Penman–Monteith method. The related data are presented in Table 1.10 for the different fields of KRB. The highest evaporation and transpiration amount, 2,127.2 mm, is associated with the north lands of Hofel and lowest, 1,594.4 mm, is associated with Evan field. The mean

Table 1.7. A cropping pattern of the arable lands in the northern fields of Karkheh Dam command area

Planting type	Crops	Area (ha)				Total area (ha)	Percent of total land
		Irrigated farming		Dryland farming			
		Area	%	Area	%		
Main crop	Wheat	20,436	79.6	14,588	48.7	35,024	63
	Barley	1,173	4.6	4,233	14.2	5,406	7.9
	Plasticulture of cucurbits	1,180	4.6			1,180	2.1
	Plasticulture of vegetables	466	1.8			466	0.8
	Onions	400	1.5			400	0.7
	Plasticulture of tomato	489	1.9			489	0.9
	Canola	154	0.6			154	0.3
	Other vegetables	813	3.2			813	1.5
	Sugar beet	552	2.1			552	1
	Orchards	19	0.1			19	0.1
	Fallow	-	-	11,110	37.1	11,110	20
Total area of crop lands		**25,682**	**100**	**29,931**	**100**	**55,613**	**100**
Second crop	Summer cucurbits and vegetables	2,099	8.2			2099	3.8
	Summer maize	3,909	15.2			3,909	7
	Rice	930	3.6			930	1.7
	Sudan grass	30	0.1			30	0.1
	Other summer crops	1,082	4.2			1,082	1.9
Total second cropping		**8,050**	**31.3**			**8,050**	**14.5**
Total density		**33,732**	**131.3**	**18,821**	**62.9**	**52,553**	**94.5**

amount of evaporation and transpiration in the upper lands of Karkheh water is 1,792 mm, in the lower lands it is 1,738 mm, and for the irrigated lands of the translocation tunnel it is 2,012 mm.

1.3.6 Crop water requirement

Among other factors, planting patterns are affected by the water requirements of different crops. Crops with different characteristics, like growing season and planting date, have different water requirements. Crops planted in spring and summer, when the rate of evapotranspiration is high; require more water for vital processes in order to produce an optimum yield. In contrast, plants cultivated in the autumn and winter have lower water requirements. The water requirements of field and orchard crops for the northern fields of lower KRB are estimated and presented in Table 1.11.

Table 1.8. Cropping combination of the arable lands in Evan fields.

Planting type	Crops	Area (ha)				Total area (ha)	Percent of total land
		Irrigated farming		Dryland farming			
		Area	%	Area	%		
Main crop	Wheat	10,220	84.7	1,238	60.2	11,458	81.2
	Barley	35	0.3	57	2.8	92	0.7
	Plasticulture of cucurbits	42	0.3			42	0.3
	Plasticulture of vegetables	190	1.6			190	1.3
	Onions	400	3.3			400	2.8
	Plasticulture of tomato	85	0.7			85	0.6
	Canola	154	1.3			154	1.1
	Other vegetables	371	3.1			371	2.6
	Sugar beet	552	4.6			552	3.9
	Orchards			760	37	760	5.4
	Fallow	13	0.1			13	0.1
Total area of crop lands		**12,062**	**100**	**2,055**	**100**	**14,117**	**100**
Second crop	Summer cucurbits and vegetables	695	5.8			695	4.9
	Summer maize	3309	27.4			3309	23.4
	Other summer crops	84	0.7			84	0.6
Total second cropping		**4,088**	**33.9**			**4,088**	**28.9**
Total density		**16,150**	**133.9**	**1,295**	**63**	**17,455**	**123.5**

Table 1.9. Mean yield of crops grown in the northern parts of lower KRB.

Crop	Yield of major crops (t/ha)
Irrigated wheat	3
Irrigated barley	2.5
Dryland wheat	0.7
Dryland barley	0.6
Off-season plasticulture melon	15
Off-season plasticulture watermelon	22
Onions	20
Plasticulture tomato	20
Canola	1.2
Vegetables (lettuce)	22
Sugar beet	40
Summer melon and watermelon	20
Summer cucumber	16
Summer corn	5
Summer sesame	0.7
Summer bean	1.4
Rice	3
Sudan grass	45
Citrus	7
Dates	3
Plasticulture cucumber	14

Table 1.10. Mean monthly value of reference evapotranspiration (ETo in mm) in different agricultural plains/regions of the lower part of Karkheh dam computed using the Penman-Monteith method (FAO Irrigation and Drainage Paper. No. 56, 1998).

Plain/ region	Mar-Apr	Apr-May	May-Jun	Jun-Jul	Jul-Aug	Aug-Sep	Sep-Oct	Oct-Nov	Nov-Dec	Dec-Jan	Jan-Feb	Feb-Mar	Annual
Evan	124.2	186.0	233.8	242.2	233.1	180.9	121.7	72.2	43.9	39.1	50.4	76.9	1594.4
Dosalag	129.9	185.3	238.0	262.4	250.2	201.7	132.1	103.1	63.5	44.7	53.9	81.2	1746.0
Arayez	141.2	198.6	249.4	267.6	252.8	202.2	136.4	90.9	57.2	46.1	58.6	88.8	1790.5
Abbas	123.4	184.4	233.8	246.8	230.0	188.0	125.1	76.0	48.3	42.5	50.8	85.8	164.9
Dehloran	146.4	214.2	265.6	273.3	253.0	212.9	145.3	95.1	58.6	48.7	62.5	87.7	1863.3
Mosiyan	137.9	202.6	256.1	267.7	250.4	210.2	141.5	90.5	56.6	47.0	59.1	83.4	1804.0
Kosar	154.4	217.2	287.7	294.5	270.5	222.8	152.1	97.1	60.5	50.8	65.8	98.0	1971.4
Bageh	157.7	217.7	273.9	295.1	283.2	234.1	162.6	112.3	71.8	57.3	69.0	102.3	2037.0
Gods	161.6	220.9	279.7	297.8	279.8	228.3	158.3	107.2	67.0	54.6	68.9	103.9	2028.0
Azadegan	153.9	211.1	271.3	291.7	276.6	228.7	158.6	105.8	64.6	51.9	66.5	100.9	1981.6
Ein Khosh	123.0	181.1	230.2	243.6	226.8	184.9	122.9	76.2	47.9	42.4	51.6	75.7	1606.3
Fakeh	137.3	196.5	251.7	271.8	256.3	204.1	135.6	90.1	57.2	46.0	57.4	86.6	1790.5
Zamzam	161.6	220.9	279.7	297.8	279.8	228.3	158.3	107.2	67.0	54.6	68.9	103.9	2028.0
Hamidieh network and Elhaghieh lands	159.6	223.3	285.1	300.4	274.8	226.5	155.7	99.9	62.5	42.6	68.5	101.6	2010.5
Southern lands of Karkheh Noor	159.9	217.0	280.7	308.6	295.1	243.6	167.9	112.8	69.2	54.0	68.8	105.1	2082.7
Shahid Chamran lands	154.0	215.3	278.0	295.6	272.3	225.9	155.1	98.6	60.6	50.7	66.6	99.3	1972.0
Lands north of Hofel	165.1	227.3	288.2	312.2	298.1	243.1	168.0	116.1	73.1	57.6	71.7	106.7	2127.2
Development lands of south Karkheh Noor	155.0	211.6	273.8	297.4	281.2	232.7	160.0	104.7	63.4	50.7	66.1	101.1	1997.7
Haghabeh Baran north of Hamidieh	150.4	212.4	271.4	286.3	263.3	218.1	149.3	95.5	60.1	50.3	64.2	95.5	1916.8

Table 1.11. Average monthly net irrigation water required (mm) by field and orchard crops in the northern parts of lower KRB.

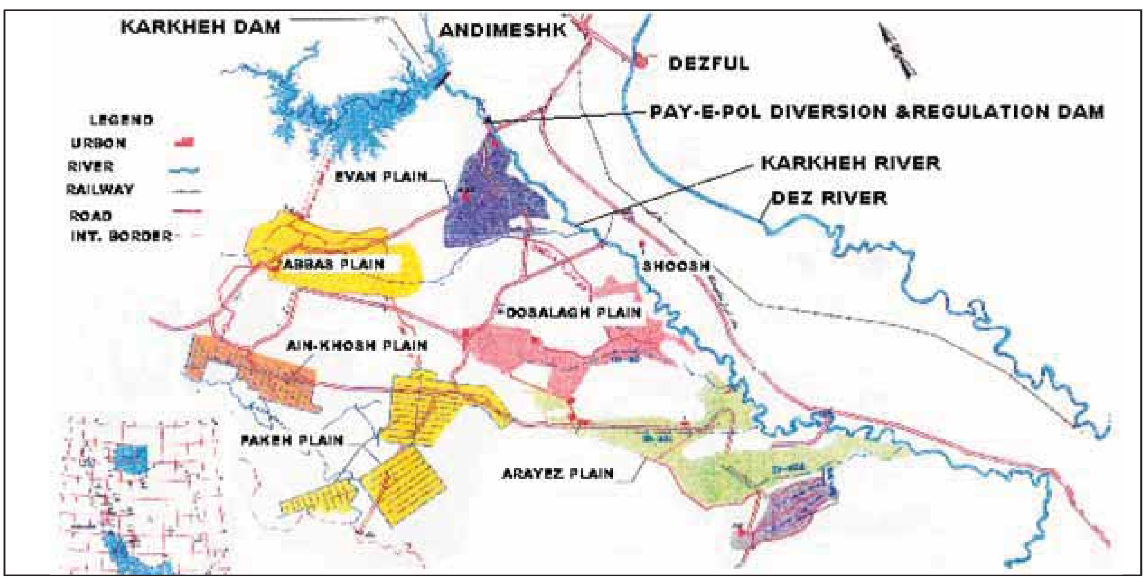
Crop	Mar-Apr	Apr-May	May-Jun	Jun-Jul	Jul-Aug	Aug-Sep	Sep-Oct	Oct-Nov	Nov-Dec	Dec-Jan	Jan-Feb	Feb-Mar	Total
Wheat	870	0	0	0	0	0	0	0	530	50	370	740	2,560
Grain barley	290	0	0	0	0	0	0	0	530	80	390	670	1,960
Corn	0	0	0	800	1,280	2,070	1,370	310	0	0	0	0	5,830
Broad bean	380	0	0	0	0	0	0	600	70	160	410	650	2,270
Bean	0	0	0	800	1,310	2,110	1,070	20	0	0	0	0	5,310
Plasticulture cucumber	1,100	1450	0	0	0	0	0	0	0	500	0	400	3,450
Plasticulture tomato	1,350	1,800	730	0	0	0	0	0	0	500	0	590	4,970
Plastic culture watermelon	1,160	1,670	780	0	0	0	0	0	0	500	0	480	4,590
Onions	980	0	0	0	0	0	730	300	240	200	360	620	3,430
Vegetables (carrots)	0	0	0	0	0	0	0	790	250	220	330	180	1,770
Alfalfa	910	1,750	2,310	2,550	2,110	1,740	1,140	640	280	160	260	530	14,380
Sudan grass	0	0	1,250	2,190	1,720	1,460	240	0	0	0	0	0	6,860
Forage barley	50	0	0	0	0	0	0	580	70	130	260	510	1,600
Sugar beet	600	0	0	0	0	0	730	300	250	230	410	690	3,210
Canola	170	0	0	0	0	0	0	740	150	200	410	550	2,220
Plasticulture eggplant	1,190	1,860	2,020	0	0	0	0	0	0	0	610	470	6,150
Cucumber	0	0	0	0	1,440	1,600	1,190	360	0	0	0	0	4,590
Rice	0	0	931	5,557	3,906	3,384	1,887	0	0	0	0	0	15,665
Citrus	990	1,590	2,040	2,190	2,060	1,660	1,090	640	280	170	310	540	13,560

1.4 Site description

In the north, around Dezful, is a second large plain with irrigated agriculture and soils that are less affected by salinity than in the southern alluvial plain. The Sorkheh extension area, located in Evan Plain, is just inside the area of the KRB and offers a benchmark site that is representative of these conditions (Map 1.1). The remainder of this agricultural region is much less attractive from agricultural perspective. Low-quality rangelands cover about 52% of the region. Severely eroded and gullied sediments and rocks occupy about 23% of the region, and another 17% is covered with sand dunes.

The study was conducted in Sorkheh Plain, a representative irrigated area of the lower KRB. Sorkheh is located in eastern KRB, west of Khozestan Province and downstream of the Karkheh Dam. The region has a semi-arid climate (De Martonne classification). The temperature in this region ranges between 6.7° C and 45.6° C and the humidity between 27.4% and 74.5%. The rainy season usually starts in October and continues till the middle of May with an average annual rainfall of about 330 mm.

The annual potential evaporation in this region is about 2400 mm, ranging between 50 mm/month during December and January and 400 mm/month during June and July. The Sorkheh agricultural area is about 10,000 ha, of which about 4,100 ha is under surface canal irrigation network, 5,800 ha has groundwater well water resources, and 460 ha is irrigated by pumping surface water (rivers). In total, there are 196 wells in this area and 29 pumps for pumping water from rivers. Winter wheat-maize is the main cropping system in this region. Wheat is grown from mid-November to mid-May. The rainfall does not fully meet the needs of wheat for its normal growth, especially during the dry, windy spring season.



Map 1.1 Location of the Evan, other plains, and the nearest cities with respect to Karkheh River and Dam

Therefore, three to four irrigations are needed to maintain high yields. Maize is grown from late July to late October, when the rainfall is almost zero, and is totally dependent on irrigation.

Evan Plain does not have limiting semi-permeable layers or deep drainage problems. Only a limited part of the fields (2,600 ha) have fine textured soils that could have a drainage system. A drainage system is not needed for the agricultural areas of Evan Plain.

Cropping combinations of the arable lands of Evan fields are presented in Table 1.12. Of the 14,117 ha of arable land, 12,062 ha (85.4%) are irrigated while the rest, nearly 2,055 ha (14.6%), are dry lands. Most of the irrigated farms are planted to wheat (11,485 ha) and maize (3,309 ha). The net amounts of water required for field and orchard crops in Evan Plain are presented in Table 1.13.

Table 1.12. Cropping combination of arable lands in Evan fields.

Type of crops	Crops	Area (ha)				Total Area (ha)	Percent of total land
		Irrigated farming		Dryland farming			
		Area	%	Area	%		
Main crop	Wheat	10,220	84.7	1,238	60.2	11,458	81.2
	Barley	35	0.3	57	2.8	92	0.7
	Plasticulture of cucurbits	42	0.3			42	0.3
	Plasticulture of vegetables	190	1.6			190	1.3
	Onions	400	3.3			400	2.8
	Plasticulture of tomato	85	0.7			85	0.6
	Canola	154	1.3			154	1.1
	Other vegetables	371	3.1			371	2.6
	Sugar beet	552	4.6			552	3.9
	Orchards	-	-	760	37	760	5.4
	Fallow	13	0.1			13	0.1
Total area of main crop land		**12,062**	**100**	**2,055**	**100**	**14,117**	**100**
Second crop	Summer cucurbits and vegetables	695	5.8			695	4.9
	Summer maize	3,309	27.4			3,309	23.4
	Other summer crops	84	0.7			84	0.6
Total second cropping		**4,088**	**33.9**			**4,088**	**28.9**
Total density		**16,150**	**133.9**	**1,295**	**63**	**17,455**	**123.5**

Table 1.13. Average monthly net water required (m^3/ha) by field and orchard crops in Evan Plain.

Crop	Mar-Apr	Apr-May	May-Jun	Jun-Jul	Jul-Aug	Aug-Sep	Sep-Oct	Oct-Nov	Nov-Dec	Dec-Jan	Jan-Feb	Feb-Mar	Total
Wheat	730	0	0	0	0	0	0	590	0	0	220	610	2,150
Grain barley	330	0	0	0	0	0	0	590	0	0	260	550	1,730
Corn	0	0	0	790	1,880	1,880	1,260	240	0	0	0	0	5,350
Broad bean	350	0	0	0	0	0	0	590	0	0	260	550	1,750
Bean	0	0	0	790	1200	1920	990	10	0	0	0	0	4,910
Plastic culture cucumber	950	1,370	0	0	0	0	0	0	0	500	0	190	3,010
Plastic culture tomato	1,150	1,680	700	0	0	0	0	0	0	500	0	330	4,360
Plastic culture watermelon	1,000	1,570	740	0	0	0	0	0	0	500	0	250	4,060
Vegetables (carrots)	0	0	0	0	0	0	0	750	130	130	230	140	1,380
Alfalfa	790	1640	2,170	2,330	1,850	1,540	1,030	470	140	70	150	420	12,600
Sudan grass	0	0	1,270	2,060	1,610	1,360	220	0	0	0	0	0	6,520
Sugar beet	510	0	0	0	0	0	730	240	120	140	310	570	2,620
Canola	350	0	0	0	0	0	0	630	30	80	300	550	1,940
Cucumber	0	0	0	0	1,390	1,480	1,100	280	0	0	0	0	4,250
Citrus	870	1,520	1,990	2,060	1,900	1,540	1,010	500	150	90	220	450	12,300
Citrus	679	1,186	1,552	1,607	1,482	1,201	788	390	117	70	172	351	9,594
Onions	840	0	0	0	0	0	730	240	120	120	260	510	2,820
Forage barley	50	0	0	0	0	0	0	560	0	0	140	420	1,170
Plastic culture eggplant	1,030	1,750	1,950	0	0	0	0	0	0	0	550	380	5,660

1.4.1 General observations on the living conditions of farmers inhabiting Evan Plain (Sorkheh region)

Sorkheh Plain is located on the west side of Karkheh River. Its northeastern part is adjacent to Andimeshk and the northwestern part is adjacent to Ilam Province (Dasht-e Abbas region of Dehloran city). Cities near Sorkheh include Shush, Andimeshk, and Dezful. From the Sorkheh Agricultural Service Center (SASC) it is 30 km to Shush, 38 km to Andimeshk, and 48 km to Dezful. This region is a part of Shush city. Inhabitants of this region are mostly Iranian Arabs and a minority is Lors.

1.4.2 Characteristics of the villages of Evan Plain

Villages under the supervision of SASC include Fathe, Salare Shahidan, Mohajerin, Ghods, Shahid Fallahi, Esteghlal, and Meskin. Some information on the social facilities and populations of these villages is listed in Table 1.14.

1.4.3 Cooperatives and other establishments

The SASC is located at Fathe village. Farmers of other villages have easy access to the service center. The distance from the SASC to Karkheh bridge is 15 km. The irrigation and drainage network of Evan field was established in 1999. Farmers of the region have shares in the Danesh rural district cooperative. Its office and store are also located at Fathe village. Corn drying facilities, seed cleaners, 2500 tonne and 5000 tonne storage, 60 tonne scales, and open shopping centers on the west side of Karkheh are under the supervision of the Danesh rural district cooperative and are located opposite Ghods village past the Karkheh bridge. The office of the rural district is located at Fathe village. The production cooperative of Dasht-e Narges in Sorkheh region consists of farmers of Fathe village. This cooperative was registered in 1997 in order to improve the agricultural situation of the farmers. Area and ownership status of lands under the supervision of the Agricultural Jihad service center and Dasht-e Narges cooperative are presented in Table 1.15.

1.4.4 Condition of the land

The condition of the land of Evan Plain, from the stand point of soil texture and topography, is not the same. Soil texture in this region is from semi-heavy to light and sandy. Land in some places takes the form of rising ground, which has been leveled in some parts. The condition of the land is presented by village. In Table 1.16 the number of farmers, type of land tenure, and the land area are presented by village.

Ghods village
The soil texture of the land of this village is sandy and sandy clay; in some parts there is a small percentage of stone. Most of the land in this region has been leveled and it is located at the beginning of the irrigation network of Evan Plain.

Mohajerin village
The land of this village has an optimum situation and is worked by pioneer farmers. The soil texture is semi-light to semi-heavy. Most of the land has been leveled. All of this land is irrigated by the Evan network and only a small part is watered from wells, since lateral irrigation canals have not been constructed yet. Parts of land in this village are on the riverside with a light and sandy textured alluvial soil.

Salare Shahidan village
Salare Shahidan village with its vast and scattered lands has many different soil textures and topographies and is divided into several categories. This village is located between Mohajerin and Fathe

villages. The soil texture of some parts of the village is semi-heavy and leveled. Parts of land of this village, which are located on both sides of Fakeh road, have a sandy, semi-heavy soil texture. It is steep ground surface that should be leveled. One-third of the land is located at Karkheh riverside. It has light alluvial soils. The land is irrigated from water wells and the irrigation network of Evan field.

Shahid Fallahi and Esteghlal
The land characteristics of Shahid Fallahi and Esteghlal are similar. The soils are light. The ground surface is steep and has a fairly uniform topography. Some of the farmers have leveled their lands. These lands are watered from water wells and Esteghlal village has some lands on the Karkheh riverside, which are irrigated from the Karkheh River. These regions require basic operations like leveling, canal covering, etc.

Fathe village
This village is located at the center of the region and the service center is located in this village. The land of this village is located between those of Salare Shahidan and Esteghlal villages. Land located around Fathe village has better condition than the rest. Some parts of the land, which are adjacent to that of Salare Shahidan village, have a topography that requires investment and basic operations. Water is provided from water wells and an irrigation network and some lands, which are located at Karkheh riverside, are irrigated from river by gravity.

1.4.5 Provision of irrigation water

The presence of the Karkheh River and Kheng seasonal river, which passes through Shahid Fallahi village and finally joins Karkheh River, have caused flourishing conditions in the region. With the completion of the Dasht-e Evan irrigation network, all of the lands that are graded and shaped will go under irrigation. The provision of agricultural water sources and area are presented in Table 1.17.

1.4.6 Providing agricultural water from the river

Agricultural water for the Karkheh River banks is provided by gravity or pumping. Agricultural water for Mohajerin village, by the side of the river, is provided by pumping. In the lands of Salare Shahidan and Fathe villages water is provided by pumping and it is also gravity-fed. The lands of Esteghlal village receive water by the traditional canal and gravity. The presence of a traditional canal on the border lands of the Karkheh River provides water for these lands. This traditional canal begins from Salare Shahidan village and irrigates riverside lands at Salare Shahidan Fathe, Esteghlad, and Mohajerian villages. The areas of the lands irrigated from the traditional canal are presented in Table 1.18.

1.4.7 Providing irrigation water from Dasht-e Evan network

Exploitation of Dasht-e Evan irrigation network began in AH 1378 (1999). The water of the Dasht-e Evan network is supplied from the Karkheh River by pumping. The main canal network is 46 km long and the primary and secondary channels total 80 km. The length of the main drainage network is 69 km and primary and secondary channels total 82 km. The total area irrigated by the network when it is complete will be 11,000 ha.

Table 1.14. Social welfare characteristics of Dasht-e Evan villages.

No.	Previous village name	Current village name	Total population	Number of families	Distance to city (km)	Distance to rural center (km)
1	Meskin	Meskin	2312	330	30.2	Near
2	Zaghan	Shahid Fallahi	1615	283	38.8	8.8
3	Mallehe	Esteghlal	439	62	43	12.8
4	Naderi	Ghods	453	64	44	13.5
5	Fallih	Mohajerin	478	68	26	4.4
6	Saleh Davood	Salare Shahidan	451	69	22	8.2
7	Saleh moshatat	Fateh	106	14	48	8.5

No.	Cooperative	Clinic	Telephone	Piped water	Electricity	School
1	Y	Y	Y	Y	Y	H,G,E
2	N	Y	N	Y	Y	E
3	N	N	N	Y	Y	E
4	N	N	N	Y	Y	E
5	N	N	N	Y	Y	E
6	N	N	N	Y	Y	E
7	N	N	N	Y	Y	E

Y: Yes, N: No, H: High school, G: Guidance school, E: Elementary school.

Table 1.15. Area served by the cooperative (ha).

Service provider	Total area of operated land					
	Irrigated	Dry land	Board	Ordered	Natural resource	Defloration
SASC	6,650	1,953	3,220	2,438	400	2,545
Dasht-e Narges cooperative	2,450	717	1,570	1,162	-	435
Total	9,100	2,670	4,790	3,600	400	2,980

Table 1.16. Number of farmers, type of land tenure, and area of land in the villages of the Sorkheh region.

Village name	Number of farmers	Ownership status of lands				Irrigated land	Dry land
		Ordered	Board	Natural resource	Defloration		
Ghods	42	205	-	132	200	477	60
Mohajerin	34	618	-	80	328	986	40
Salare Shahidan	231	1,014.5	2,094.5	192	922	3,750	473
Fateh	59	221	729	200	5	580	575
Esteghlal	26	211	90	121.5	211	426.5	207
Shahid Fallahi	89	241	1,078	403	282	1,029	975
Meskin	2	28	-	55	-	63	20
Total	483	2,538.5	3,991.5	1,183.5	1948	7,311.5	2,350

Table 1.17. area water sources and area (ha).

Service provider	Agricultural water sources irrigated area (ha)				
	Modern network	Number of wells	Pumping from well	Pumping from river	Number of motors
Agri. Service Center of Sorkheh	2,980	129	3,319	351	15
Dasht-e Narges cooperative	1,120	57	1,247	83	12
Total	4,100	186	4,566	434	27

Table 1.18. Area of land irrigated by water from the traditional canal.

Village name	How water is abstracted		Channel length (km)	Area (ha)
	Gravity	Pumping		
Salare Shahidan	†	†	6	192
Fateh	†	†	5	300
Esteghlal	†		11	69
Mohajerin		†	0.4	195

Note: † Where the farm has lower level compaered to the canal, water is delivered to the farm by gravity.

1.4.8 Providing irrigation water from wells

Irrigation water for some of the lands is provided from wells. These lands are either outside the limits of the presently available network, or outside its boundaries. Also, some lands receive water from both wells and the network. All of the lands of Shahid Fallahi, Esteghlal, Meskin villages, and some the lands of Fathe village are irrigated from wells.

1.4.9 Agricultural equipment

The availability of financial facilities and the promotion of new and improved technologies have increased the use of agricultural equipment in the region, such as tractors, row planters, sprayers, levelers, and others. These have contributed to increase mechanized farming. The statistics on the equipment available in the region are presented in Table 1.19.

Table 1.19. Number of available farm equipment by villages of Evan fields.

Equipment		Village						Total
		Ghods	Mohajerin	Salare Shahidan	Fateh	Esteghlal	Shahid Fallahi	
Moldboard plow		13	22	93	9	6	3	146
Disk		11	22	87	8	5	3	136
Leveler	2 Wile	6	13	57	2	4	3	85
Grain drill		2	7	21			1	31
Manure spreader		9	19	72	6	6	3	115
Borderer		5	15	56	4	5	3	88
Ditcher		8	16	59	5	4	3	59
Corrugators		5	5	19	2		1	32
Trailer	2 Wile	3		3	2		1	9
	4 Wile	3	9	15	1	2		30
Sprayer	Handy	7	13	52	2	3	1	78
	Motorized	9	15	82	6	6	3	121
	Pooling	4	15	39	3	5	2	68
Furrower		5	3	13	2	3		26
Baler		1		4				5
Drum teacher				11	1	1		13
Manure distributor				3				3
Cultivator		1	1					2
Potato digger			1	6				7
Tractor		8	20	92	8	6	4	138

Chapter 2.

Assessment of wheat water productivity

Chapter 2. Assessment of wheat water productivity

2.1 Introduction

Wheat is the main agricultural product in Iran. In 2004/05, the total irrigated area under wheat was 2.2 Mha, with an average yield of 3 t/ha, and the dryland area under wheat was 3.51 Mha with an average yield of 0.7 t/ha. The self-sufficiency rate for wheat fluctuated between 60% and 80% during these years. To achieve complete self-sufficiency in wheat production, an average yield of 4.8 t/ha is required from the irrigated cultivation and 1.16 t/ha from the rainfed.

The main factors causing the low level of wheat yield are:

- Deficiency of supply and untimely application of agricultural inputs (such as seed, fertilizer, herbicide, etc.) and high levels of waste at various stages of production
- Limitations of the water resources or lack of appropriate irrigation in most regions of the country
- Loss and damages stemming from pests, weeds, and blight and a lack of appropriate control over these
- Sub-optimal and incorrect application of inorganic fertilizers
- Disorganized and inappropriate use of agricultural equipment and machinery
- Lack of mechanization on many farms
- Inadequate budgets for agricultural research, training, and extension
- Lack of investment in agricultural production
- Problems in planning and policies for agricultural production.

Mary *et al.* (2001), in an investigation study of the effect of water deficit on 16 kinds of vernal wheat in Idaho, found that lower humidity results in lower performance in the sense of less clusters. They also showed that, in comparison with the desired humidity (irrigation every week), mild humidity stress (irrigation every other week) reduced the performance by 16% and high stress (no irrigation) reduced it by 44%. A sensitivity index analysis showed that long wheat, for producing biomass, has a better potential for seed kernelling. Genotypes with high pore conductivity have lower ability to maintain and store humidity than those with low conductivity. Regan *et al.* (1997) suggested that the effects of water blockage on seeds and crop performance depend on the stress intensity and growth stage of the plants, and germination is one of the most sensitive stages.

Shpiler and Blum (1991) report that the most sensitive stages are double-enation and pollination because of the negative effect on the cluster and number of seeds. Royo *et al.* (2000) indicated that dry stress from pollination to ripeness, especially with increased temperature, may lead to pre-maturation of leaves and reduction the time and speed of kernelling and the average seed weight. Water shortage during pollination will decrease crop performance due to a reduction in cluster numbers and fertility.

In semi-arid areas, humidity and nutrients are among the most significant factors influencing crop production. These factors are interrelated and nutrients must be supplied with respect to the humidity regime of the soil. The numbers of clusters and seeds play important roles in responding to moisture stress and if the bundle weight experiences stability through the transfer of assimilate (before pollination), water blockage at the blooming stage leads to 51% and 15.6% decreases in performance in comparison with the plastic and milkweed stages, respectively. Stress at any stage may lead to performance reduction. The kernelling stage (from pollination to the plastic stage) and the stage of rapid growth (from stem elongation to pollination) are significantly sensitive to humidity and this may result in performance reduction.

Farhad Nato (2005) described how timely and proper irrigation can improve wheat yield by 15%, while late irrigation during blooming may decrease it by 8%. An additional irrigation during physiological ripening results in 15% more production. Accordingly, with a greater number of irrigations from the flowering stage to physiological ripening, and with less water consumption, performance stability will increase. If the last irrigation is applied 3 days after flowering (appearance of the flag leaf) in southern Khuzestan and similar areas, the root will exploit the deep soil moisture and this will improve the remobilization process. Hence, farm lands experiencing late rains along with temperatures above 30 °C during kernelling, also experience lower performance.

Agronomic practices that reduce soil water evaporation via a larger plant canopy and early ground cover and, at the same time increase the crop's ability to extract soil water, may increase the amount of water transpired and, consequently, the WUE (Cooper *et al.*, 1983; French and Schultz, 1984; Siddique *et al.*, 1990; Zhang *et al.*, 1999). Nitrogen deficiency is another major constraint in canopy development in the Mediterranean region (Anderson, 1985). Crop responses to N fertilization depend on the level of water available (Pala *et al.*, 1996). Application of fertilizer not only increases plant shoot and root growth (Brown *et al.*, 1987), but also increases ET through a larger root system and greater extraction of stored water (Cooper *et al.*, 1987a). In addition, a large and early canopy cover resulting from the application of N can reduce soil water evaporation and increase crop WUE (Zhang *et al*., 1999).

Fischer *et al.*, (1981) found that the most sensitive stage to water stress is 15 days before pollination, which broadly influences the number of clusters. This period (between 5 and 16 days before cluster forming) coincides with the elongation of the stems, anthers, and pistils. Fischer *et al.*, (1981) mention that stress effects coincide with the meiosis of seed cells in the anther. In their research, the plants had abnormal anthers, but the normal pistil parts.

Keim and Kronstad (1981) studied 10 cultivars of winter wheat in order to analyze their performance under moisture stress in three different regions. The study implied a positive significant correlation between performances in two regions out of three. Among many germplasms, a large part of dryness tolerance and high performance may be contributed to pre-maturity and this gives the plant resistance against dryness. Osmosis potential, as a measure of water conditions, is positively correlated with performance and performance components, such as the number of seeds and their weights. This mechanism helps the plant to survive water stress or in low water potential. Through this process, the plant can restart its life cycle before the beginning of the high stress.

Global agriculture in the 21st century faces two major challenges; total food production needs to increase to feed a still growing world population and this increase needs to be achieved under an increasing scarcity of water resources.

Falkenmark and Rockström (2004) estimated that, to adequately feed 9.3 billion people in 2050, consumptive water use (i.e. transpired water) by all food and fodder crops needs to increase from its present estimated level of 7000 km^3/year to 12,586 km^3/year. However, fresh water resources are becoming increasingly scarce because of increased competition among a multitude of users (Pimentel *et al*., 2004; Rijsberman, 2006). The challenge to produce more food under increasing water scarcity has led to the notion that crop WP needs to increase (see Kijne *et al*., 2002; 2003; for recent overviews).

Crop-water production functions for wheat were derived from SI experiments conducted in Syria (Zhang and Oweis, 1999), the North China Plain (Zhang *et al*., 1999) and Oregon State, USA (English and Nakamura, 1989).

The productivity of the total applied water (PAW) is defined as the crop yield per unit volume of water supplied (rainfall + irrigation) to the crops (Molden, 1997). Figure 2.1 shows the relationship between PAW and the level of water application for wheat in northern Syria, the North China Plain, and Oregon, USA, and for chickpea and lentil in northern Syria. The crop production functions were used to derive the productivity of the applied water. For wheat, the PAW for these three locations representing different climatic conditions, increases sharply at a low water supply level and reaches a maximum at a certain level of water supply. After this maximum, the PAW shows a decrease with increasing water supply, depending on the response of the yield to water. The level of water application at the maximum PAW differs considerably for the three locations. The most productive use of water was reached with between 440 mm and 500 mm of supplied water (between 140 mm and 180 mm from irrigation) in northern Syria, 400 mm (between 120 mm and 160 mm from irrigation) in the North China Plain, and between 750 mm and 850 mm (between 350 mm and 450 mm from irrigation) in Oregon, USA. For grain-legume crops in northern Syria, the PAW gradually increases with increasing water supply and reaches a plateau at a maximum PAW of about 0.5 kg/m^3 for chickpea and 0.4 kg/m^3 for lentil. Significant differences in the PAW have been observed between crops. In north Syria, wheat has a PAW (1 kg/m^3) which is twice as high as that for grain-legume crops (from 0.4 kg/m^3 to 0.5 kg/m^3) (Zhang and Oweis, 1999). Although the three experiments represent very different climatic conditions, the maximum PAW for wheat is between 1 kg/m^3 and 1.2 kg/m^3. Rice has a relatively low PAW of between 0.37 kg/m^3 and 0.68 kg/m^3 (Tuong and Bhuiyan, 1999). Maize has a relatively high PAW of between 1.2 kg/m^3 and 1.5 kg/m^3. PAW values of 0.4 kg/m^3 were reported for cotton (Droogers *et al*., 2000).

In WANA, water resources are generally scarce, and agriculture's share of these resources is declining because of competition from the domestic and industrial sectors. In this region, a typical Mediterranean climate prevails, with rain falling mainly during the winter (and a lesser amount during the warmer spring period); this rainy season is followed by a hot, dry summer. Rainfed crop production under this climate thus depends strongly on both the amount and distribution of rain. In the WANA region, the amount of rainfall is low and generally poorly distributed, so periods of soil water deficiency occur during the grain-filling stage of wheat almost every year (Oweis *et al*., 1992). As a result, crop yield and WUE are generally low and variable. The production of 1 kg of wheat (*T. aestivum* L.) grain under fully irrigated conditions requires from 1 m^3 to 2 m^3 of irrigation water (Perrier and Salkini 1991); in rainfed areas it requires from 1 m^3 to 3 m^3 of rainwater (Cooper *et al*., 1987a; Perrier and Salkini, 1991). Since water is the major limiting factor for agriculture in the WANA region, improving WUE is vital to meet the increasing food demand (Cooper *et al*., 1987b). SI is defined as the application of a limited amount of water to rainfed crops when precipitation fails to provide the essential moisture for normal plant growth. This practice has shown the potential to alleviate the adverse effects of unfavorable rain patterns and thus improve and stabilize crop yields (Perrier and Salkini, 1991; Oweis *et al*., 1998; Zhang and Oweis, 1999). Early studies at ICARDA experimental farms showed that applying two or three irrigations (of between 80 mm and 200 mm) to wheat increased crop grain yield by 36% to 450%, and produced similar or even higher grain yields than under fully irrigated conditions (Perrier and Salkini, 1991; Oweis, 1994). SI is widely practiced in Syria and in southern and eastern Mediterranean countries. However, excessive use of water in SI because of low irrigation costs and attractive gains from increased yields has resulted in a decline of aquifers and deterioration of water quality in many areas (Ward and Smith, 1994).

Increasing the proportion of water used for plant transpiration through a large and early canopy can increase WUE. In Mediterranean environments, where crop canopy development in winter is slow and rain occurs as frequent and small events, soil water evaporation may account for 30% to 60% of the seasonal ET (Cooper *et al.*, 1983; French and Schultz 1984; Siddique *et al.*, 1990). Thus, agronomic practices that reduce soil water evaporation through a larger plant canopy and early ground cover, and at the same time increase the crop's ability to extract soil water, may increase the amount of water transpiration and, consequently, the WUE. Nitrogen deficiency is another major constraint in canopy development in the Mediterranean region (Anderson, 1985). Crop responses to N fertilization depend on the level of water availability (Pala *et al*., 1996). Application of fertilizers not only increases plant shoot and root growth (Brown *et al*., 1987), but also increases ET through a larger root system and greater extraction of stored water (Cooper *et al*., 1987a). In addition, a large and early canopy cover resulting from the application of N can reduce soil water evaporation and increase crop WUE (Zhang *et al*., 1999). Under rainfed conditions, the date of the first significant rain determines the sowing date. Early sowing of appropriate cultivars is a recognized means of increasing wheat yields in other Mediterranean-type environments, such as Western Australia (Anderson and Smith, 1990; Anderson, 1992).

In rainfed Mediterranean environments, WUE can be substantially improved by adopting deficit SI to satisfy up to two-thirds of the irrigation requirements, along with early sowing and appropriate levels of N (Oweis *et al*., 1998). In the water-scarce areas of WANA, water (not land) is the most limiting factor to crop production. Satisfying crop water requirements, although maximizes production from the land unit, it does not necessarily maximize the return per unit volume of water. Improving WP can contribute to water savings, which can be used to irrigate additional lands resulting in a higher total production and/or improved sustainability of the existing water resources. It is assumed that maximum WUE may be achieved at irrigation levels below those that satisfy the full crop irrigation requirements. However, the SI level, N rate, and sowing date at which WUE can be maximized under the rainfed conditions of the WANA Mediterranean need to be evaluated before improved management strategies can be devised. Our objective for this work was a better understanding of the effects of applying different levels of these inputs and climate interaction on the ET and WUE of bread wheat in northern Syria.

No comprehensive information is available on efficiency of water consumption in Iran, particularly for different basins. Only some case studies have been conducted in different regions of the country.

Based on the results of two national studies on irrigation efficiency conducted by Heidari and Haghayeghi Moghaddam (2001) at different location of Iran, wheat water use efficiency (yield/applied water) ranged from 0.34 kg/m^3 to 0.84 kg/m^3 (Table 2.1). The findings imply that the irrigation method and its management can significantly affect water consumption. A large number of irrigation efficiency problems are attributed to the management shortcomings, the betterment and correction of which do not require enormous investments, but need more attempts at better planning and management.

Mamanpoush *et al*. (2001) in a case study in Zayandehrood River Basin reported that the basin WUE is about 1.1 kg/m^3. Neirizi and Helmi Fakhrdavoud (2004), in a study involving water consumption efficiency in Torbat Heidarieh, Torbat Jam, and Chenaran for the cultivation of wheat and sugar beet with two methods of irrigation (namely surface irrigation and rain irrigation), showed that the efficiency of water consumption for wheat cultivation in Chenaran was 0.38 kg/m^3, in Torbat Heidarieh, 0.73 kg/m^3, and in Torbat Jam, 0.44 kg/m^3. The higher efficiency in Torbat Heidarieh was a consequence of the rain irrigation system and scientific management.

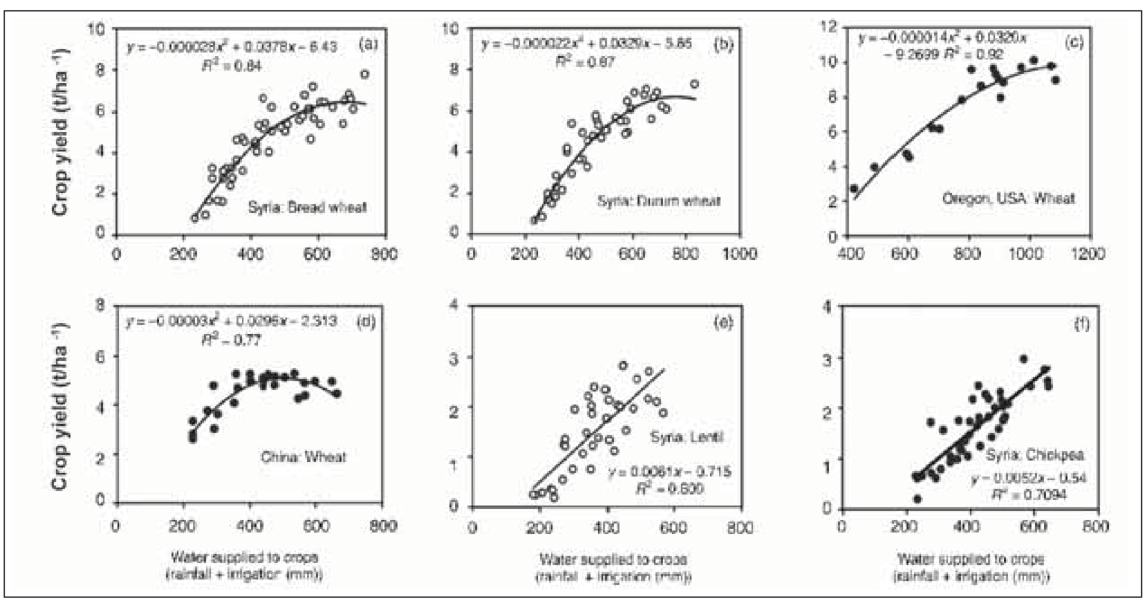


Figure 2.1. Crop production functions for wheat in China (Zhang *et al*., 1999) and Oregon, USA (English and Nakamura 1989), and chickpea and lentil in Syria (Zhang and Oweis 1999).

Table 2.1. Calculated value of water use efficiency for wheat cultivation (courtesy of Heidari and Haghayeghi Moghaddam, 2001).

Village name	How water is abstracted		Channel length (km)	Area (ha)
	Gravity	Pumping		
Salare Shahidan	†	†	6	192
Fateh	†	†	5	300
Esteghlal	†		11	69
Mohajerin		†	0.4	195

Zwart and Bastiaansen (2004), based on 84 case studies conducted over the last 25 years, evaluated WP in plants like wheat, rice, cotton, and corn and compared the data to previous figures reported by FAO. According to this broad study, the average WP for wheat was 1.09 kg/m^3, for rice, 1.09 kg/m^3, for cotton (for seed), 0.65 kg/m^3, for cotton (for boll), 1.23 kg/m^3, and for corn was, 18 kg/m^3. The range of this index for these crops varied widely – for wheat, rice, cotton (for seed), cotton (for boll), and corn the range was from 0.6 kg/m^3 to 1.7 kg/m^3. The variations in the wheat WUE largely depended on climate, irrigation management, and fertilization. The study clearly showed that WP may vary largely because of water stress or a reduction in irrigation. They suggested that large potential and opportunities exist for maintaining or increasing WUE by between 20% and 40% (higher production with lower water consumption).

Heidari *et al*. (2006) analyzed the WUE of agricultural plants in different regions (such as Kerman, Hamedan, Moghan, Golestan, and Khozestan) for various crop management scenarios. They reported WUE values of 0.75 kg/m^3 for wheat, 0.64 kg/m^3 for sugar beet (sugar yield),2.06 kg/m^3 for potato, 5.58 kg/m^3 for field corn, 1.46 kg/m^3 for alfalfa (dry weight), 0.56 kg/m^3 for oat, and 0.29 kg/m^3 for sugar cane (sugar yield). They reported management and agricultural science as the most important factors influencing water efficiency and recommended informative and skill training programs through education and the propagation of new methods as powerful levers for improving of WUE.

Irrigation efficiency expressed as released water from Karkheh Dam to actual ET (ETa) is also low at KRB. Evidence shows that different factors contribute to this phenomenon, including inefficient delivery systems, inappropriate cultivation patterns, and poor farm management practices, such as irrigation, which result in instability of yield and salinity of the low lands.

The northern lands of the KRB, which are the subject of the present study, indicate that farmers in these areas have lower awareness of irrigation management in comparison to other regions and the subject suffers from a lack of sufficient studies. With regard to the high potential of farmlands and the possibility of appropriate consumption of water stored at the dams, the useful employment of these lands will have a significant effect on the agricultural economy of the region, and the nation as a whole.

This study identifies the wheat WUE in the Sorkheh irrigation grid and addresses the influencing factors of the irrigation grids of Dez and upper Karkheh.

2.2 Materials and methods

This study was carried out during the period 2005 to 2007 in Sorkheh. Based on the sources of farm water supply, the following seven irrigation units were selected; two units using wells, three units receiving water from irrigation network canals, one unit that pumps water from the river, and one unit that uses both the network and as well as a well. The geographical locations and geometrical characteristics of the selected farms are shown in Tables 2.2 and 2.3. In each irrigation unit, three farms were chosen. The choice was based on the distance from the farm to the water source, the crop cultivar, management of irrigation, and farming practices. The total amount of applied irrigation water (I m^3/ha) was measured (inflow) using a calibrated cutthroat flume installed at the farm water entrance. The runoff (outflow) was measured using a calibrated cutthroat flume of smaller size installed at the end of the farm.

The total yield (Y kg/ha) was measured based on the total yield harvested by combine. Simultaneously, three samples, each of 6 m^2 (two 4-m ridges) were cut from each farm to measure the number of plant per unit area, rate of kernel yield, and total dry matter.

The physical and chemical properties of the soil (texture, pH, and the electrical conductivity of the saturation extract of the soil (ECe)) and fertility, nutrient status, and organic carbon were analyzed based on soil sampling before the cultivation season. Soil samples were collected at 0 cm to 30 cm depth from five different locations on the farm and mixed for analysis.

To calculate the daily wheat evapotranspiration, daily climatic factors, such as the minimum, maximum, and average temperature, solar radiation, humidity, wind speed, hours of sunshine, evaporation from a Class A evaporation pan, and daily rainfall rate were collected from Dezful weather station.

To monitor the farm situation and management, various data were collected during the irrigation season which could be grouped as follows;

- Farm specification: Length of furrow, slope of the land in the direction of irrigation, area of farm under irrigation
- Crop and farm management: Crop variety, farming, and breeding activities, implementation date of the tillage activities during the crop growth stages, rate and timing of fertilizer and pesticide applications, seeding rate
- Crop calendar: Time of planting, duration of the initial stage of growth (germination), beginning of generative stage, duration of generative stage, beginning of ripening stage, duration of ripening stage, harvest date.

Wheat WP ($WP_{(I+R)}$) was calculated using equation 2-1.

$$WP_{I+R} = \frac{Y}{I+R} \qquad (2\text{-}1)$$

where R m^3/ha is the amount of rainfall. The irrigation application efficiency (IE) (expressed as a percent) for all the irrigation events was calculated using equation 2-2.

$$IE = \frac{ETci}{I} \times 100 \qquad (2\text{-}2)$$

where ETci (m^3/ha) is the crop water requirement from the first irrigation after the winter season.
Wheat WPETc, based on the wheat water requirement (ETc m^3/ha), can be calculated as follows:

$$WP_{ETc} = \frac{Y}{ETc} \qquad (2\text{-}3)$$

Table 2.2. Source of water, geographical location and area of the selected farms in 2005/06.

Field No.	Source	Geographic information	Area (ha)
1	Network (1 unit)	Elevation =36.0 m 3219.485 N and 4806.598 E	3.6
2	Network (1 unit)		3.2
3	Network (1 unit)		3.3
4	Network (1 unit)		2.0
5	Network (2 units)	Elevation 93.9 m 3220.190 N and 4804.676 E	4.5
6	Network (2 units)		3.9
7	Network (2 units)		5.0
8	Network (2 units)		3.3
9	Network (3 units)	Elevation 148.7 m 3220.571 N and 4800.954 E	2.3
10	Network (3 units)		1.6
11	Network (3 units)		12.0
12	Network and well	Elevation 135.6 m 3223.040 N and 4806.597 E	14.1
13	Network and well		11.8
14	Network and well		17.7
15	Well (1 unit)	Elevation 33.8 m 3221.858 N and 4808.059 E	4.4
16	Well (1 unit)		7.7
17	Well (1 unit)		4.3
18	Well (2 units)	Elevation 30.5 m 3212.592 N and 4808.009 E	3.7
19	Well (2 units)		4.7
20	River	Elevation 44.8 m 3221.841 N and 4809.060 E	5.3
21	River		10.5
22	River		4.9

Table 2.3. Source of water, geographical location and area of the selected farms in 2006/07.

Field No.	Source	Geographic information	Area (ha)
1	Network (1 unit)	Elevation 36.0 m 3219.485 N and 4806.598 E	3.2
2	Network (1 unit)		0.9
3	Network (1 unit)		3.3
4	Network (2 units)	Elevation 93.9 m 3220.190 N and 4804.676 E	5.9
5	Network (2 units)		3.9
6	Network (2 units)		4.9
7	Network (3 units)	Elevation 148.7 m 3220.571 N and 4800.954 E	2.3
8	Network (3 units)		2.3
9	Network (3 units)		1.6
10	Network and well	Elevation 135.6 m 3223.040 N and 4806.597 E	8.4
11	Network and well		8.1
12	Network and well		9.3
13	Well (1 unit)	Elevation 33.8 m 3221.858 N and 4808.059 E	17.7
14	Well (1 unit)		7.7
15	Well (1 unit)		8.4
16	Well (2 units)	Elevation 30.5 m 3212.592 N and 4808.009 E	4.3
17	Well (2 units)		3.7
18	Well (unit-2)		3.9
19	River	Elevation 4 3221.841 N and 4809.060 E	10.5
20	River		4.9
21	River		4.4

2.3 Results and discussion

2.3.1 Soil properties

Soil samples taken at 0 cm and 30 cm depth from five points in the field before planting were analyzed for electrical conductivity of the saturated extract, nutrient status, organic carbon, and pH. The results of the soil analyses are presented in Tables 2.4 and 2.5.

2.3.2 Climatic characteristics of the region

The average annual temperature change between 2005 and 2007 was about 3ºC. The average daily temperature and monthly climatic and meteorological characteristics of Safiabad-Dezfoul region are provided in Tables 2.6 and 2.7. A review of the average annual temperatures indicated that the range of such changes was close to 3ºC. Changes in the average annual temperature are related to changes in solar energy and the climatic systems.

Table 2.4. Chemical and physical properties of the soil of the selected farms in 2006.

Field No.	Soil texture	Element		pH	Electrical conductivity (dS/m)	Organic carbon (%)
		K (ppm)	P (ppm)			
1	L	149	7.5	7.5	2.9	0.4
2	Si.L	1589	6.9	7.6	2.3	0.61
3	Si.L-L	149	5.2	7.4	2.55	0.38
4	L	149.2	2.6	7.8	1.9	0.41
5	L	94.8	2.6	7.8	1.9	0.34
7	L	121	4.7	7.47	2.4	0.42
8	L	69	16.2	6.9	2.5	0.34
9	Si.L	158.6	7	7.2	6	0.61
10	L	121.4	9.7	7.6	2.3	0.48
11	L	95	8.4	7.6	1.2	0.39
12	Si.L	94.8	1.9	7.7	1.4	0.25
13	L	130.6	4.2	7	1.7	0.46
14	Si.C.L	319.6	21	7.3	4.4	0.54
15	Si.L	262.6	7.4	7.5	4.1	0.49
17	Si.L-Sa.L	121.4	3.5	7.5	4	0.27
18	Si.L	60	1.1	7.0	3.3	0.07
21	Sa.L-L	131	9.4	7.6	1.25	0.39
22	Sa.L	60	4.3	7.6	1.5	0.29
23	L	86	5.2	7.3	2.2	0.37

L – loam; Si.L – silty loam; Sa.L – sandy loam; Si.C.L – silty clay loam.

Table 2.5. Chemical and physical properties of the soil of the selected farms in 2007.

Field No.	Soil texture	Element		pH	Electrical conductivity (dS/m)	Organic carbon (%)
		K (ppm)	P (ppm)			
1	L	69	7.5	6.8	3.33	0.41
2	Si.L	98	6.9	7.1	1.34	0.19
3	Si.L-L	109.7	5.2	6.9	1.50	0.15
5	L	107	2.6	7.2	0.72	0.17
6	L	80	2.6	6.8	5.87	0.28
7	L	80.7		6.9	2.43	0.29
9	L	92	4.7	6.7	1.93	0.55
10	L	77	16.2	6.7	3.40	0.31
11	Si.L	142.7	7	6.9	2.40	0.37
12	L	137.7	9.7	7.2	1.17	0.36
13	L	106.3	8.4	7.2	1.30	0.18
14	Si.L	77.3	1.9	7.3	1.25	0.24
15	L	451.3	4.2	6.9	9.83	0.26
16	Si.C.L	137.7	21	7.0	10.27	0.24
17	SI.L	130.7	7.4	7.1	8.37	0.28
18	SI.L-L	80		6.8	3.50	0.48
19	Si.L-Sa.L	74.7	3.5	6.9	3.10	0.09
20	Si.L	92.33	1.1	6.9	3.63	0.09
21	SI.L	52.00	-	6.8	3.67	0.37
22	Sa.L-L	60.3	9.4	7.2	2.30	0.44
23	Sa.L	54.3	4.3	6.8	4.50	0.34

Table 2.6. Climatic characteristics in Sorkheh during 2005/06.

Month	max	min	av	Rain (mm)	(m/s)	date	Pan evaporation (mm)	Sun shine (hr)	Relative humidity (%)
Dec	15.2	5.4	10.3	90.7	13.0	16	77.4	159.7	34.9
Jan	16.4	5.3	10.8	60.5	11.0	11	75.5	168.4	41.2
Feb	20.4	9.0	14.7	52.7	11.0	3	71.8	184.3	69.7
Mar	23.7	9.9	16.8	66.3	17.0	26	65.2	207.7	111.4
Apr	29.2	16.2	22.7	60.1	17.0	13	59.9	171.9	153.7
May	40.6	22.5	31.5	5.0	12.0	15	40.9	205.9	265.5
Jun	45.3	23.9	34.6	0.0	11.0	10	35.4	336.7	371.6

Table 2.7. Climatic characteristics in Sorkheh during 2006/07.

Month	max	min	av	Rain (mm)	(m/s)	date	Pan evaporation (mm)	Sun shine (hr)	Relative humidity (%)
Dec	19.0	8.2	13.6	45.9	12.0	6	72.9	160.0	51.5
Jan	14.1	3.9	9.0	64.7	15.0	5	73.5	163.4	41.8
Feb	21.0	7.0	14.0	1.2	15.0	14	56.2	184.5	98.9
Mar	29.3	13.2	21.3	0.0	9.0	22	48.8	207.4	187.2
Apr	34.2	16.5	25.3	12.0	14.0	30	49.8	208.2	209.4
May	39.1	20.9	30.0	0.1	20.0	21	40.0	235.2	340.6
Jun	44.7	25.1	34.9	0.0	15.0	23	28.9	258.4	453.5

2.3.3 Wheat water productivity

The germination date and other information on agronomic and irrigation practices are shown in Tables 2.8 and 2.9. The grain yields and volumes of water used for different farms are shown in Figure 2.2. The results indicate that in the first year, the average grain yield was 4430 kg/ha with four irrigations and an average water use of 4840 m^3/ha. Therefore, the average irrigation and rain WP ($WP_{(I+R)}$) was 0.97 kg/m^3 in the first year. However, during the second year the average grain yield was 5609 kg with an average water use of 15,770 m^3/ha, resulting in an average $WP_{(I+R)}$ of 0.40 kg/m^3. There was approximately a 10% reduction in crop yield as a result of an attack by aphids during 2005/06.

Tables 2.4 and 2.5 show the low levels of organic material in the soils of the selected farms compared to the suggested level for wheat production. Figure 2.3 shows the total amount of water applied versus the yield for the seasons 2005/06 and 2006/07 and Figure 2.4 shows the yield versus the WP for the same two periods.

As can be seen in Figure 2.3 the changes in $WP_{(I+R)}$ have positive relation with the yield, while Figure 2.4 shows the negative relation between $WP_{(I+R)}$ and the amount of water used. The slope of the regression line is the same for grain yields in both years of the experiment. The slope of the changes in $WP=_{(I+R)}$ with the amount of water used is to some extent steeper in the second year than in the first.

The mean grain yield, applied water, and $WP_{(I+R)}$ for the various fields with different sources of water, the different cultivar planted, and the different land use history before planting wheat are shown in Tables 2.10, 2.11, and 2.12. It can be seen that farms irrigated by water from the network consumed more water in both years. The average grain yield in the 2005/06 season was highest where water was applied from the well, and the network and well combination. In 2006/07, grain yield was highest for water applied from the network and well combination only. Obviously, higher water consumption on the farms drawing from the irrigation network resulted from having a reliable water allocation from this source – water was available when it was needed. Among the wheat cultivars, the grain yields of Chamran and Vierinak were quite similar. The grain yield from the Dez cultivar was relatively constant over the two seasons. On farms where wheat was sown after corn, the yield and $WP_{(I+R)}$ were higher than on farms that had been fallowed before the wheat mainly due to the wheat variteis.

Table 2.8. Agronomic practices and wheat WP in 2005/06.

Field No.	Variety	Seed rate (kg/ ha)	Germination date (d.m.y)	No. of irri	Border length (m)	Average irri depth (mm)	Average discharge rate (l/s)	Crop water requirement ETc-req (mm)	Grain yield (kg/ ha)	IE (%)	WP (ETc) (kg/ m^3)	$WP_{(I+R)}$ (kg/ m^3)
1	Chamran	250	09.12.2005	3	255	79	2.1	125	5,089	0.525	1.605	1.183
2	Vierinak	300	12. 01.2006	3	212	87	2.55	203	4,807	0.775	1.393	1.190
3	Vierinak	300	12. 01.2006	4	262	89	1.96	203	4,674	0.572	1.355	0.940
4	Dez	280	17. 12.2005	3	470	121	2.72	104	5,769	0.287	1.949	1.039
5	Dez	280	12.12.2005	3	362	198		97	3,514	0.164	1.220	0.448
6	Dez	280	12.12.2005	3	472	59		97	4,189	0.551	1.454	1.141
7	Chamran	300	30.01.2006	4	480	73	4.08	242	4,846	0.829	1.434	1.249
8	Vierinak	350	16.12.2005	4	360	74	5.25	113	5,493	0.382	1.807	1.128
9	Chamran	250	18.12.2005	4	275	90	4.41	143	4,003	0.398	1.321	0.771
10	Dez	300	11.12.2005	5	200	93	3.72	117	4,208	0.252	1.362	0.642
11	Dez	154	05.12.2005	4	410	70	2.98	106	4,611	0.377	1.441	0.931
12	Dez	185	05.12.2005	4	300	48	2.05	102	3,652	0.531	1.159	0.902
13	Vierinak	250	18.01.2006	4	383	65	2.87	244	5,736	0.938	1.625	1.554
14	Chamran	270	16.12.2005	3	315	56	3.81	115	4,720	0.680	1.543	1.311
15	Chamran	270	15.12.2005	3	270	96	3.73	109	4,447	0.380	1.482	0.930
16	Chamran	180	20.12.2005	3	235	111	2.69	243	4,865	0.730	1.378	1.098
17	Chamran	280	09.12.2005	8	230	77	5.33	102	3,385	0.166	1.095	0.411
18	Vierinak	250	12.012006	7	235	42	2.42	214	4,509	0.728	1.266	1.034
19	Vierinak	250	12.01.2006	7	240	34	2.24	214	2914	0.895	0.819	0.765
20	Vierinak	280	16.01.2006	4	242	98	4.82	232	3869	0.590	1.135	0.771
21	Vierinak	280	16.01.2006	4	358	87	5.93	232	3241	0.667	0.950	0.709
22	D-79-18	300	16.01.2006	3	375	99	6.81	232	4953	0.781	1.452	1.220

Table 2.9. Agronomic practices and wheat WP in 2006/07.

Field No.	Variety	Seed rate (kg/ ha)	Germination date (d.m.y)	No. of irri	Border length (m)	Average irri depth (mm)	Average discharge rate (l/s)	Crop water requirement ETc-req (mm)	Grain yield (kg/ ha)	IE (%)	WP (ETc) (kg/ m^3)	$WP_{(I+R)}$ (kg/ m^3)
1	Sheva	290	13.12.2006	5	208	80	1.60	367	4,734	0.915	1.449	1.027
2	Sheva	330	12.12.2006	5	270	48	1.65	382	4,690	1.579	2.023	1.595
3	Sheva	330	12.12.2006	5	235	68	1.84	382	4,690	1.130	1.909	1.202
4	Dez	300	28.12.2006	12	290	101	3.36	335	2,269	0.276	2.015	0.174
5	Sheva	280	06.12.2006	10	365	111	4.33	347	3,896	0.314	2.164	0.338
6	D-79-18	300	14.12.2006	10	480	87	7.85	350	1,549	0.401	1.285	0.168
7	Vierinak	300	13.12.2006	5	275	165	6.19	348	2,505	0.423	2.254	0.287
8	D-79-18	280	13.12.2006	7	150	212	6.84	356	3,072	0.239	1.528	0.200
9	D-79-18	290	13.12.2006	6	220	107	5.28	356	3,840	0.553	1.929	0.552
10	Star	140	24.11.2006	6	238	114	4.42	332	4,606	0.486	0.752	0.593
11	Star	160	14.12.2006	5	243	129	5.07	331	2,899	0.512	1.455	0.415
12	Vierinak	185	26.12.2006	5	239	155	5.39	347	5,144	0.447	1.453	0.622
13	Vierinak	220	14.12.2006	5	311	64	2.20	335	5,678	1.040	1.971	1.522
14	Vierinak	220	15.12.2006	5	270	138	3.78	335	4,470	0.486	2.211	0.603
15	Vierinak	220	15.12.2006	5	335	123	4.38	335	3,366	0.543	2.123	0.504
16	Chamran	240	06.12.2006	6	253	86	3.62	309	3,818	0.600	1.553	0.634
17	Vierinak	250	24.01,2007	6	229	104	3.86	348	2,238	0.558	1.463	0.345
18	Vierinak	250	24.01.2007	6	181	103	3.59	348	4,006	0.566	1.946	0.627
19	Vierinak	250	26.12.2006	5	357	147	5.27	325	2,384	0.442	1.580	0.304
20	Dez	270	31.12.2006	5	275	122	4.94	334	3,747	0.548	1.929	0.569
21	Dez	280	03.01.2007	5	380	104	3.85	335	6,134	0.645	1.622	1.080

Table 2.10. Mean wheat grain yield, WP, and water use on farms with different sources of water.

Source of water	Field No.	Yield (t/ha)		$WP_{(I+R)}$ (kg/m^3)		Water consumption (mm)	
		Average	SD*	Average	SD*	Average	SD
		2005/06 season					
Network	10	4.7	0.5	1.0	0.2	508.7	95.8
Network and well	3	4.7	0.7	1.3	0.5	423.0	48.0
Well	6	4.1	0.7	0.9	0.2	486.8	112.1
River	3	4.0	0.6	0.9	0.2	455.0	32.7
		2006/07 season					
Network	9	3.5	1.0	0.6	0.4	848.1	344.8
Network and well	3	4.2	0.9	0.5	0.1	767.7	45.8
Well	6	3.9	0.8	0.7	0.3	611.8	82.9
River	3	4.1	1.4	0.7	0.3	670.3	75.8

** SD is Standard Deviation*

Table 2.11. Mean wheat grain yield, WP,, and water use for different wheat varieties.

Source of water	Field No.	Yield (t/ha)		$WP_{(I+R)}$ (kg/m^3)		Water consumption (mm)	
		Average	SD*	Average	SD*	Average	SD
		2005/06 season					
Chamran	7	4.5	0.5	1.0	0.2	318.0	15.7
Vierinak	8	4.4	0.8	1.0	0.2	342.6	10.5
Dez	6	4.3	0.6	0.9	0.2	302.7	12.0
D-79-18	1	4.9		1.2		341.0	
		2006/07 season					
Chamran	1	3.8		0.6		396.0	
Vierinak	8	3.7	1.1	0.6	0.2	384.0	8.5
Dez	3	4.0	1.4	0.8	0.3	397.3	17.8
D-79-18	3	2.8	0.8	0.4	0.2	405.7	3.1
Star	2	3.8	0.9	0.5	0.1	404.5	21.5
Sheva	4	4.5	0.3	1.3	0.2	422.8	13.4

** SD is Standard Deviation*

Table 2.12. Mean wheat grain yield and WP on farms with different histories before planting wheat.

Land use before wheat	Field No	Wheat yield (t/ha)		$WP_{(I+R)}$ (kg/m^3)	
		Average	**SD***	**Average**	**SD***
		2005/06 season			
Corn	10	4.8	0.4	1.1	0.2
Fallow	9	4.3	0.7	0.9	0.2
Land grading	3	3.5	0.4	0.8	0.2
		2006/07season			
Corn	9	4.6	0.8	0.9	0.4
Fallow	10	3.3	0.7	0.5	0.1
Land grading	2	2.7	1.2	0.2	0.1

** SD is Standard Deviation*

The interval between irrigations is another management factor that is important and is assessed by determining the available soil moisture balance for the plants during the growth period. The available moisture balances in the root zones during the growing periods on farms 7, 14, and 15 are shown in Figure 2.5. All three fields are similar in cultivar used and crop rotations. The length of the strip and the inflow rate to the width of the strip are based on recommendations. A negative value for the moisture balance of the soil indicates a lack of water that plants need which led to the moisture stress (it does not a negative physical aspect of any parameter). Farms 14 and 15 are similar in their planting date and irrigation period, but they have different yields. Comparing their corresponding soil moisture balances showed that, in the case of a drought stress in stages three and four, soil moisture at Farm 15 was kept at field capacity for more days thanat Farm 14. It can be concluded that excess soil moisture can lead to a reduction in oxygen in the rhizosphere during the heading stage until grain ripening, and this reduced the grain yield by 10% at Farm 15. Despite the delayed planting date (50 days) at Farm 7 from that at farms 14 and, the reduction in yield due to the delay was compensated for by 60 mm irrigation. Therefore, the on-time irrigation (50-60 mm depth irrigation) after the heading stage until grain ripening is more important than the planting date.

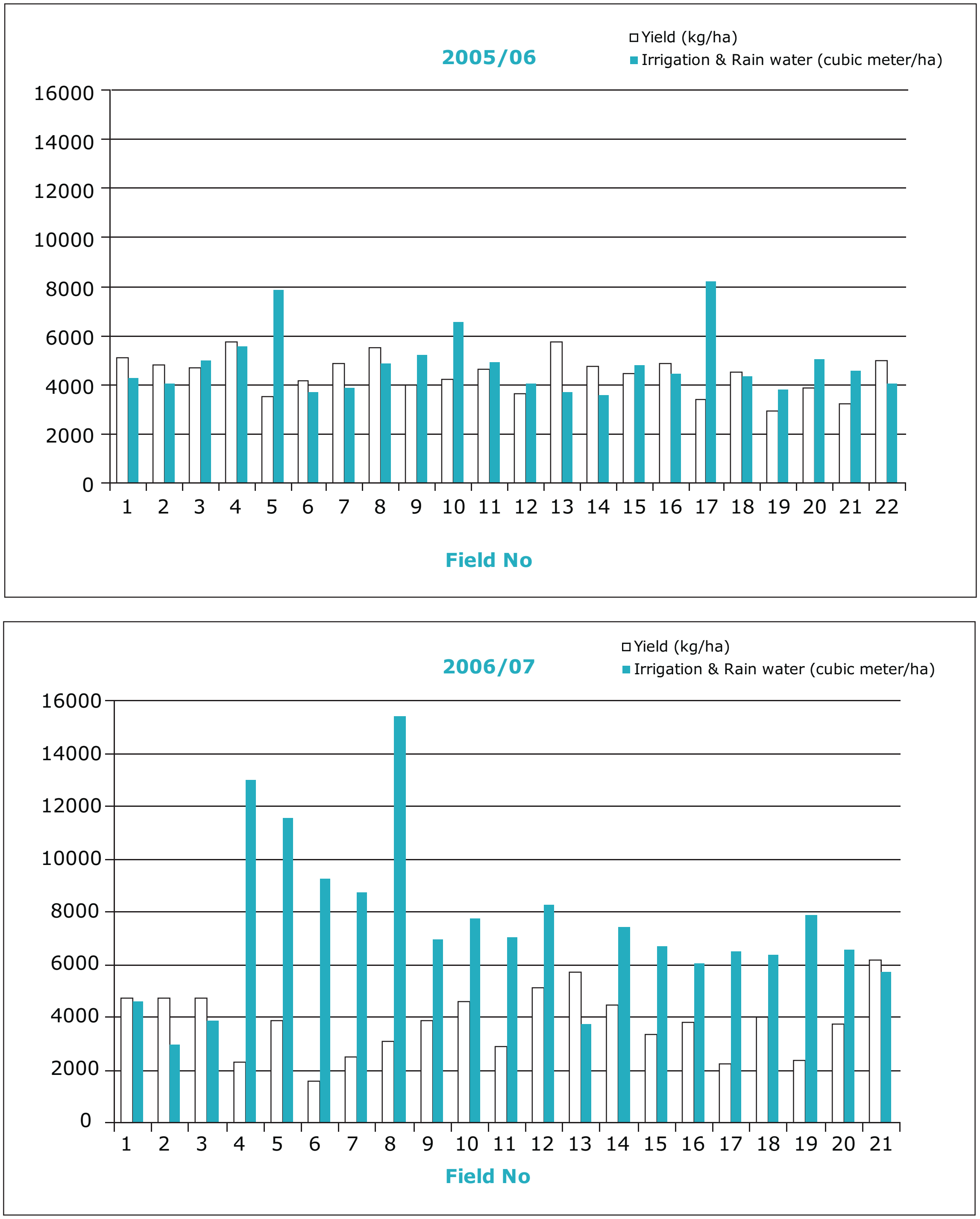
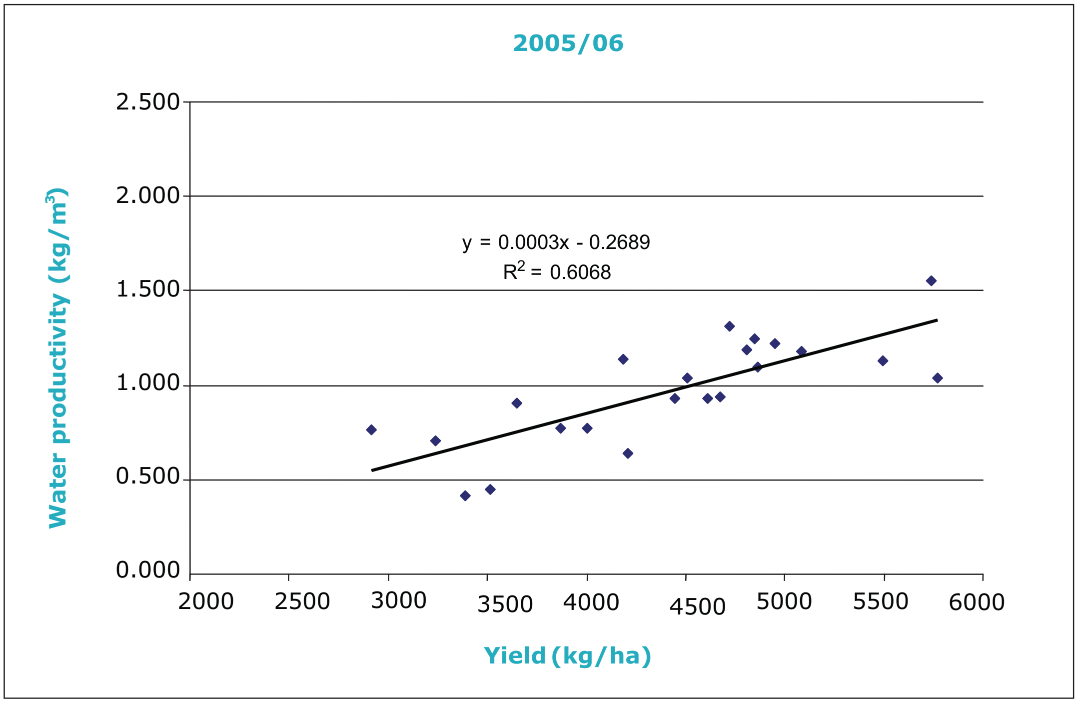


Figure 2.2 Wheat yield and $WP_{(I+R)}$ in the selected farms during 2005/06 and 2006/07.



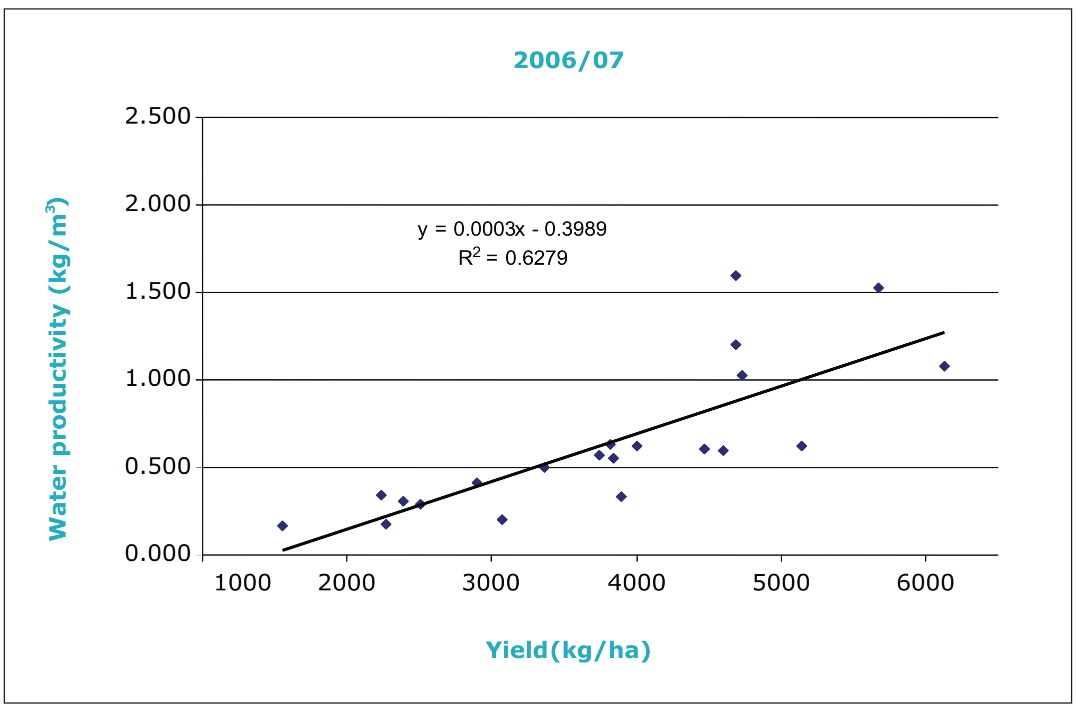
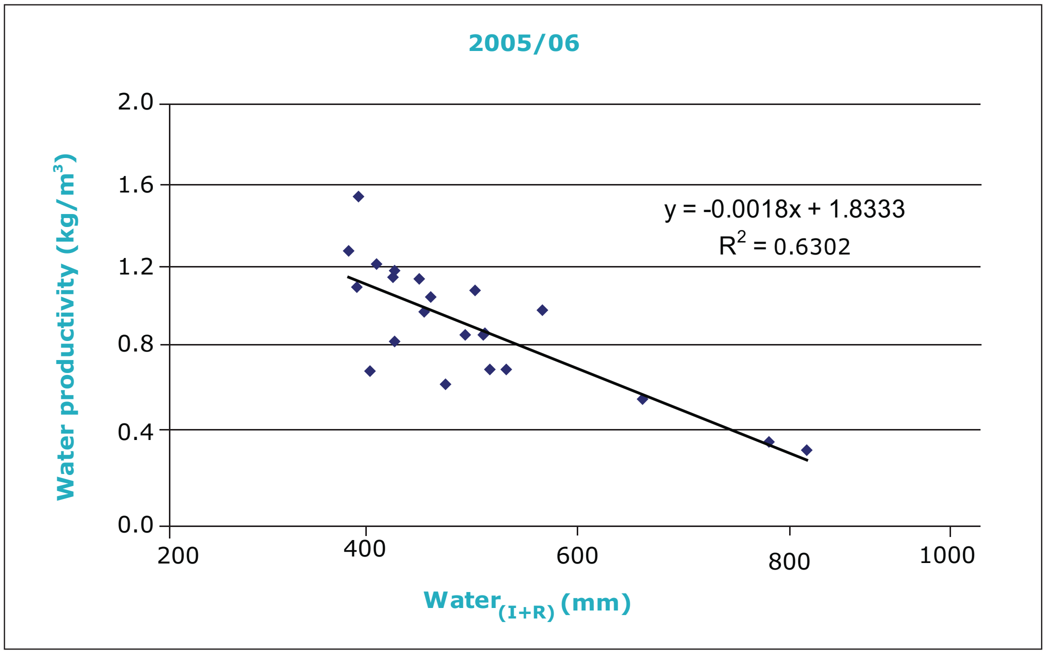


Figure 2.3 Changes in $WP_{(I+R)}$ with yield on selected farms between 2005 and 2007.



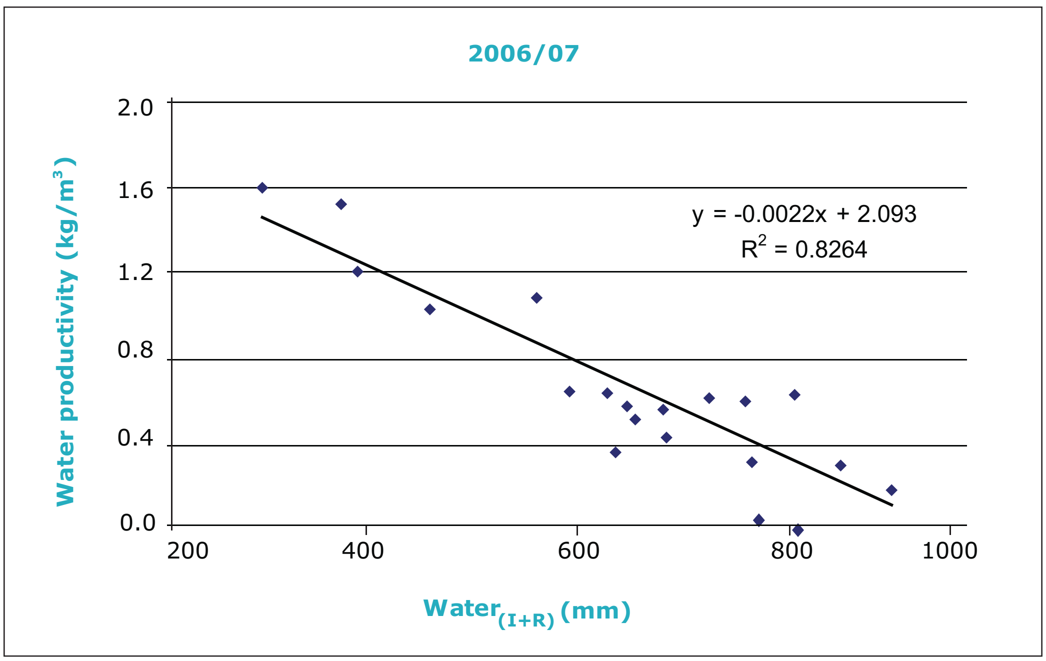


Figure 2.4 Changes in wheat $WP_{(I+R)}$ with the amount of applied water (irrigation + precipitation) on selected farms between 2005 and 2007.

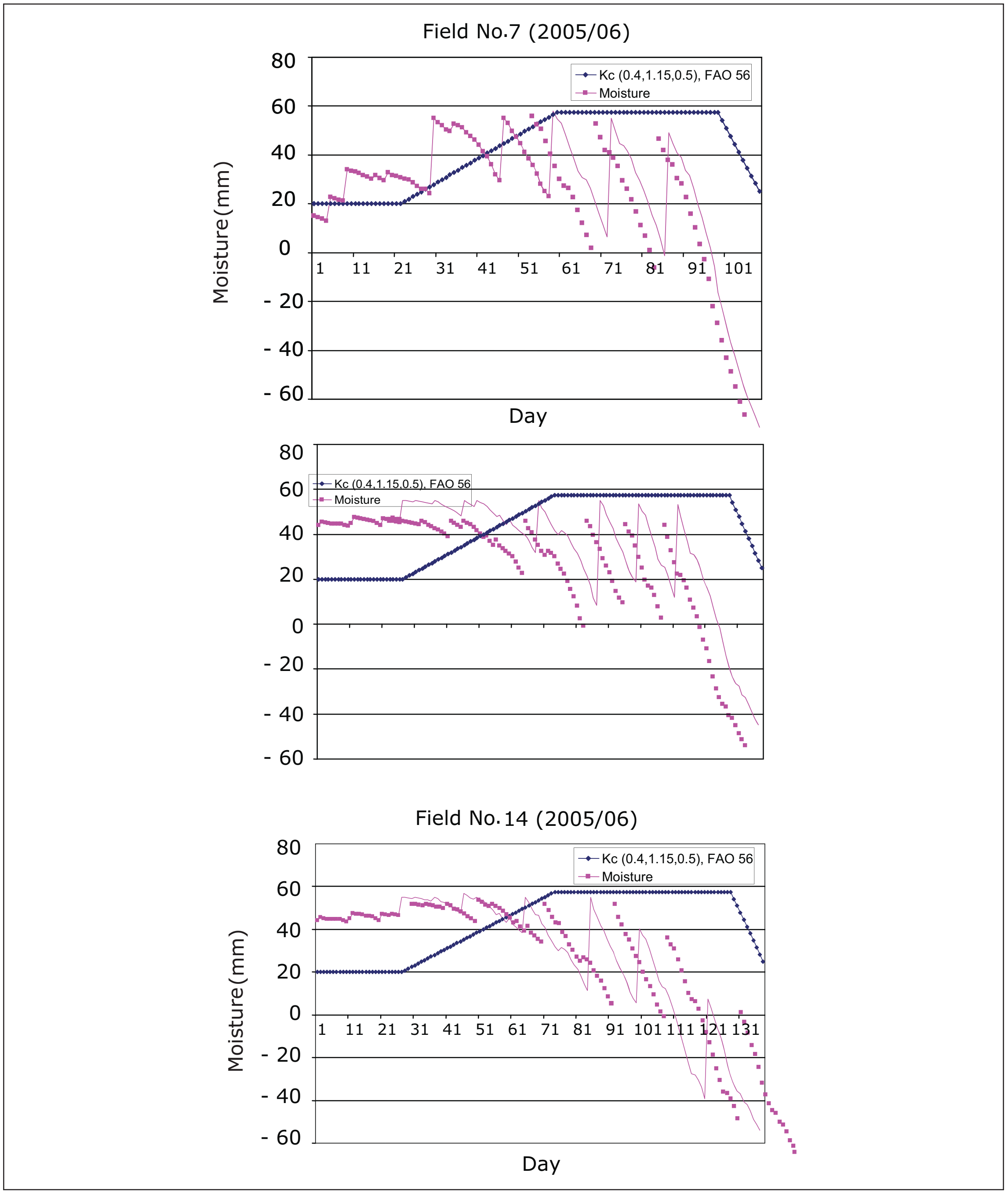


Figure 2.5. Soil moisture levels in the root zone in the Farms 7, 14 and 15.

2.4 Summary of results

- The fertility of the selected farms was low
- The average irrigation WP for wheat in the Sorkheh site was 0.84 kg/m^3 which can be improved to 1.1 kg/m^3 by improving farm and irrigation management
- The mean yield was about 4120 kg/ha from 4963 m^3 of applied water
- Farms with network water resources consumed more water, while the grain yields were higher on farms using wells/network water resources
- The yields of all three of the varieties mentioned were reduced in 2006/07. The reduction in the yield of the Dez cultivar, however, was less than that of the other two.
- The yield and WP were higher on the farms where the wheat was cultivated after corn as compared to those where it was grown after fallow
- The plant is most sensitive to drought stress at the heading stage until the grain has ripened. Therefore, three or four irrigations (50 mm each) are recommended during the period 15 March until 20 April
- The recommended length of the furrow is 250m with an inflow rate of 3.5-4.0 L/s.

Chapter 3.

Assessment of maize water productivity

Chapter 3. Assessment of maize water productivity

3.1 Introduction

Because of its diversified characteristics and wide adaptability to various climatic conditions, maize cultivation has spread throughout the world and stands in third place after wheat and rice with respect to the area under cultivation. Scientific experiences and numerous tests have indicated that in addition to being very suitable forage for livestock, maize is unique with regard to its supply of energy (Kazemi-Arbat, 1995). Other factors helping the expansion of the area under cultivation of this crop are (Kazemi-Arbat, 1995):

- Relative tolerance against drought and lodging
- High yield and WP per hectare compared with other grain crops
- Possibility of inclusion in different rotations with other crops in various climates
- Suitability for mechanization at planting and at the different stages of growth
- Important foodstuff for humans, livestock, and poultry
- Main crop for bio-fuel production.

Maize is cultivated mostly for its kernels with the biomass being used as fodder. Between 20% and 25% of the world maize crop is used in different forms (such as corn flour, pastries, conserves, corn porridge) to feed humans and between 60% and 75% is used for livestock feeding in such different forms as kernel, paste, powder, silo, etc. In addition, about 5% of the maize production is used for industrial purposes.

In upstream Karkheh, maize is planted between mid-July and early August. With a growing period of about 100 to 115 days, it is harvested in late October to late November after full maturation. Maize is usually irrigated in furrows. This crop needs water for completion of its life cycle and production of a suitable yield. The total maize water requirement is between 400 mm and 600 mm in the form of evapotranspiration during the growing period in upstream Karkheh.

Fatemi and Shokrollahi (1993) determined that the overall efficiency of irrigation on non-integrated lands of about 5000 ha in an irrigation network in Dez, Khouzestan Province, was 26%; the nine year average, from 1982 to 1990, was about 21%. Also, they estimated that irrigation efficiency in some parts of the irrigation network of the Dez River, covering 8932 ha, was at most 37%, and on average was 32%. Asadi *et al.* (1996), report that irrigation methods have great effect on the efficiency of irrigation, and farm water losses mainly result from the deep percolation of the water out of the root zone. Kashkouli *et al*. (2000) assessed water loss and irrigation efficiency on two farms on sugar cane plantations in Haft Tapeh, neighboring KRB, and estimated the mean water-application efficiency at 52% and 69%. They reported that the irrigation intervals were too long, and the fields were over irrigated. No data is reported in these studies on crop yield or economic earnings as a result of irrigation.

Agricultural specialists use different definitions for efficiency. Viets (1962) used WUE – the ratio of yield to the amount of water used by the crop. WUE indicates the total yield per unit of water used i.e. WUE=Y/W. Here, Y can be the total biomass of the harvested yield, the total dry matter produced, or the economic return per unit land area, while W can be the total transpiration, the total evapotranspiration, and/or the total water used for irrigation.

The word 'efficiency' has had some ambiguities with respect to the rate of crop yield in comparison with the efficiency of irrigation and/or the efficiency of the water source (Oweis *et al*., 1999). However, some agricultural specialists insist on introducing the rate of yield in the unit area. But, as a result of the looming water scarcity crisis, dystrophy, and environmental issues resulting from overuse of some water sources, the ideas have more been inclined to the concept of yield per unit of water used. In an effort to end these ambiguities, Molden (1997) introduced the term 'Water Productivity' (WP).

Molden (1997) provided the fundamentals and the definitions required for calculating basin WP by estimating the basin water balance. Within such a framework, the methods for presenting the results of actions related to water and irrigation in the agricultural sector (farm operations) and their impacts in the watershed (from the area of the farm to the water distribution system and the basin) have been presented. The reviews indicate that WP for the same crops is very different throughout the world. Water productivity for the cultivation of rice in India has been reported as being between 0.5 kg/m^3 and 1.1 kg/m^3 while in the Philippines it is between and 1.4 kg/m^3 and 1.6 kg/m^3 (Bouman and Tuony, 2001). Water productivity for maize is 1.5 kg/m^3 in China (Kang *et al*., 2000) as well as in India (Mishra *et al*., 2001). Water productivity for wheat is between 0.6 kg/m^3 and 1.9 kg/m^3 (Musick and Porter, 1990), and for potato it is between 6.2 kg/m^3 and 11.6 kg/m^3 – on average 7.5 kg/m^3 – in America (Wright and Stark, 1990). For forages it has been reported to be between 7 kg/m^3 and 8 kg/m^3 (Saeed and El-Nadi, 1988).
A variety of factors affect the optimization of WP. These include environmental and crop factors (Fischer and Turner, 1978) as well as management factors (Kramer, 1988; Hamblin *et al*., 1990).

On the basis of a review of 84 research cases carried out world-wide during the last 25 years, Zwart and Bastiaansen (2004) found that the WP for maize was more than that previously reported by the UN-FAO. According to them, the mean WP for maize is 1.8 kg/m^3. They attributed the variations in this index mainly to such factors as climate, irrigation, and fertilizer management. The obvious result of this research was that water productivity index can be significantly increased by a reduction in the amount of irrigation water. They concluded that the potentials for retention and/or enhancement of water use productivity are high i.e. more production with less water (between 20% and 40% less).

Heidari *et al*. (2006) reported WP for different crops in many parts of Iran, including Kerman, Hamedan, Moghan, Golestan, and Khouzestanunder.
They reported WP values of 0.75 kg/m^3 for wheat, 0.64 kg/m^3 for sugar beet (produced sugar), 2.06 kg/m^3 for potato, 5.58 kg/m^3 for forage maize, 0.71 kg/m^3 for cotton, 1.46 kg/m^3 for alfalfa (dry weight), 0.56 kg/m^3 for barley, and 0.29 kg/m^3 for sugar cane (sugar produced). They described the most important factors influencing WP as farming management and the technical knowledge of the farmers. The enhancement of the knowledge and skill of farmers through different educational and participatory programs is among the important measures that should be taken into consideration in programs for the promotion and enhancement of WP.

Haghayeghi Moghadam *et al*. (2004) assessed the WUE and crop yield of sugar beet under surface and sprinkler irrigation methods. On the basis of root weight and unrefined sugar, their results indicated that the water use rate and water productivity were significantly different at the 5% level, with sprinkler irrigation being superior to the surface irrigation methods. In comparison with furrow irrigation, sprinkler irrigation showed a 31% reduction in the rate of water use and a 55% increase in WP on the basis of the marketable yield.

Irrigation water efficiency and WP are low in KRB. Different factors causing this situation include low Ea, an inappropriate cropping pattern, poor farm management, and an irrigation management that cause salinization of the downstream lands of the basin.

In the northern part of the downstream lands of Karkheh Dam, which is the site of the present study, farmers' knowledge of irrigation and farm management is less than that of farmers in the neighboring basins. Also, not much research has been conducted in this regard. Given the high potential of the farm lands and the availability of suitable quality water in the dams constructed in the region, efficient use of these land and water resources will have a significant impact on the regional as well as the national agricultural economy.

The objective of the present research was to assess irrigation water productivity (WPI) for maize (the dominant summer crop with high water use) in the Sorkheh irrigation network and to identify the factors influencing it.

3.2 Materials and methods

This study was carried out during the growing season 2005-07 in Sorkheh. Based on the sources of farm water supply, seven irrigation units were selected – two units using wells, three units receiving water from irrigation network canals, one unit pumping water from the river, and one unit using both the irrigation network and a well. In each irrigation unit, three farms were chosen. The choice took into consideration such variables as distance to water source, method of water supply, crop cultivar, management of irrigation, and the farming practices. The geographic location and characteristics of the selected farms are shown in Tables 3.1 and 3.2.

The total amount of irrigation water applied (I) was measured (inflow) using a calibrated cutthroat flume installed at the farm water entrance. The runoff (outflow) was measured using a calibrated cutthroat flume of smaller size installed at the end of the farm.

The total yield (Y) was measured based on the total yield harvested by combine. Simultaneously, three samples, each of 6 m^2 (two 4-m ridges) were cut from each farm and the number of plant per unit area, rate of kernel yield, and total dry matter, measured.

The physical and chemical properties of the soil (soil texture, pH, and ECe) and its fertility (N, P, and K), nutrient status, and organic carbon were measured from soil samples taken before planting. Soil samples were collected from depths of between 0 cm and 30 cm from five different locations on the farm and mixed for analysis.

To calculate daily wheat crop water requirement (ETc), daily climatic factors such as the minimum, maximum, and average temperatures, solar radiation, humidity, wind speed, hours of sunshine, evaporation from a Class A evaporation pan, and daily rainfall rate were aquired from Dezful weather station.

To monitor the farming conditionsand management various data were collected during the irrigation season. These data were grouped as follows;

- Farm specification: Length of furrow, slope of the land in the direction of irrigation, area of farm under irrigation
- Crop and farm management: Crop variety, farming and breeding activities, start date of the tillage activities during the crop growth stages, rate and time of fertilizer and pesticide application, seeding rate

Table 3.1. Geographic location and characteristics of the selected farms in 2006.

Field No.	Source of water	Geographic information	Slope length (%)	Area (ha)
1	Network (1 unit)	Elevation 36.0 m 3219.485 N and 4806.598 E	0.005	3.2
2	Network (1 unit)		0.004	2.8
3	Network (1 unit)		0.005	3.3
4	Network (2 units)		0.005	3.6
5	Network (2 units)	Elevation 93.9 m 3220.190 N and 4804.676 E	0.00425	5.9
6	Network (2 units)		0.00478	5.0
7	Network (2 units)		0.0055	8.8
8	Network (3 units)	Elevation 148.7 m 3220.571 N and 4800.954 E	0.006	3.0
9	Network (3 units)		0.009	1.6
10	Network (3 units)		0.005	3.3
11	Network and well	Elevation 135.6 m 3223.040 N and 4806.597 E	0.0053	11.8
12	Network and well		0.004	8.4
13	Network and well		0.00389	8.1
14	Well (1 unit)	Elevation 33.8 m 3221.858 N and 4808.059 E	0.0033	17.7
15	Well (1unit)		0.0021	4.4
16	Well (2 units)	Elevation 30.5 m 3212.592 N and 4808.009 E	0.0022	3.7
17	Well (2 units)		0.0035	3.7
18	Well (2 units)		0.0025	4.0
19	River	Elevation 44.8 m 3221.841 N and 4809.060 E	0.0035	5.3
20	River		0.003	4.9
21	River		0.0027	10.5

Table 3.2. Geographic location and characteristics of the selected farms in 2007.

Field No.	Source of water	Geographic information	Area (ha)
1	Network (1 unit)	Elevation 118 ft 3219.485 N and 4806.598 E	3.2
2	Network (1 unit)		0.9
3	Network (1 unit)		3.3
4	Network (2 units)	Elevation 308 ft 3220.190 N and 4804.676 E	3.9
5	Network (2 units)		2.0
6	Network (2 units)		2.8
7	Network (3 units)	Elevation 488 ft 3220.571 N and 4800.954 E	2.3
8	Network (3 units)		6.4
9	Network (3 units)		1.6
10	Network and well	Elevation 445 ft 3223.040 N and 4806.597 E	12.0
11	Network and well		14.1
12	Network and well		9.3
13	Well (1 unit)	Elevation 111 ft 3221.858 N and 4808.059 E	17.7
14	Well (1 unit)		4.4
15	Well (2 units)	Elevation 100 ft 3212.592 N and 4808.009 E	3.7
16	Well (2 units)		4.3
17	Well (2 units)		3.7
18	River	Elevation 147 ft 3221.841 N and 4809.060 E	4.9
19	River		10.5
20	River		8.9

- Crop calendar: Time of planting, duration of the initial stage of growth (germination), beginning of generative stage, duration of generative stage, beginning of ripening stage, duration of ripening stage, harvest date.

Maize water productivity ($WP_{(I+R)}$ and IE were calculated using equations 2-1 and 2-2.

3.3 Results and discussion

3.3.1 Soil properties

The results of the soil analyses are presented in Tables 3.3 and 3.4. The soil pH ranged between 6.57 and 8.12 and the electrical conductivity varied between 0.96 dS/m and 3.80 dS/m. According to the results in Tables 3.3 and 3.4 the organic matter content of the soils of

Table 3.3. Some chemical and physical properties of the soil of the selected farms in 2006.

Field No.	Soil texture	Element		pH	Electrical conductivity (dS/m)	Organic carbon (%)
		Potassium (ppm)	Phosphorus (ppm)			
1	L	121	3.9	7.32	2.3	0.31
2	L-Sa.L	343	6	7.04	2.65	0.61
3	L	121	10.6	7.04	1.5	0.43
4	L	140	3.3	6.6	2.1	0.53
5	L	121	3	6.81	2.5	0.28
6	L	131	6.6	6.84	1.6	0.39
7	L	131	20.8	6.72	1.75	0.43
8	Sa.L	69	5	7.6	1.3	0.36
9	L	263	7.3	7.27	1.3	0.96
10	Sa.L	86	3.7	7.37	1.1	0.4
11	L	149	6.3	7.553	1.7	0.76
12	Si.L	69	2.4	8.02	0.96	0.39
13	L	149	8	7.65	1.25	0.75
14	L	168	7.5	8.12	2	0.64
15	Si.L	178	7.7	7.71	2.5	0.59
16	Si.L	95	1.6	6.75	3.8	0.23
17	Sa.L	77	2.7	7.22	3.3	0.42
18	Si.L	104	2	7.06	3.3	0.37
19	L	178	9	7.2	1.5	0.77
20	Sa.L	121	3.9	6.57	2.5	0.66
21	L	131	6.4	6.84	1.6	0.51

L – loam; Sa.L – sandy loam; Si.L – silty loam

the selected farms was low. Following a suitable crop rotation, cultivating leguminous plants, and applying organic fertilizers, such a shortage will be addressed and the yield of irrigated crops will be improved.

3.3.2 Climatic characteristics of the region

The average daily temperature and monthly climatic and meteorological characteristics of the Safi Abad-Dezfoul region during the maize growth season are provided in Tables 3.5 and 3.6.

3.3.3 Maize water productivity

The lower yield recorded by combine was attributed to a delay in the harvesting operation, which led to a reduced yield as a result of the negative effects of some natural pests (mice, hogs, etc.).

The average irrigation WUE for the studied farms, as measured in 2006 was

Table 3.4. Some chemical and physical properties of the soil of the selected farms in 2007.

Field No.	Soil texture	Element		pH	Electrical conductivity (dS/m)	Organic carbon (%)
		Potassium (ppm)	Phosphorus (ppm)			
1	L	188	10.7	7.1	4.9	0.75
4	L	86	3.6	7.46	1.4	0.4
5	L	140	5.7	7.26	3.2	0.98
6	L	121	5	7.19	2.9	0.48
7	Sa-L	95	2.7	7.27	3	0.31
8	L	104	8.3	7.62	1.4	0.47
9	Sa-L	77	8.5	7.57	1.6	0.55
10	-†	131	4.2	7.54	1.6	0.23
11	-	140	3.3	7.63	1.4	0.32
12	-	178	6.2	7.65	1.5	0.53
13	-	251	5.2	7.66	2.8	0.23
14	-	159	4.5	7.72	2.2	0.23
15	Si-L	131	16.5	7.34	3.9	0.58
16	L	131	11.9	7.23	3.8	0.6
17	L	95	4.5	7.38	4.2	0.25
18	Sa-L	43	5	7.28	2	0.45
19	Sa-L	69	6.1	7.2	2.7	0.46
20	Sa-L	60	4.4	7.34	2.7	0.49

†Not measured.

0.56 and in 2007 it was 0.57. The interval between irrigations in both years was about nine days. Taking into consideration an average daily evaporation of 10 mm during late July to mid-September, and allowing 70 mm cumulative evaporation from a Class A pan between irrigations, an average weekly irrigation interval is recommended (Saremi, 1998).

Considering the results presented in Tables 3.7 and 3.8, all of the selected farms received much more water than the crop water requirement. As a result, the WPI values have a direct and positive relation with the yield of kernel, and a negative relation with the amount of water applied (Figures 3.1, 3.2 and 3.3). According to Figures 3.2 and 3.3, the slope of the changes in WP with the amount of water used is more in 2007.

Figure 3.4 shows the change in yield with the planting density as it applied to the selected fields. According to the result, beyond of treshhold palting density (70000 plants/ha), any further increase in planting density has a negative impact on the crop yield.

Table 3.5. Climatic characteristics of the region during 2006.

Month	Temperature (⁰C)			Rain (mm/ month)	Maximum wind velocity		Relative humidity (%)	Sun shine (hr/ month)	Evapo-ration (mm)
	max	min	av		(m/s)	date			
Jul	46.6	25.8	36.2	0.0	12.0	7	33.0	354.6	410.9
Aug	46.1	27.5	36.8	0.0	7.0	5	37.2	333.3	361.9
Sep	40.4	20.9	30.7	0.0	5.0	3	44.7	312.8	260.7
Oct	34.5	20.4	27.5	38.2	25.0	29	52.1	196.3	199.1
Nov	23.6	11.7	17.6	37.7	8.0	19	66.4	205.8	69.8
Dec	15.2	5.4	10.3	90.7	13.0	16	77.4	159.7	34.9

Table 3.6. Climatic characteristics of the region during 2007.

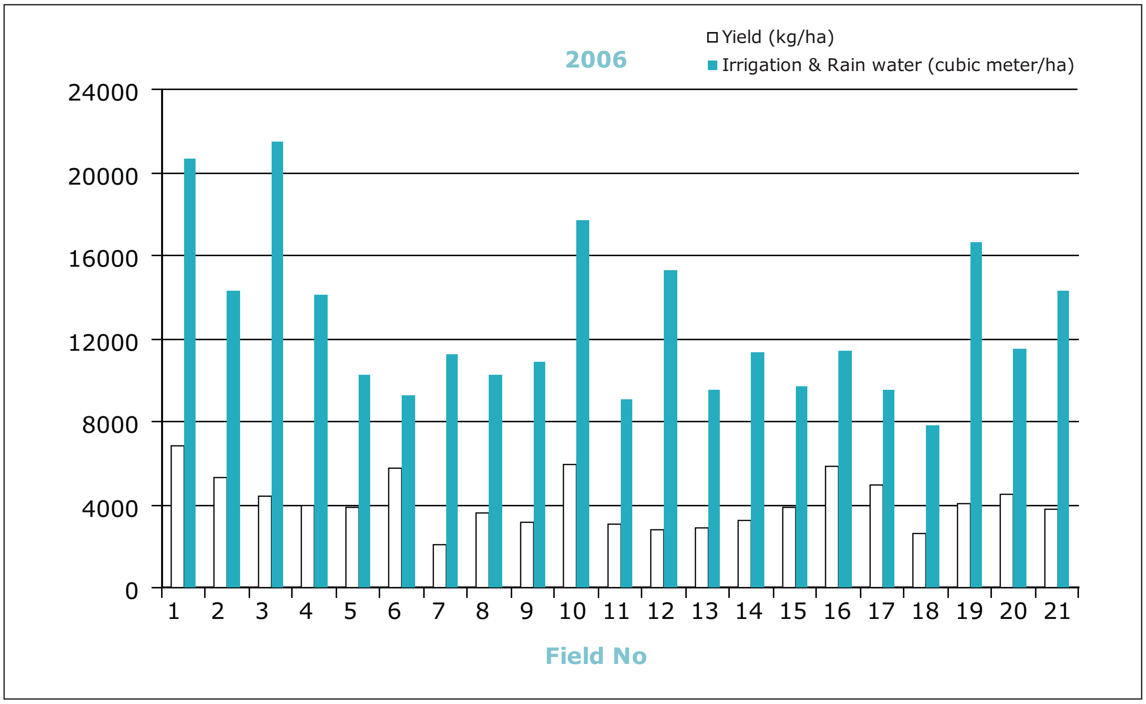
Month	Temperature (⁰C)			Rain (mm/ month)	Maximum wind velocity		Relative humid-ity (%)	Sun shine (hr/ month)	Evapo-ration (mm)
	max	min	av		(m/s)	date			
Jul	45.8	25.7	35.8	0.0	8.0	3	34.4	322.7	385.7
Aug	45.8	25.8	35.8	0.0	15.0	28	36.9	330.0	382.7
Sep	41.3	21.6	31.4	0.0	10.0	14	45.0	303.5	259.0
Oct	35.3	17.1	26.2	0.0	7.0	6	52.8	281.0	180.7
Nov	26.7	11.4	19.1	3.6	10.0	20	56.6	198.2	109.1
Dec	19.0	8.2	13.6	45.9	12.0	6	72.9	160.0	51.5

Table 3.7. Agronomic practices and maize water productivity in 2006.

Field No.	Planting date	Harvesting date	Days between first and second irrigation	Plant density	No. of irriga-tion events	Runoff (m^3/ha)	Irrigation require-ment (ET) (m^3)	Grain yield-by combine (kg/ha)	Grain yield by sampling (kg/ha)	IE (%)	WP (ET) (kg/m^3)	WPI (kg/m^3)
1	31.06.06	06.12.05	3	70,000	11	2,380	6,270	6,836	6,386	0.303	1.019	0.373
2	28.o6.06	29.11.06	4	62,963	10	4,200	6,570	5,268	4,129	0.460	0.752	0.522
3	28.06.06	29.11.06	5	63,704	11	4,370	6,570	4,425	5,496	0.306	0.631	0.259
4	27.06.06	01.12.06	5	57,037	11	0	6,660	3,990	4,731	0.471	0.561	0.282
5	02.07.06	04.12.06	7	72,222	10	990	6,050	3,899	7,984	0.589	0.597	0.420
6	12.07.06	11.12.06	7	58,148	9	1,320	5,080	5,748	4,564	0.546	1.005	0.720
7	03.07.06	05.12.06	15	47,037	10	980	5,950	2,096	3,313	0.528	0.325	0.204
8	30.06.06	29.11.06	6	55,926	14	2,190	6,160	3,573	6,005	0.599	0.539	0.441
9	19.07.06	16.12.06	5	58,519	12	3,360	4,910	3,124	4,376	0.451	0.564	0.415
10	20.06.06	29.11.06	6	91,111	15	3,510	7,500	5,967	4,987	0.424	0.774	0.421
11	13.07.06	15.12.06	7	51,852	6	0	4,730	3,013	4,704	0.521	0.562	0.332
12	20.06.06	27.11.06	12	48,519	12	2,900	7,470	2,791	6,053	0.488	0.363	0.225
13	.02.07.06	28.11.06	9	50,000	8	0	5,860	2,854	4,636	0.616	0.448	0.300
14	22.07.06	01.12.06	3	70,741	13	5,110	7,450	3,211	5,323	0.655	0.418	0.513
15	01.07.06	02.12.06	10	55,185	10	3,980	6,150	3,883	7,027	0.633	0.586	0.678
16	07.04.06	04.12.06	7	99,259	11	4,840	5,870	5,863	4,934	0.515	0.920	0.895
17	24.06.06	28.11.06	8	70,370	13	2,740	7,040	4,936	6,555	0.736	0.666	0.724
18	15.06.06	27.11.06	4	51,852	13	2,160	7,530	2,596	4,842	0.959	0.337	0.456
19	29.06.06	03.12.06	3	61,481	11	3,670	6,470	4,057	5,731	0.389	0.585	0.313
20	03.07.06	06.12.06	3	78,148	9	1,670	6,470	4,495	6,273	0.564	0.645	0.458
21	29.06.06	03.12.06	9	76,296	8	1,220	5,950	3,774	6,847	0.416	0.586	0.288

Table 3.8. Agronomic practices and maize water productivity in 2007.

Field No.	Planting date	Harvesting date	No. days betw-een first and second irriga-tion	Plant density (plant/ha)	No. of irriga-tion events	Inflow (m^3/ha)	Runoff (m^3/ha)	Irrigation require-ment (ET) (m^3)	Grain yield-by combine (kg/ha)	Grain yield-by samp-ling (kg/ha)	IE (%)	WP (ET) (kg/m^3)	WPI (kg/m^3)
1	21.06.07	30.11.05	4	71,667	11	11,530	2,560	8,450	4,608	6,394	0.733	0.545	0.400
2	11.06.07	25.11.06	6	71,111	12	14,040	2,540	9,060	5,211	7,363	0.646	0.575	0.371
3	11.06.07	25.11.06	6	82,222	12	13,630	2,730	9,060	5,705	5,606	0.665	0.629	0.419
4	22.06.07	13.12.06	6	58,333	12	12,120	2,260	8,270	5,716	8,064	0.682	0.692	0.472
5	01.07.07	13.12.06	8	57,778	10	11,050	1,740	7,250	5,899	5,835	0.656	0.814	0.534
6	09.07.07	13.12.06	6	48,889	10	8,730	2,040	6,400	4,465	5,065	0.733	0.698	0.512
7	25.06.07	13.12.06	4	95,556	17	17,540	8,590	8,090	2,893	8,022	0.461	0.358	0.165
8	25.06.07	30.11.06	5	86,111	17	16,170	7,920	8,090	3,479	4,791	0.500	0.430	0.215
9	23.06.07	01.12.06	6	92,778	17	20,440	10,180	8,270	7,594	7,867	0.404	0.919	0.372
10	24.06.07	02.12.06	11		10	27,460	13,460	8,170	5,854		0.298	0.716	0.213
11	07.06.07	04.12.06	6	96,667	10	24,900	12,200	9,460	4,641	6,414	0.380	0.491	0.186
12	10.06.07	25.11.06	5		10	24,900	12,320	9,180	6,965		0.368	0.759	0.280
13	24.06.07	25.11.06	7	68,889	11	18,380	2,860	8,170	7,726	9,837	0.445	0.945	0.420
14	25.06.07	30.11.06	7	72,222	11	20,060	5,420	8,090	9,295	12,238	0.403	1.149	0.463
15	26.06.07	04.12.06	4	62,222	12	11,890	4,760	8,020	3,464	5,877	0.674	0.432	0.291
16	27.06.07	16.12.06	4	60,556	12	20,580	5,180	7,920	4,858	8,553	0.385	0.614	0.236
17	06.07.07	16.12.06	5	36,111	10	13,850	7,840	6,690	2,189	3,769	0.483	0.327	0.158
18	27.06.07	16.12.06	4	60,556	10	10,980	1,130	7,720	7,584	8,668	0.703	0.982	0.691
19	28.06.07	18.12.06	3	55,000	10	11,260	1,040	7,640	7,721	6,420	0.678	1.011	0.686
20	04.07.07	15.12.06	6	57,222	10	6,000	0	6,870	6,321	5,445	1.145	0.920	1.054



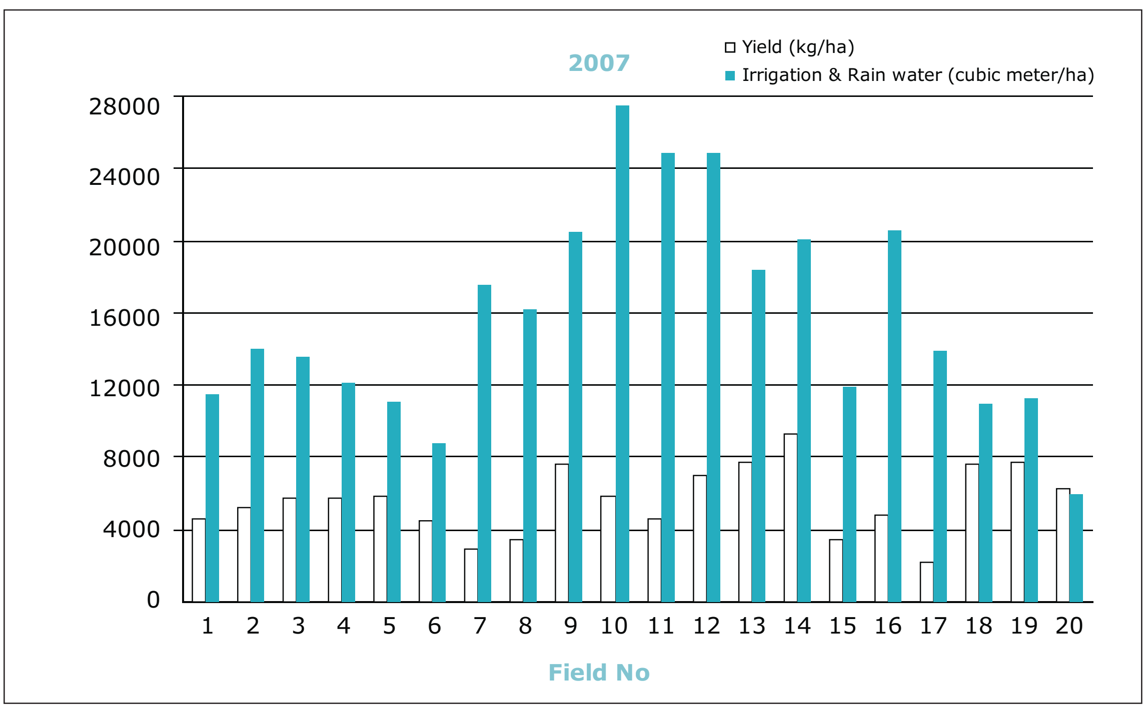


Figure 3.1. Yield of maize kernel and amount of irrigation water applied on the farms during 2006/07.

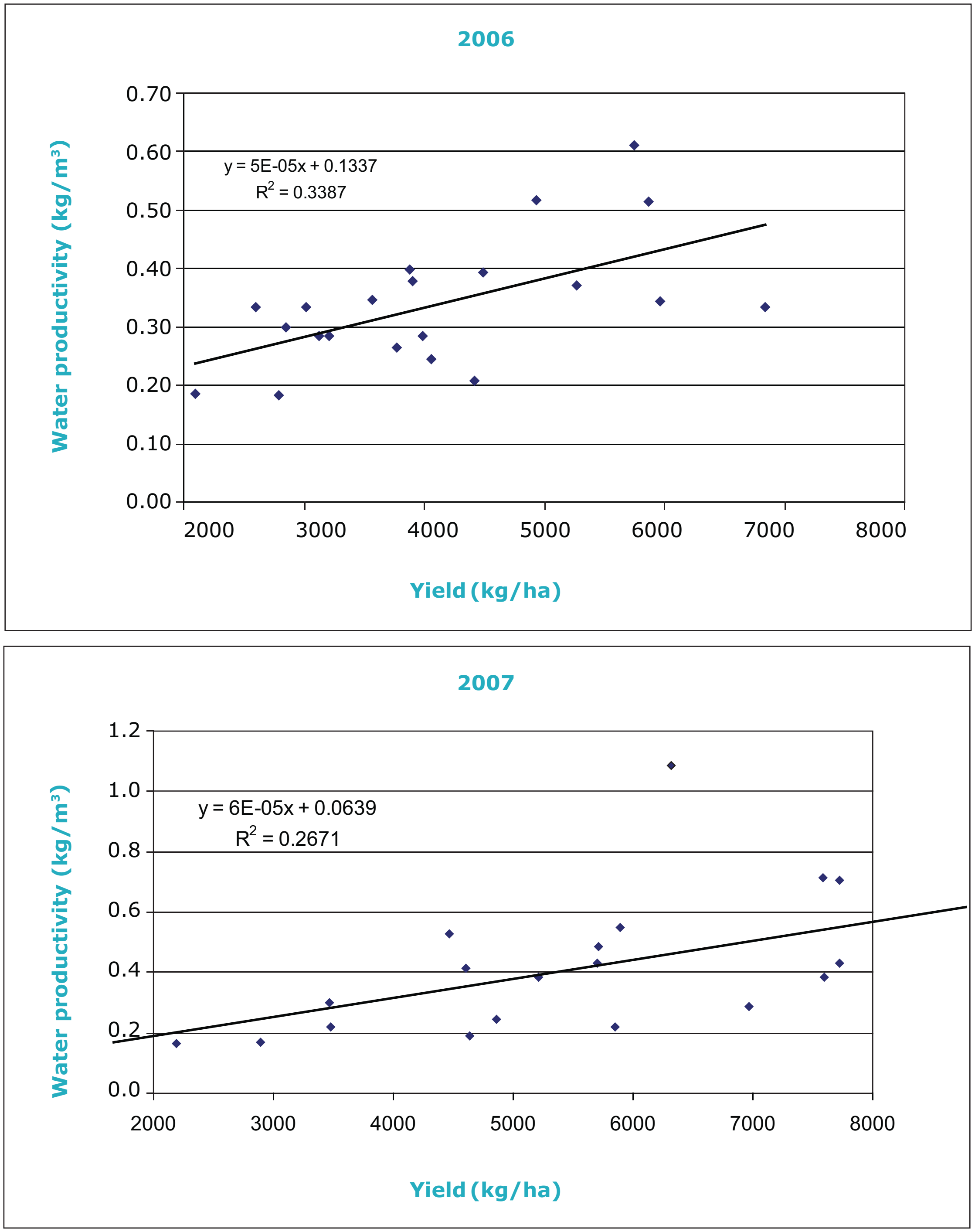
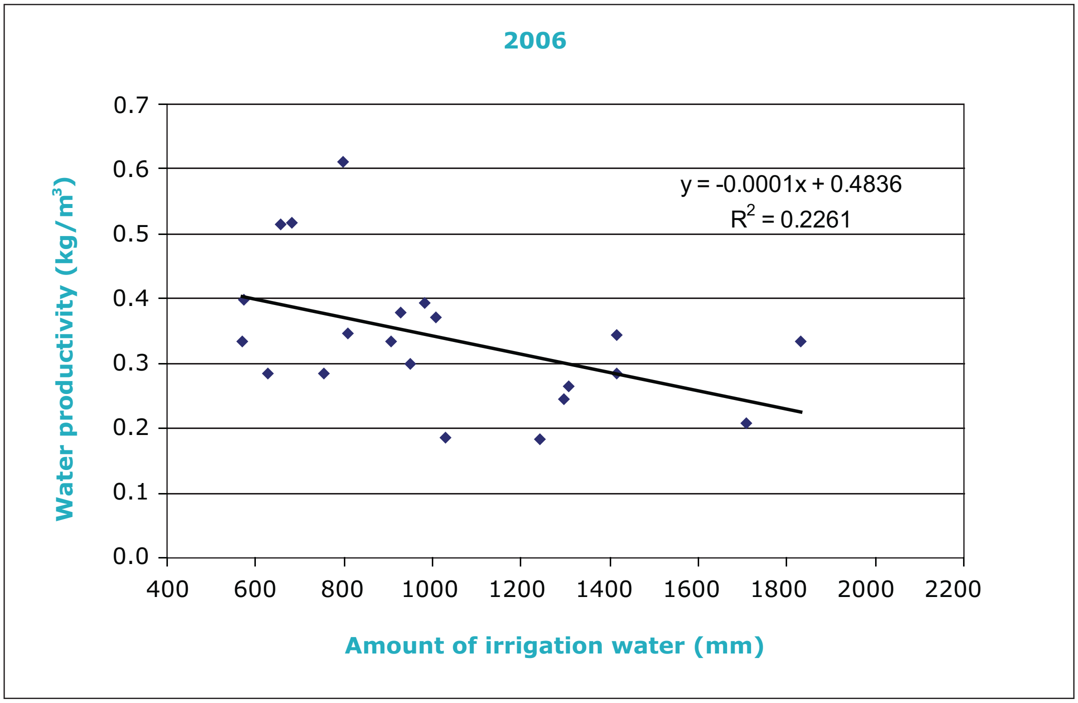


Figure 3.2. Changes in WPI with the yield of kernel for selected farms during 2006/07.



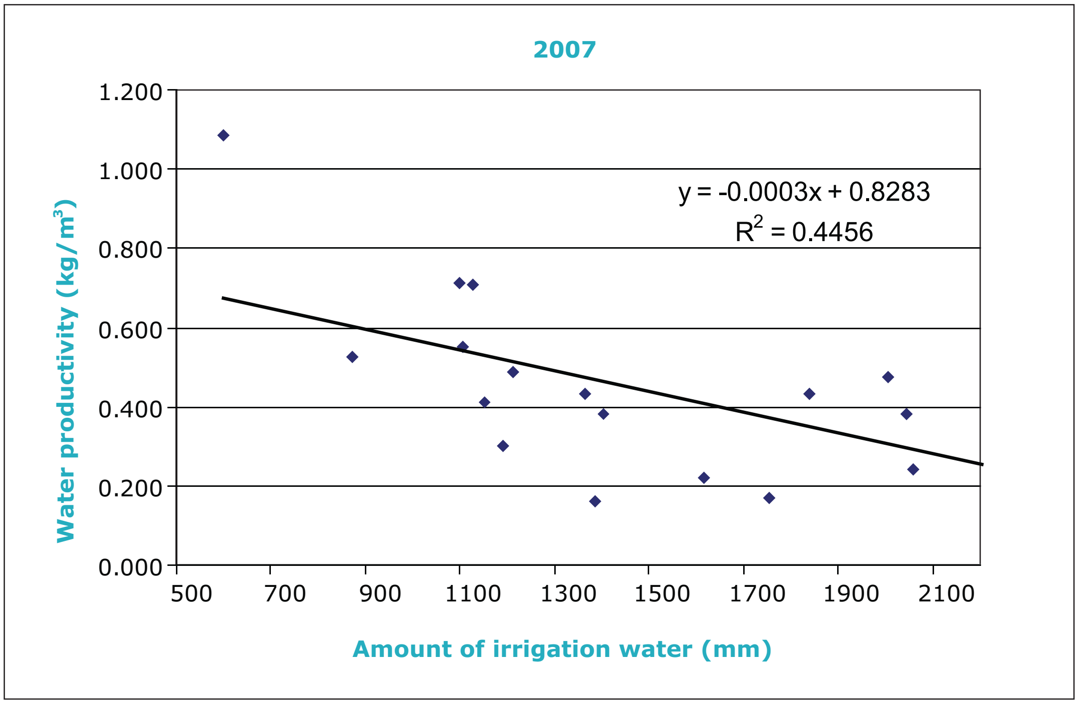


Figure 3.3. Changes in WP with the amount of irrigation water applied for selected farms during 2006/07.

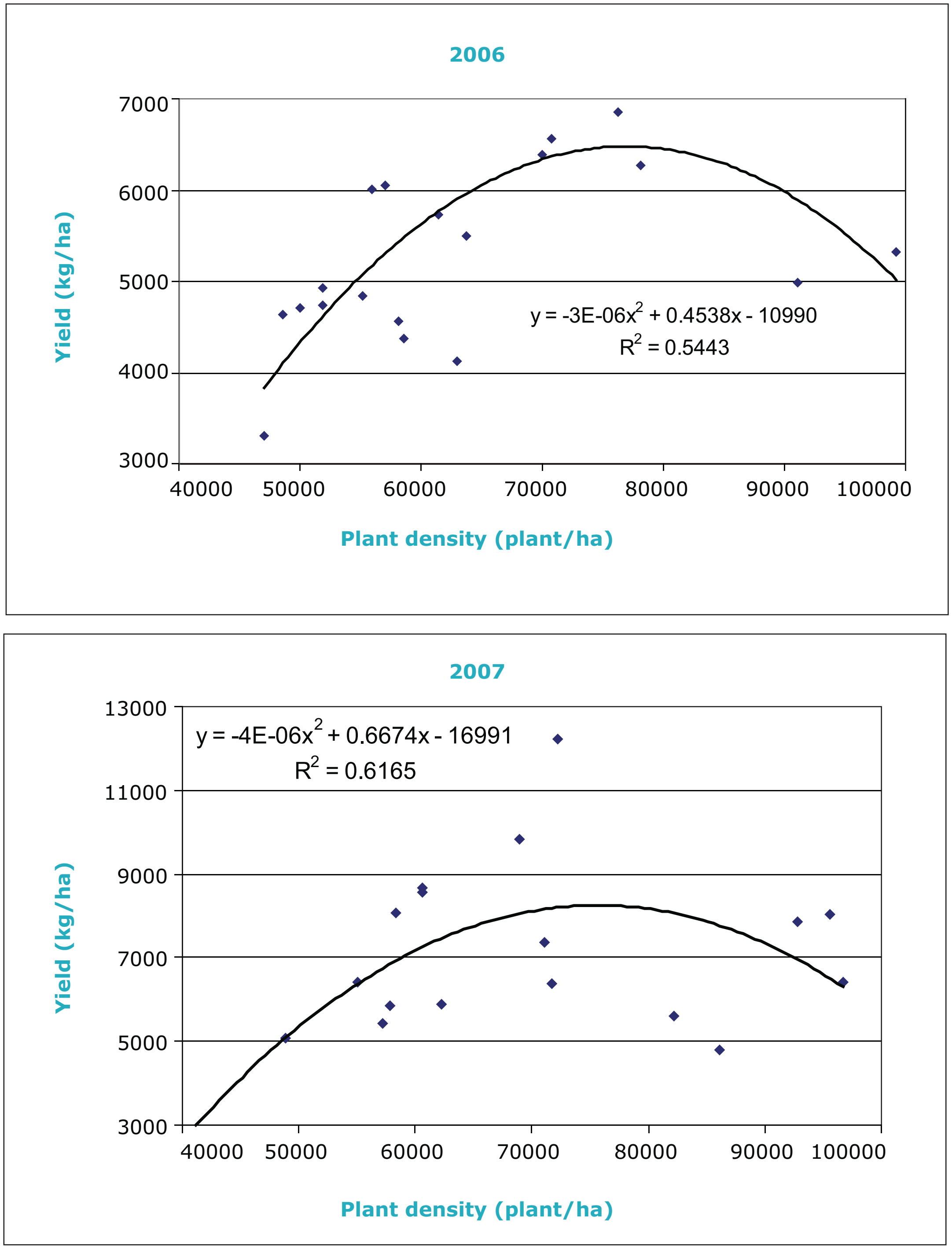


Figure 3.4. Changes in the yield of maize kernel with plant density on selected farms during 2006/07.

3.4 Summary of results

- The average amount of organic matter available in the soil of the selected farms (1%) was low compared to the recommended level (3%).
- The average WP for maize at the Sorkheh site was 0.42 kg/m^3
- The highest yield is achieved with a planting density of 75,000 plants/ha
- Despite the overuse of water, the water need of the crop was not satisfied. The intervals between irrigations were more than those recommended. It is recommended by us to observe a seven day interval between irrigations
- If the yield remains the same under different water management practices, the irrigation water efficiency can be enhanced to a maximum of about 50% by improvement in irrigation practices, schemes and technique.

Chapter 4.

Methods of improving water productivity for wheat

Chapter 4. Methods of improving water productivity for wheat

4.1 Introduction

The WP for wheat has been estimated at about 0.84 kg/m^3 in parts of the command area of the Karkheh Dam. In other words, 1.25 m^3 of water are used to produce 1 kg of wheat grain. In order to ensure a food supply for the growing population of Iran, WP must increase to 1.9 kg/m^3 (double the current amount), by the year 2020 (Keshavarz and Ashrafi, 2004). To achieve this, various options are available:

- Produce improved genotypes of plants that can tolerate drought
- Implement a comprehensive management plan for water resources in a basin or watershed
- Adopt improved water management techniques at the farm and network level
- Study different systems and establish institutions to control and monitor water quality.

In Iran, In spite of governmental plans to expand pressure irrigation, more than 90% of the irrigated land uses surface and traditional methods. Gravity irrigation is, by far, the main method used for wheat by the farmers. Although the wheat yield is somewhat dependent on the precipitation in autumn, winter, and spring, a limited number of irrigation applications – between two and seven – has a significant effect on the yield. Optimizing surface irrigation methods and introducing the best method for planting wheat under different climate and soil conditions are important factors in increasing yield and WP – the objectives of this project.

There has been a substantial amount of research, some of which is reviewed in the following paragraphs, comparing different sowing and irrigation methods. Wang *et al*. (2001) investigated the relationship between irrigation, evapotranspiration, and WP in a wheat-corn rotation. The results showed that by using a mulch to reduce evaporation, water consumption was reduced by 800 m^3/ha and, consequently, water productivity increased. Feng-Min Li *et al*. (2001) compared three irrigation regimes according to the different fractions of moisture in the top layers of the rhizosphere and concluded that the highest WP for wheat was obtained when the crop was irrigated to achieve a soil moisture content of between 50% and 60% of the total field capacity.

As reported by Agrawal *et al*. (1982), studies in the USA have shown that, for winter wheat in Colombia, reducing irrigation water by 24% and constant costs by 32% led to reductions of 41% in other irrigation costs (energy, labor, etc.), and 27% in the cost of chemical fertilizers and pesticides. It also reduced the cost incurred by the practice of sowing until harvest. These reductions have been confirmed by farmers who also benefited from the more economical use of water (Agrawal *et al*., 1982).

Other research in the USA (English and Nakamura, 1989), studied the relationship between the variable costs of irrigation and other variables. This study showed that increasing the depth of irrigation led to changes in the variable costs of irrigation (fuel, energy, labor, etc.) which were less than the changes in the other variable costs. Using different crops in rotation is another important consideration, because some crops (wheat, barley, and corn) may do better under the management regime and schedule of limited irrigated, while other crops are more suitable for full irrigation.

Afzali Nia *et al*. (2008) reported that cropping patterns had no significant impact on the yield of wheat, but that a combination of sowing using a seed drill, and implementing basin irrigation resulted in the highest yield. An economic comparison showed that the same management practices also had the advantage of lower costs. Malik *et al*. (1987) studied the effect of four irrigation methods (furrow, basin, border, and sprinkler) on yield and WP for wheat; they reported that the highest yield was associated with basin irrigation and the highest water productivity with sprinkler irrigation. Mudiare (1993) studied the effects of three methods of irrigation (furrow, basin, and border) on the vegetative growth and yield of wheat with irrigation intervals of one, two, and three weeks. He reported that the highest yields obtained for all irrigation intervals was under furrow, basin, and border irrigation, in decreasing order.

Farshi and Ghaemi (2000) studied how irrigation intervals and depth affected the yield of wheat. The results showed that in order to produce acceptable wheat yields in double planting rows in a ridges system; irrigation must be applied after 65% of available water in the root zone has been depleted. Farshi and Ghaemi also reported that the highest WP was achieved when 95% of the available water in the root zone had been depleted.

The WP increases under deficit irrigation compared to full irrigation, as shown experimentally for many crops (Zwart and Bastiaansen, 2004; Fan *et al*., 2005). Wang *et al*. (2004) found that growing winter wheat in beds and irrigating the plants via furrows rather than through flood irrigation could save as much as 30% of the applied irrigation water; it also resulted in more efficient water use. Furthermore, grain yield was found to increase by more than 10%. Compared with bed planting, furrow planting resulted in greater storage of soil water; however, the stored soil water was less dispersed in the 0–90 cm layer of the furrow field compared to a similar layer in the field where wheat was grown on beds. Dispersion of stored soil water at the 100–120 cm layer was similar for furrow planting and bed planting (Yu *et al*., 2005). As for water movement after irrigation, this was slower for both bed planting and furrow planting than it was for row planting on top of the furrows (Kang *et al*., 2000).

According to research that took place over two years in Yazd Province, Iran, planting wheat in bed furrows at a density of 550 seeds/m^2 produced 4.86 t/ha of grain. This method was recommended because it reduced the build-up of salt in the furrows (Mostafavi, 1991). Taking account of Mostafavi's results, and in order to prevent soil erosion caused by irrigation water, the researchers in Yazd proposed furrow irrigation, double-row planting and three-row planting on 75 cm and 90 cm wide bed ridges. Planting on beds (between 60 cm and 90 cm wide) increases water availability for plants, makes it easier to control weeds, fertilize, and harvest, and improves surface drainage (Rawson and Macpherson, 2000).

In our research, the main hypothesis is that applying particular methods of planting can conserve soil moisture, prevent erosion, and enhance yield and WP. More specifically, in the case of planting winter wheat after corn in the autumn, additional problems can arise because of the limited time for planting, the presence of corn residues at the field surface, and the high moisture content in the soil caused by the autumn precipitation. The irrigated lands of the Karkheh Basin have played an essential role in increasing corn production, so determining the best planting method for winter wheat following corn has special importance in this regard. In our experiments, the objective is to determine the most efficient use of water for irrigating land downstream of the Karkheh Dam, and to decide on suitable agronomic practices for increasing agricultural WP, with farmers participating in the research by applinying experimental treatments in their fields.

4.2 Materials and methods

4.2.1 Geographic location

Trials were conducted in the Sorkheh district of the Avan Plain (Dasht-e Avan) in the lower Karkheh River Basin (KRB) of Iran during the 2005, 2006, and 2007 growing seasons. This plain has a semi-arid climate with an average rainfall of about 350 mm. The climate is also a Mediterranean type and, therefore, lacks summer rainfall. Characteristics of the selected fields are shown in Table 4.1 and Table 4.2.

On the Avan Plain, two types of agricultural rotation are quite common – wheat-vegetable/fallow-wheat and wheat-corn/fallow-wheat. In the research, farmers' fields incorporating these two rotations were tested, and same rotation was conducted at the Safi Abad Agricultural Research Center, during the 2005, 2006, and 2007 growing seasons.

For the research, two farms were selected with the participation of farmers, and different farming and surface irrigation management regimes were tested, using a t-test for data analysis. For the on-farm trials, treatments were carried out according to the equipment that was available on the farm. However, at the Safi Abad Agricultural Research Center, a complete set of treatments was applied.

4.2.2 Treatments

Trials on farms using the wheat-fallow/vegetable-wheat rotation

The trials included five surface irrigation treatments for the wheat crops:

I_1 - Furrow irrigation with three-row planting on 60 cm-wide raised beds or ridges (planting with drill)
I_2 - Furrow irrigation (broadcasting, disk, corrugators, and border)
I_3 - Border irrigation (seeding, disk and border)
I_4 - Border irrigation (row planting, border)
I_5 - Farmers' practices

Trials on farms using wheat-corn-wheat rotation (planting in corn residue)

The trials included treatments for managing corn residues and irrigation treatments, as follows:
I_6 - Corrugation irrigation (residue chopper, seeding)
I_7 - Border irrigation (residue chopper, seeding)
I_8 - Border irrigation (disk, seeding)
I_9 - Farmers' practices.

The durum wheat cultivar D-79-15 and two bread wheat cultivars, Chamran and Vierinak, were planted in the corn-wheat rotation. The sowing density in the experimental plots was 400 seeds/m^2, while the width of the plots was between 12 m and 15 m; the length of the plots varied from 235 m to 400 m according to the dimensions of the farm. The following measurements were taken at all the trial farms:

- Soil testing for soil salinity (ECe), fertilizer requirement, and pH, at a depth of from 0 cm to 30 cm, samples being taken from five points in the field before planting
- Slope of the land in the direction of irrigation and the length of the furrow
- Inflow and outflow of water during all irrigations
- Meteorological parameters, such as minimum, maximum, and average temperatures, solar radiation, soil moisture, wind speed, hours of sunshine, evaporation from a Class A evaporation pan, daily rainfall
- Water need, using evaporation data from a Class A evaporation pan
- Agronomic parameters and phonological data, such as germination date, number of seeds emerging per unit area, stem elongation date, heading date, pollination date, physiological ripening date, leaf area index, and plant density. Also, 10 plants from each treatment were cut from each farm and their biological yield, grain yield, harvest index, and other parameters were determined.

In our statistical analysis, the means of yields were compared using a t-test. Parameters such as the amount of irrigation water applied, yield, WP (equation 2-1), IE (equation 2-2), and net profit were determined and compared to the results obtained by the collected data from farmers' field.

4.3 Results and discussion

4.3.1 Characteristics of the trial fields

The characteristics of the fields where the studies were carried out are shown in Table 4.1 and Table 4.2.

4.3.2 Soil test results

The results of the soil analyses are presented in Table 4.3 and Table 4.4.

Table 4.1. Some characteristics of the fields selected for wheat trials in 2006

Field No.	Source of water	Location	Use before wheat	Land slope (m/m)	Length of run (m)
1	Irrigation network and well	Sorkheh	Fallow	0.0053	400
2	Irrigation network and well	Sorkheh	Corn	0.0055	300
3	Well	Sorkheh	Fallow	0.0022	235
4	Well	Sorkheh	Corn	0.0033	315

Table 4.2. Some characteristics of the fields selected for wheat trials in 2007.

Field No.	Source	Location	Use before wheat	Land slope (m/m)	Length of run (m)
1	Irrigation network and well	Sorkheh	Fallow	0.0038	240
2	Well	Sorkheh	Fallow	0.0022	295
3	Well	Sorkheh	Corn	0.0025	230
4	Well	Sorkheh	Corn	0.0035	180

4.3.3 Meteorological data

In Table 4.5 and Table 4.6, climatic data for the 2005–2007 seasons are shown. These were reported by the meteorological station at the Safi Abad Agricultural Research Center, which is between 1 km and 2 km from the selected experimental sites.

4.3.4 Experimental results

Results obtained for the different irrigation treatments during the two years of the study are shown in Tables 4.7 and 4.8.

Table 4.3. Some chemical and physical properties of the soils on the farms selected for wheat trials in 2006.

Field No.	Soil texture	Element		pH	EC (dS/m)	Organic carbon (%)
		P (ppm)	K (ppm)			
1	Si.L	1.9	94.8	7.7	1.4	0.25
2	L	4.2	130.6	7.0	1.7	0.46
3	Si.L-L	15.1	262.6	7.5	4.1	0.49
4	Si.C.L	21	319.6	7.3	4.4	0.54

Si.L – silty loam; Si.C.L – silty, clayey loam

Table 4.4. Some chemical and physical properties of the soils on the farms selected for wheat trials in 2007.

Field No.	Soil texture	Element		pH	EC (dS/m)	Organic carbon (%)
		P (ppm)	K (ppm)			
1	L	4.87	106.3	7.21	1.30	0.18
2	L	2.27	137.7	6.96	1.27	0.24
3	Si.L	1.23	74.7	6.9	3.10	0.09
4	Si.L	2.23	92.3	6.89	3.63	0.09

Table 4.5. Climatic data for Dezful 2005/06.

Month	Temperature (°C)			Rainfall (mm)	Wind		Relative humidity(%)	Sunshine (hr)	Epan (mm)
	max	min	av		speed (m/s)	date			
Dec	15.2	5.4	10.3	90.7	13.0	16	77.4	159.7	34.9
Jan	16.4	5.3	10.8	60.5	11.0	11	75.5	168.4	41.2
Feb	20.4	9.0	14.7	52.7	11.0	3	71.8	184.3	69.7
Mar	23.7	9.9	16.8	66.3	17.0	26	65.2	207.7	111.4
Apr	29.2	16.2	22.7	60.1	17.0	13	59.9	171.9	153.7
May	40.6	22.5	31.5	5.0	12.0	15	40.9	205.9	265.5
Jun	45.3	23.9	34.6	0.0	11.0	10	35.4	336.7	371.6

Table 4.6. Climatic data for dezful during the 2006/07 season of the study trials.

Month	Temperature (°C)			Rainfall (mm)	Wind		Relative humidity(%)	Sunshine (hr)	Epan (mm)
	max	**min**	**av**		**speed (m/s)**	**date**			
Dec	19.0	8.2	13.6	45.9	12.0	6	72.9	160.0	51.5
Jan	14.1	3.9	9.0	64.7	15.0	5	73.5	163.4	41.8
Feb	21.0	7.0	14.0	1.2	15.0	14	56.2	184.5	98.9
Mar	29.3	13.2	21.3	0.0	9.0	22	48.8	207.4	187.2
Apr	34.2	16.5	25.3	12.0	14.0	30	49.8	208.2	209.4
May	39.1	20.9	30.0	0.1	20.0	21	40.0	235.2	340.6
Jun	44.7	25.1	34.9	0.0	15.0	23	28.9	258.4	453.5

Table 4.7. Amount of irrigation water applied and wheat productivity for the different treatments in the field trials in 2006.

Field No.	Treatment	Variety	Number of irrigations	Applied irrigation water (mm)	ETc (mm)	Grain yield (kg/ha)	$WP_{(ETc)}$ (kg/m³)	$WP_{(I+R)}$ (kg/m³)
1	I_1	Dez	4	431	320	6512	2.03	0.98
	I_2	Dez	4	323	320	6480	2.03	1.17
	I_4	Dez	4	341	320	5904	1.85	1.03
	I_5	Dez	4	281	320	4611	1.44	0.90
2	I_6	Vierinak	4	189	353	6929	1.96	2.33
	I_7	Vierinak	4	280	353	6128	1.74	1.57
	I_9	Vierinak	4	260	353	8090	2.29	2.19
3	I_1	Chamran	3	248	353	6966	1.97	1.95
	I_2	Chamran	3	223	353	7974	2.26	2.40
	I_3	Chamran	3	278	353	6487	1.84	1.68
	I_4	Chamran	3	310	353	6664	1.89	1.59
	I_5	Chamran	3	298	353	5998	1.70	1.47
4	I_6	Chamran	2	157	306	7297	2.38	2.06
	I_7	Chamran	2	103	306	7062	2.31	2.37
	I_9	Chamran	2	159	306	4720	1.54	1.33

Table 4.8. Amount of irrigation water applied and wheat productivity for various treatments in the field trials in 2007.

Field No.	Treatment	Variety	Number of irrigations	Applied irrigation water (mm)	ETc (mm)	Grain yield (kg/ha)	$WP_{(ETc)}$ (kg/ m³)	$WP_{(I+R)}$ (kg/m³)
1	I_1	Star	6	0.539	382	7769	2.03	1.31
	I_2	Star	6	0.582	382	11228	2.94	1.77
	I_4	Star	6	0.457	382	10031	2.63	1.97
	I_5	Star	6	0.549	382	8543	2.24	1.42
2	I_6	Vierinak	6	0.341	372	5744	1.54	1.58
	I_7	Vierinak	6	0.702	372	4656	1.25	0.64
	I_8	Vierinak	6	0.582	372	3865	1.04	0.64
	I_9	Vierinak	6	0.625	372	5441	1.46	0.84
3	I_1	Vierinak	5	0.626	386	7915	2.05	1.17
	I_2	Vierinak	5	0.450	386	6993	1.81	1.40
	I_3	Vierinak	5	0.529	386	6251	1.62	1.08
	I_4	Vierinak	5	0.633	386	6506	1.69	0.95
	I_5	Vierinak	5	0.690	386	8536	2.21	1.15
4	I_6	Vierinak	6	0.301	372	6904	1.86	2.12
	I_7	Vierinak	6	0.692	372	6056	1.63	0.85
	I_8	Vierinak	6	0.500	372	6399	1.72	1.22
	I_9	Vierinak	6	0.616	372	7238	1.95	1.13

In this research, seeding rate was one of the important factores which needed to be studied. At the start of the trial period, all the farmers already used 50% to 100% more seed than the optimum rate. Corn residues before and after using a chopper are shown in Figure 4.1. There is a low level of organic matter in the soil in the study area, but chopping the corn residues increased this by accelerating the rate of decay of the residues. Independent of the effects of irrigation, using a chopper led to an improved and increased yield of wheat in the crop rotation.

Figures for the average WUE showed the superiority of treatments 2 and 6 in fallow conditions and on those farms with crop residues during the two years of the experiment (Figure 4.2 and Figure 4.3). The corrugators and furrower (60 cm) used after sowing are shown in Figure 4.4 and Figure 4.5.

In view of the higher amount, and better distribution, of precipitation in 2005, 06, less irrigation was applied than in the second year. Accordingly, the effects of the irrigation treatments were more obvious in the second year. It was then noticed that the effect of furrow irrigation treatments in farms with corn residues led to an 80% increase in wheat WP compared to those fields under the farmer’s conventional management (border irrigation).

Figure 4.1. Corn residues before and after chopping (before sowing wheat).

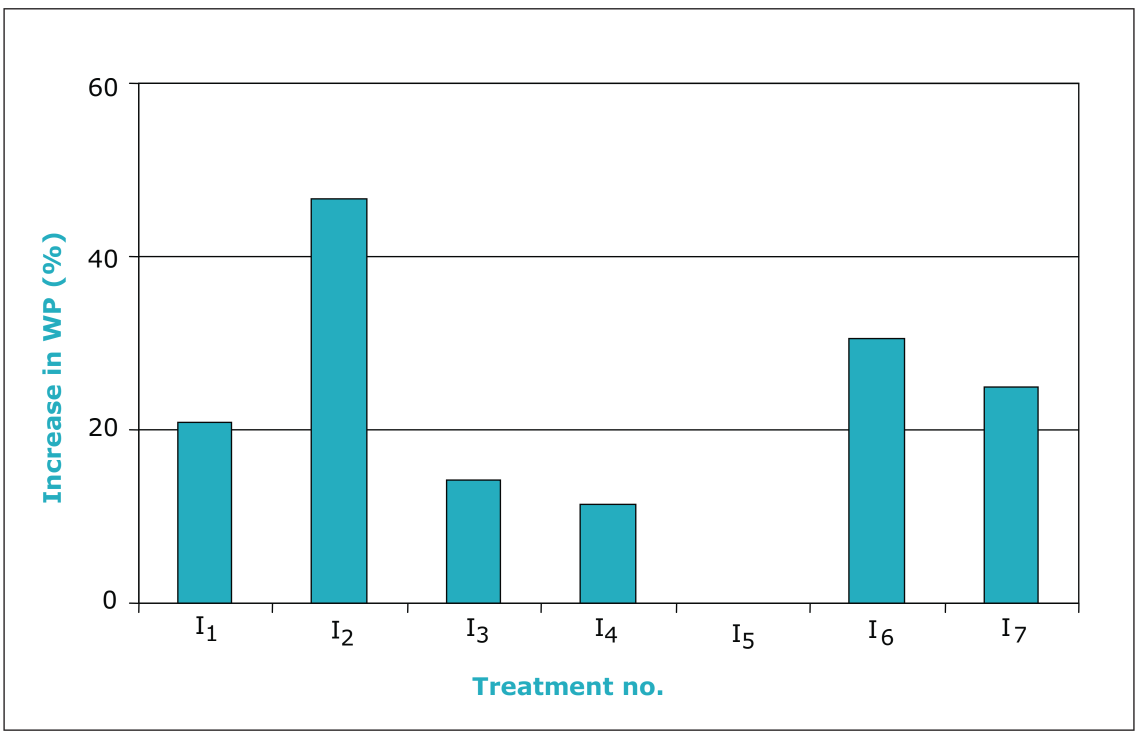


Figure 4.2. Increase in wheat water productivity for different irrigation treatments compared to the control treatment (I5) in 2005/06.

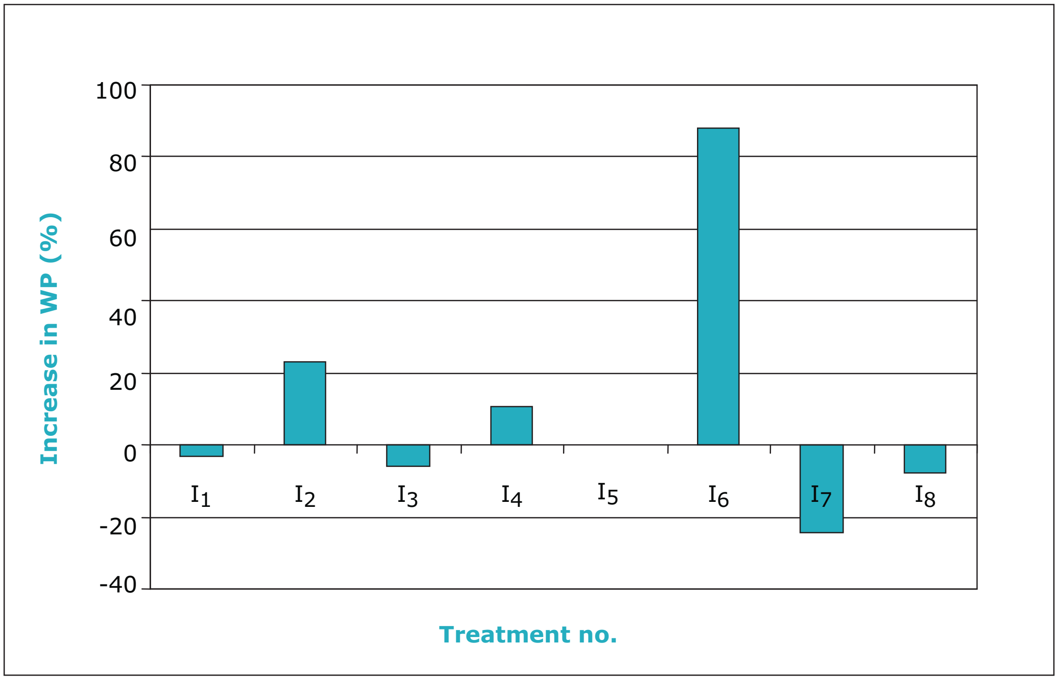


Figure 4.3. Increase (or decrease) in wheat water productivity for different irrigation treatments compared to the control treatment (I5) in 2006/07.

Figure 4.4. Corrugators used on the irrigation strips of the experimental fields.

Figure 4.5. Furrowers used on the irrigation strips of the experimental fields.

Looking at the salinity levels of the soils in filed 3 and 4 in the first year and field 2, 3, and 4 in the second year, it was concluded that where the soil had an electrical conductivity of more than 2 dS/m, creating furrows in the bed of the irrigation strips had a considerable effect on optimizing wheat WP. In addition, it was concluded that on the fields with no salinity limitations and rather steep slopes, irrigation WP was similar for strips with or without furrows. For these fields, the more straightforward method of planting rows on the flat surface of strips was therefore more desirable.

4.4 Summary of results and recommendations

- A sowing density of 400 seeds/m^2 is recommended; this represents a reduction of from 25% to 50% in the amount of wheat seeds currently sown
- Using choppers on farms with corn residues will increase the amount of organic matter in the soil and will improve the effects of the irrigation applications
- On the Evan Plain, corrugation irrigation is recommended. Various experiments where corrugation irrigation was applied to farmer's fields on the plain, both with and without corn residues, showed that the WUE for the irrigation water was increased by, on average, 45% compared with the farmers' present practices
- It is advisable to use furrows in the beds of the irrigation strips in fields with a soil salinity level of 2 dS/m or more
- Row planting on well-graded and leveled land is appropriate when the field has a relatively steep slope and no salinity limitations.

Chapter 5.

Methods of improving water productivity for maize

Chapter 5. Methods of improving water productivity for maize

5.1 Introduction

Corn is among the strategic crops that have drawn the attention of farmers and it is experiencing an ever-increasing area under cultivation in Iran for a variety of reasons such as a guaranteed purchase price. During the farming season of 2007 and despite such problems as a shortage of suitable seeds, the area under cultivation in Khouzestan Province, including the lower KRB, was more than 80,000 ha. It is expected that this will be increased to more than 100,000 ha, as planned in the Fourth National Development Program (2006–2010).

Corn is planted in rows with 75cm spacing, and is irrigated by furrows. On average, the corn water requirement (ETc) in lower KRB is between 700 mm and 750 mm. Assuming an irrigation efficiency of 30%, the seasonal irrigation water for corn will be between 21 m^3/ha and 22 m^3/ha. This water requirement and the shortage of available water set a limit to the area which can be put under the cultivation of corn. Therefore, in order to increase the area under corn cultivation in Khozestan Province the use of irrigation water must be optimized, particularly in the southern part of lower KRB where the rainfall during summer is almost zero.

Schneekloth *et al*. (1991), Hergert *et al*. (1993), and Schneekloth *et al*. (1995) obtained, using only 150 mm of water, corn yields of 81%, 86%, and79%, respectively, of those obtained using the full irrigation water requirement. The 150 mm represented about 40% of the water needed for full irrigation. Klocke *et al.* (2004) also reported corn yields of 84% and gross economic returns of between 85% and 91% using deficit irrigation as compared with the farmers' irrigation scheduling practices. These studies suggest that if water is limited, irrigating for maximum yield should not always be the objective, since reasonably high yields for less water could be obtained under deficit irrigation. A recent review of measured Crop Water Productivities (CWP) (yield per unit seasonal ET) for four major crops around the world, including corn, concluded that CWP could be significantly increased, if irrigation was reduced and crop water deficit was intentionally induced (Zwart and Bastiaanssen, 2004). Having local information about the yield response of crops under alternative water management strategies is critical to be able to optimize the use of limited water supplies. Payero *et al*. (2006) suggest that inducing stress is not a good strategy for increasing crop WP (yield per unit ETc) for corn and point out the need to minimize irrigation water losses and improve irrigation scheduling.

Doorenbos and Kassam (1979) proposed that the ratio of relative yield to relative evapotranspiration (Ky) describes the relation between water stress and the corresponding expected yield. For corn, they reported Ky values of 0.4, 1.5, 0.5, and 0.2 for the vegetative, flowering, yield formation, and ripening stages, respectively, indicating that the yield was more affected by water stress during flowering. Hanks (1974) found that the ratio of actual to potential dry matter yield was directly related to the ratio of actual to potential transpiration. Others have found a linear relationship between grain yield and actual seasonal ET (Barrett and Skogerboe, 1978; Gilley *et al*., 1980; Schneekloth *et al.*, 1991).

This suggests that the timing is not as important as the total amount of water available to the crop during the season, assuming that stress is not severe enough at any stage to actually desiccate the crop. These two apparently opposing views have motivated considerable research (Barnes and Woolley, 1969; Claassen and Shaw, 1970a, 1970b; Bryant *et al*., 1992; Traore *et al*., 2000). In Nebraska, Gilley *et al*. (1980) found that the yield was not reduced when corn was stressed during the vegetative stage, but was significantly reduced when stressed during pollination and grain-filling. However, they also found a good linear relationship between yield and actual seasonal crop ET, as also reported by Schneekloth *et al.* (1991).

According to Molden (1997), the productivity of the total applied water (WP) is defined as crop yield per unit of volume of water supplied to the crop. It is estimated by dividing crop yield by the total applied water (rainfall + irrigation). Many irrigation experiments involving different irrigations levels showed that deficit irrigation usually has higher WP than full irrigation (Zhang, 2003).

Maize is a major irrigated crop in southern Spain. It requires about 500 mm to 600 mm of SI to attain maximum yields. Aguilar *et al*. (2007) reported a mean yield loss of 17% due to limited irrigation. The main effect of limited irrigation was to reduce the ears per plant and the 1000 kernel weight. Maize yield decreased as the season length was reduced. Limited or regulated deficit irrigation is one way of maximizing the productivity of the total applied water; thus, the limited irrigation treatment achieved a higher WP value (2.66 kg/m^3) than full irrigation (1.90 kg/m^3). At both irrigation levels, WP was higher as the growth cycle increased. It can be concluded that reduced irrigation provided higher yields when applied to long cycle cultivars (FAO 700-800), with increased WP values.

Khoajeh Abdollahi and Sepaskhah (1995) reviewed the alternate furrow irrigation method with different irrigation periods for corn cultivar 704 in the two Fars regions of Bajgah and Koushk. In their research, three 4-day, 7-day, and 10-day irrigation periods and three irrigation methods – normal, fixed alternate, and every-other alternate furrow – were compared with each other. The results showed that the alternate furrow irrigation treatment with a 4-day irrigation period was the most economic method with respect to amount of irrigation water applied and the yield of the seed.

Reducing the spacing between adjoining rows in a special plant configuration has some potential advantages. First, it reduces the competition between the rows of plants for light, water, and food as a result of the very regular and identical plant configuration (Porter and Hicks, 1997). Similar plantation configurations with closer rows, improve the initial growing speed of corn in the growing season (Bullock *et al*., 1988) and result in better absorption of sunlight, more efficient use of the radiation, and a greater yield of seed (Westgate *et al*., 1997). Secondly, maximization of the canopy light absorption as a result of early closure of the canopy decreases the light transfer to the soil surface (McLachlan *et al*., 1993). This reduces the potential for an intermixing of weeds, especially species sensitive to shadow (Teasdale, 1995). Thirdly, quickly covering the soil surface early in the season decreases loss of water through evaporation. Therefore, faster coverage of the narrow rows by the crops is a means of improving soil protection and reducing soil evaporation and erosion (Mannering and Johnson, 1969).

In reviewing the consequences of one- and two- row plantation configurations and densities for four early-maturing cultivars of corn, it was determined that two-row planting configuration yielded less than the normal planting configuration in the second year, but showed no meaningful difference in the other years of the four-year research (Bavec and Bavec, 2001). In a review done by Ottman and Welch (1989) using five planting methods, including 38 cm single-row, 76 cm double-row, 76 cm single-row, 114 cm double-row, and 152 cm double-row with 13 cm space between the rows, it was indicated that the latter double-row had, at 9.7 t/ha, the least grain yield.

Sangoi *et al*. (2001) reported that the yield of corn seed was significantly influenced by the row spacing and its interaction with the planting date. Reducing the row spacing from 100 cm to 50 cm increased the yield of corn grain linearly. Within the range of row spacings considered in this test, depending on the growing season and planting date, an improvement of grain yield from 96 kg/ha to 248 kg/ha was obtained for every 10 cm reduction of row spacing.

The results of research by Teasdale (1995) and Westgate *et al*. (1997) indicated that planting corn in narrow rows had no positive impact on the grain yield. This result may be due to several factors, such as the hybrid cultivar used, plant density, soil fertility, and climate conditions during the test period.

Tharp and Kells (2001) reported that the yield of corn was similar for different row spacings. Shibles *et al*. (1966) indicated a 1.5% increase in yield for 76 cm rows as compared to 102 cm row spacing. In addition, a 3.5% increase in yield resulted from 51 cm row spacing.

Farnham (2001) reported that by changing the row spacing from 76 cm to 38 cm, the yield of corn was reduced. Cox and Cherney (2001) reported that the yield of dry matter and the yield at the maturation stage of the corn grain for 38cm row spacing was more than for 76 cm row spacing. Widdicombe and Thelen (2002) reported that the yield increment in dry matter was similar for a forage hybrid and a double cross when the row spacing was decreased from 76 cm to 38 cm. Ullah *et al*. (2007) reported that soybean + maize rotation in 90 cm spaced double row strips gave maximum maize grain yield (6.71 t/ha). The maximum land equivalent ratio (1.62) was also recorded for 90 cm spaced double row strips, intercropped with soybean. Similarly all intercropping systems gave substantially higher net incomes over mono-cropping with the highest net income occurring in the case of maize + soybean rotation followed by a sole crop of maize.

Interest in reducing maize row spacing in the short growing season regions of Brazil is increasing; there are potential advantages, such as higher radiation use efficiency (Sangoi *et al*., 2001). An experiment was conducted to evaluate the effect of reducing row spacing on grain yield of different maize cultivars planted at different dates. The reduction of row spacing from 100 cm to 50 cm increased maize grain yield – the row spacing-yield relationship was linear with a negative slope. The yield edge provided by narrow rows was higher when the maize was sown earlier in the season. Differences in hybrid cycle and plant architecture did not alter the maize response to the reduction of row spacing.

In Pakistan, Shah *et al*. (2003) concluded that WUE was a maximum (14.58 kg/ha/mm) when the maize was planted in 60 cm and 90 cm planting patterns.

It was lowest (8.01 kg/ha/mm) when the crop was ridge planted and irrigated in alternate furrows. The grain yield, resulting from the increased leaf area per plant, and the 1000-grain weight was also highest (4.57 t/ha) for the 60 cm and 90 cm planting patterns.

Water is essential for every development phase, from seed germination to maturation. Maize grain yield was decreased substantially by water deficit (Cardwell, 1982). After wheat and rice, maize (*Zea mays* L.) plays an important role in the economy of the world. Although maize grain yield has increased significantly, there is still a big gap between the potential yield and the actual yield of different cultivars arising from different agro-management practices. Among these, planting pattern is an important determinant (Cardwell, 1982). Planting patterns affect radiation use efficiency (Tollenaar and Aguilera, 1992) and the yield decreases with an increase in a vapor pressure deficit from 0.9 kPa to 1.7 kPa (Kiniry *et al*., 1989). The furrow–ridge method provides better WUE, better drainage, and saves more water than border irrigation (Chaudhary and Qureshi, 1991).

According to the available information, the water need of corn has been reported as being between 500 mm and 800 mm, depending on the environmental conditions and climate of the regions of production. For instance, Tavakoli *et al*. (1988) reported the yields of corn cultivar 704 under the influence of different irrigation intervals. Water applied after every 70 mm of cumulative evaporation from a Class A pan produced more grain than the other two treatments following 100 mm and 160 mm of cumulative evaporation. The differences in the crop yield were 1724 kg/ha and 4866 kg/ha, respectively. Also, it has been reported that the water required for corn under the climate of Ahwaz is 683 mm and under that of Dezfoul is 705 mm for a 120-day growing period.

The objectives of the present study were to:

- Determine the potential of corn WP under the existing and the proposed methods in lower KRB
- Determine the advantages and technical limits of each of the proposed methods
- Compare corn WUE under optimum farming and irrigation management with that under the farmers' management
- Investigate the impacts of the methods of cultivation and irrigation on the yield and yield components of corn.

5.2 Materials and methods

Methods for enhancing Water Productivity (WP) in water-needing lands fall into three categories, irrigation and cultivation management, the use of cultivars with higher yield potential, and the use of less water for irrigation. On this basis, the experimental treatments were selected with a combination of parameters and tested with precise measurement at the Safi Abad Agricultural Research Center.

Three trials were conducted using a participatory approach in farmers' fields downstream of Karkheh Dam and one trial with precise measurements was conducted in Safi Abad Agricultural Research Center during 2007 season. These trials are described below.

5.2.1 Improvement of corn water productivity in the farms of Dasht-e Evan

In this study, local management practices for corn cultivation were implemented with the cooperation of the farmers. Two farms located in the Dasht-e Evan region were selected and different farming and surface irrigation management practices, in the form of trial treatments were used on them with the participation of the farmers. The results were analyzed using a t-test. The treatments are summarized below.

Farm 1

Trial 1. Irrigation management treatments for corn hybrid SC-704

The treatments were as follows:

- Varied alternate furrow irrigation throughout the growing season (VA)
- Furrow irrigation following local, traditional management practices i.e. control treatment (CT)
- Furrow irrigation using cut-back flow when the advancing front reached 75% of the furrow length (RF 75%)
- Furrow irrigation using cut-back flow when the advancing front reached the end of the furrow (RF 100%)
- Corn was planted and irrigated in the bottom of the furrows during the early stages of growth, but the furrows were then replaced by ridges at the time of the fifth irrigation when a cultivator was used to control the weeds (CBP)

Trial 2 Comparison of corn cultivars

Treatments included corn varieties Hybrid SC-704, Hybrid SC-666, and Hybrid SC-602

Farm 2

Trial 3. Irrigation management treatments for corn hybrid SC-704

- Treatments were as follows:
- Furrow irrigation following traditional, local practices i.e. CT
- Furrow irrigation using cut-back flow when the advancing front reached 75% of the furrow length (RF 75%)
- Furrow irrigation using cut-back flow when the advancing front reached the end of the furrow (RF 100%)
- Furrow irrigation of the corn planted in the bed of the furrow throughout the growing season (BP).

The advantages of the selected farms were that the farmers were cooperative and the fields of the two farms were in the same vicinity. In each of the two selected farms, one field was used for conducting all those treatments different than the farmers’ practices while the rest of the farm was considered as the control treatment. After land preparation operations – included a pre-plow irrigation in mid-June, plowing to a depth of 30 cm, two disking operations perpendicular to each other, fertilizing, and a final disking – furrows were made with a 0.75 m spacing. The width of each treatment plot was 15 m (a total of 20 furrows) and its length varied somewhat, depending on the conditions of the farm, from 237 m to 270 m. The soil texture was loam and silt loam with a bulk density of 1.64 g/cm^3. The water table was lower than 9 m from the surface. In all three trials, the corn was planted using a pneumatic drill with a density of 75,000 plants/ha. After planting, the same farming practices of fertilizing, weeding, and spraying and the scheduling of irrigation were carried out for all treatments. To prevent fluctuation in the water flow, two ditches were used. The inflow to each treatment plot was measured using a cutthroat flume. For each irrigation, the time of the water advance, the rate of water inflow to the farm, and the length of the irrigation were recorded. At the end of the season, for each treatment, 15 sample plots of 3 m^2 each were randomly harvested and the yield components measured.

Trial 4 Improving irrigation water productivity for corn in Safi Abad Agricultural Research Center

To study the interaction of the commercial corn cultivars with the different systems of surface and trickle irrigation, three commercial hybrid cultivars, SC-704, SC-666, and SC-602, were tested in an experiment with split plots in a completely randomized block design with three replications. The main plot (horizontal) included six treatments of farming and irrigation management as follows:

- Planting on 75 cm ridges with full irrigation as the CT
- Planting on 75 cm ridges with varied alternate furrow irrigation (VF)
- Double-row planting on 75 cm ridges (DRP)
- Single-row planting inside 75 cm spaced furrows and replacing furrows with ridges at the two- to four-leaves stage (BC-shift)
- Single-row planting inside 75 cm furrows – fixed ridge furrow (BC)
- Planting on 75 cm ridges – full-trickle irrigation (Drip)

Each treatment plot consisted of 7 furrows 130 m long. The soil texture was silt clay loam with a bulk density of 1.62 g/cm^3. The water table was lower than 12 m. In this trial, corn cultivars were planted manually maintaining a stand of 75,000 plants/ha. The furrows were continuously irrigated along their full length. The parameters for a number of the infiltration curves of the U.S. Soil Conservation System (SCS), land slope, and the most suitable inflow rates were determined. Then, by measuring the time of advance into each furrow during irrigation, the duration of irrigation was determined using the method recommended by SCS, taking into consideration the depth of irrigation. The rate at which irrigation water was applied by the existing methods was measured from the beginning of the planting season.

Crop coefficients were estimated at the different stages of growth according to Allen *et al*. (1998). The planting date was decided on the basis of previous research and the irrigation period was considered on the basis of the 70±5 mm cumulative evaporation from a Class A pan. In the surface irrigation treatments, to prevent the fluctuation in the flow of water and to stabilize the water surface in the upstream ditch, two ditches – a first and a second – were considered. To measure the inflow for the different treatments, a Washington State College flume was installed. At each irrigation, the rate of advance of the water, the amount of water inflow to the farm, and the irrigation time were measured and recorded. At harvest time, in each treatment plot, a 8 m^2 sampling area was selected and plants in the two middle lines were removed for measurement of the yield and the yield components. From each plot, 5 plants were cut for the determination of dry matter. A statistical comparison of the means was performed using the Duncan test.

5.3 Results

5.3.1 On-farm trials

In Table 5.1, the mean yield of shoots with 60% moisture, grain yield, and irrigation WP are shown. The comparison of the means of the yields from the different treatments, leads to the following conclusions (Figure 5.1).

For Farm 1, the treatment of the bed of furrow planting i.e. CBP is the best treatment with respect to grain yield. It shows a significant difference, at p=0.001 level, in comparison with the VA, CT, and RF 75% treatments. Also, in the case of irrigation WP, the same treatment is the best, and has a significant difference with other treatments at p=0.001 level. For Farm 2, RF 75% is the best treatment with respect to the grain yield, and shows a significant difference in comparison with treatments CT and RF 100% at p=0.001 level, and with the BP treatment at p=0.005 level. For the irrigation WP, RF 75% is, again, the best treatment with a significant difference from the other treatments at p=0.001 level. For the yield of shoots, however, it was determined that ridge-planted treatments have higher yields than those planted in the bottom of the furrows. In both farms, the control treatment i.e. management of irrigation by the farmer, had the lowest yield for the grain and the irrigation WP.

The results of the trials for the comparison of corn cultivars are presented in Table 5.2. Statistical analysis of the means using a t-test indicated that there is a significant difference between treatments at p=0.001 level with respect to grain yield and irrigation WP. According to these results, cultivar 602 stands at the top, followed, in order, by cultivars 704 and 666. Furthermore, the higher yield of cultivar 602 resulted in an increase of about 20% in irrigation WP when compared with the prevalent cultivar of the region (i.e. cultivar 704). There is a significant difference between cultivar 602 and cultivars 704 and 666 at p=0.001 level in the yield of shoots.

On the basis of the meteorological data, the cumulative Class A pan evaporation during the growing period of the corn (2007) was about 900 mm and the water need, calculated through the method of the Class A evaporation pan, was 590 mm. the number of irrigations in Farm 1 and Farm 2, and the dates of the

Table 5.1. Mean yield, dry matter produced, and irrigation water productivity for different treatments.

Treatment	Shoots (60% moisture) (t/ha)		Grain yield (14% moisture) (kg/ha)		WP-grain yield (kg/m^3)	
	Farm 1	Farm 2	Farm 1	Farm 2	Farm 1	Farm 2
I1	23,406		10,771		0.563	
I2	27,043	27,016	7,100	8,173	0.288	0.409
I3	28,501	31,812	11,064	10,087	0.580	0.658
I4	32,538	29,430	11,391	8,507	0.595	0.539
I5	23,558	26,456	11,732	9,785	0.706	0.608

Table 5.2. Mean yield, dry matter produced, and irrigation water productivity for different corn cultivars.

Variety	Shoots (60% moisture) (t/ha)	Grain yield (14% moisture) (kg/ha)	Irrigation WP-grain yield (kg/m^3)
704	21,046	6,370	0.26
666	22,100	5,477	0.223
602	27,294	7,631	0.311

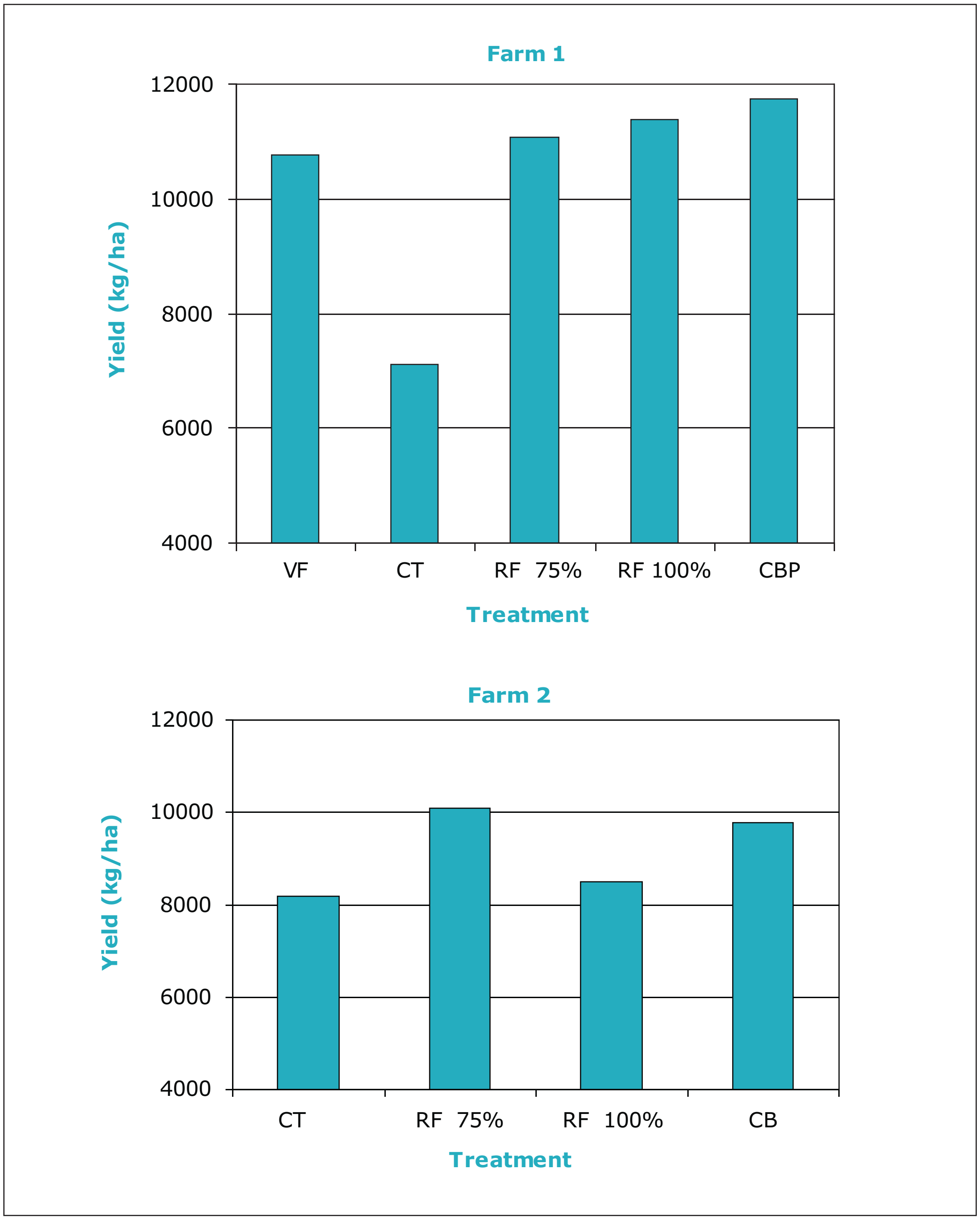


Figure 5.1. Mean yield of corn seed under different treatments.

irrigations are provided in Table 5.3. For the different treatments, the reductions in water consumption in comparison with the control treatment and the efficiency of the applied water on the basis of the calculated crop water need, are given in Table 5.4, where the crop water requirement for Farm 1 was 590mm and Farm 2, 582mm.

A comparison of the amount of water applied with the calculated crop water requirement indicates that all treatments received more water than needed. In other words, the treatments had only achieved some reduction in the rate of over-irrigation. Figure 5.2 shows the relationship between the yield of grain produced and the water consumed for the different treatments at the two farms. Irrespective of the regression equations and resulting correlation coefficients, the total trend for the change of product with the amount of water consumed indicates extreme irrigation in the applied treatments.

Compared with the control treatment, decrease in the amount of water applied in the treatment where corn was planted in the bottom of furrows was 32% on Farm 1 and 20% on Farm 2. Also, the irrigation water efficiency, based on the calculated crop water requirement, was between 8% and 10% higher in this treatment than that used following the farmers› practices. As stated in the explanation of treatments on Farm 1, simultaneously with the top-dressing of fertilizer operation and weed control (at the time of the fifth irrigation), the locations of the ridges and furrows were replaced – ridges were turned into furrow and vice versa. From this stage

Table 5.3. Number and date of irrigation in the trial farms.

Irrigation	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th
Farm 1	21 Jul	31 Jul	7 Aug	18 Aug	29 Aug	3 Sep	15 Sep	25 Sep	5 Oct	14 Oct	
Farm 2	25 Jul	30 Jul	7 Aug	12 Aug	17 Aug	31 Aug	9 Sep	16 sep	24 Sep	4 Oct	16 Oct

Table 5.4. Total amount of irrigation water applied, rate of reduction of water consumption cf. control treatment, and irrigation efficiency on the basis of the calculated crop water requirement.

Treatment	Amount of irrigation water applied m³/ha		Reduction in amount of water consumed cf. the control treatment (%)		Irrigation efficiency – based on ETc (%)	
	Farm 1	Farm 2	Farm 1	Farm 2	Farm 1	Farm 2
VF	19,177		22		31	
CT	24,523	20,050			24	29
RF 75%	19,058	15,313	22	24	31	39
RF 100%	20,286	15,777	17	21	29	37
CB	16,632	16,087	32	20	35	37

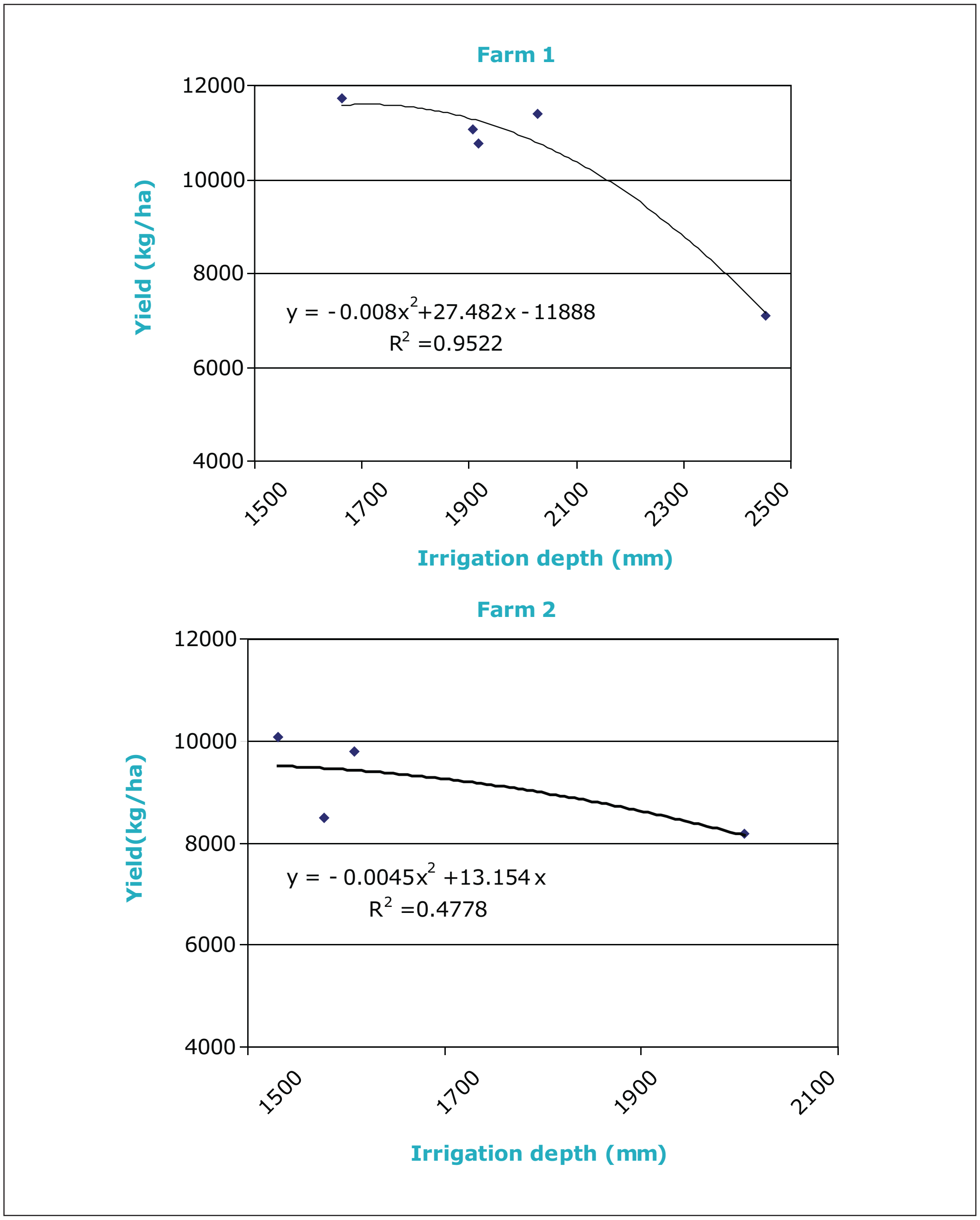


Figure 5.2. Changes in the yield of the corn crop (at 14% moisture) with changes in the amount of water applied.

on, irrigation of this treatment was undertaken through the flow reduction (cut back) method. As a result, 32% less water was applied as compared to the control treatment. On Farm 2, for the BP treatment, application of irrigation treatments started from the sixth irrigation, and a 20% reduction in the amount of irrigation water was obtained as compared to the control treatment. Furthermore, in comparison with the control treatment, the irrigation WP of this treatment showed an increase of 100% on Farm 1 and an increase of 50% on Farm 2 (Figure 5.3).

Conclusions and suggestions

- In the Dasht-e Evan region, a major cause of the low WP and yields from corn fields is over-irrigation
- Under the farmers› management practices, planting corn in the bottom of furrows can reduce the amount of water applied by between 20% and 30%, increase grain yield, and enhance irrigation WP by between 50% and 100%
- With these water savings and improved WP, the area under cultivation can be increased by at least 30% in the studies area.

5.3.2 Results of the experiments at the Safi Abad Agricultural Research Center

The yield of shoots, grain yield, and irrigation WP are given in Table 5.5. Comparison of the mean yields and yield components for the different treatments led to the following conclusions (Figure 5.4). In this trial, trickle irrigation was found to be the best treatment. This treatment showed a statistically significant higher WP from the other treatments, at p=0.001 level, with respect to grain yield, biomass, and irrigation WP measured by the amount of dry matter and the grain yield produced.

Also, statistically significant differences were observed between the corn cultivars at p=0.005 level; cultivar 602, with a mean yield of 8179 kg/ha, had the highest yield.

Among the surface irrigation treatments, planting two lines on the ridge resulted in the highest yield – a mean grain yield of 8844 kg/ha. This was yield followed by the treatment of planting in the bottom of the furrows – a mean yield of 7404 kg/ha. Water productivity based on grain yield was better for the BC and DRP treatments. For the former – planting inside the furrows – the average yield was 0.76 kg/m^3, while for the latter – double- row planting on 75 cm ridges – the average yield was 0.61 kg/m^3.

The reduction in the amount of water consumed relative to the control treatment and the efficiency of water application according to the computed water needs for each one of the treatments are presented in Table 5.6. The crop water requirement was 534 mm. A comparison between the amount of water applied and that calculated for the crop water requirement shows that all treatments had received more water than needed. In other words, the treatments had achieved limited reduction in the rate of over-irrigation. For the BC treatment, the water consumption showed a 33% reduction and WUE an 18% increase relative to the control treatment. For the drip treatment, water consumption was decreased to below one-half of that of the control treatment. As per existing recommendations for surface methods, the irrigation interval was set for after 70 mm cumulative evaporation from a Class A pan, while for the drip irrigation it was set for after 35 mm cumulative evaporation.

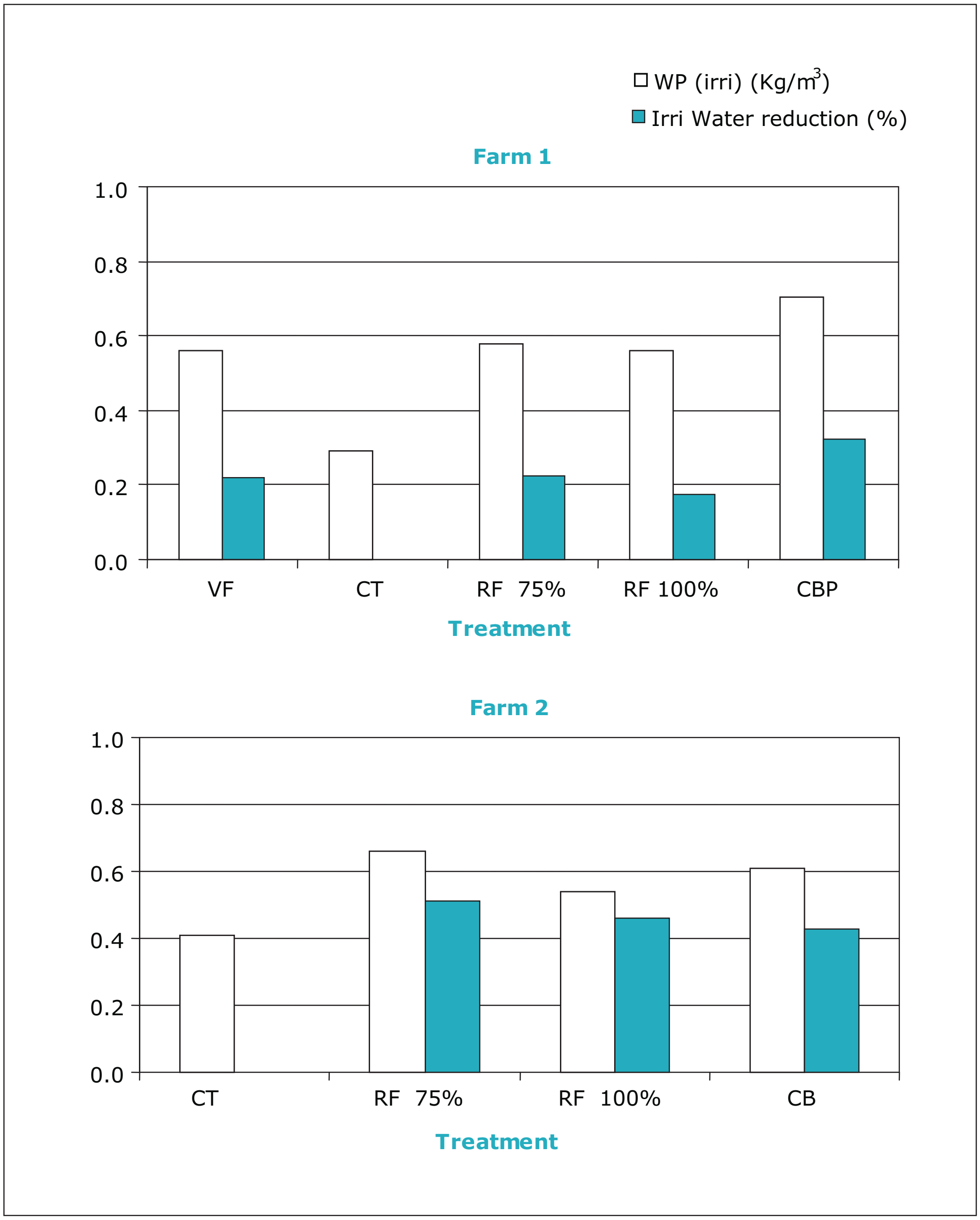


Figure 5.3. Irrigation water productivity and percent reduction in the amount of water applied for the different treatments compared to the farmers' management practices

Table 5.5. Mean yield, biomass, and irrigation water productivity for different treatments.

			Water productivity	
Irrigation treatment	**Biomass (60% moisture) kg/ha**	**Grain yield (14% moisture) kg/ha**	**Biomass (kg/m^3)**	**Grain (kg/m^3)**
CT	14,600	6,957	1.009	0.481
VF	11,862	6,561	1.028	0.569
DRP	15,708	8,844	1.083	0.610
BC-shift	13,334	6,872	1.091	0.562
BC	13,845	7,404	1.424	0.762
Drip	16,814	9,556	2.165	1.422
Corn variety treatment				
704	0.677	1.287	7,090	15,161
666	0.731	1.332	7,828	14,316
602	0.794	1.28	8,179	13,604

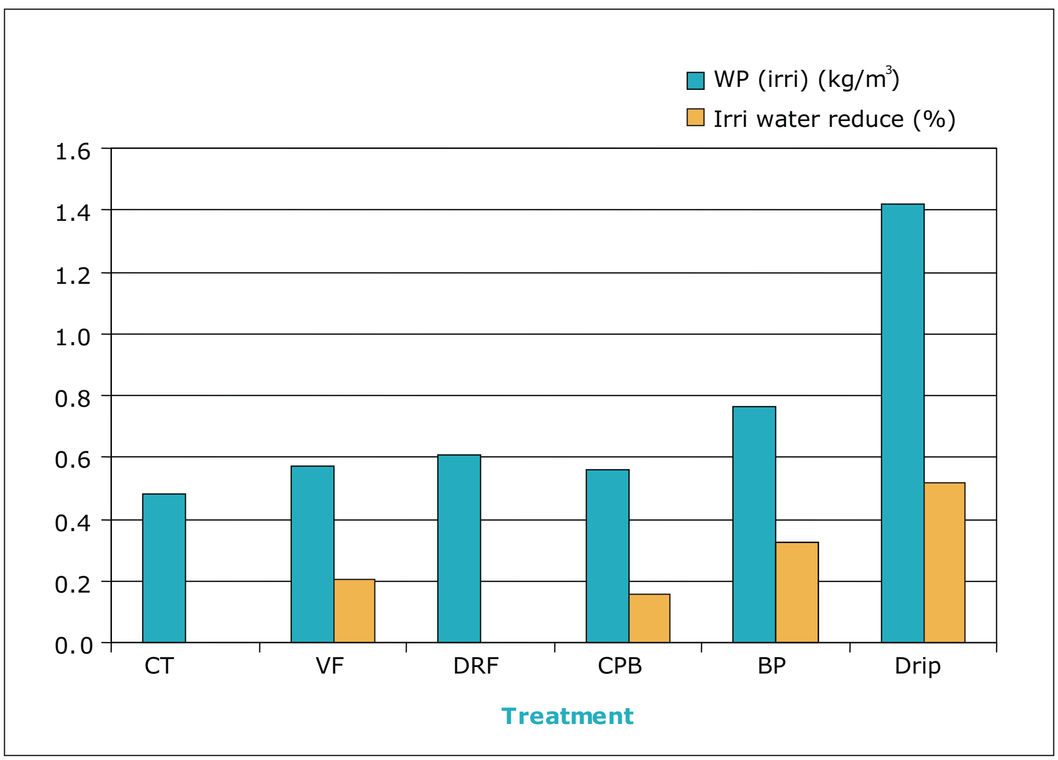


Figure 5.4. Irrigation water productivity and percent reduction in the amount of water consumed for different treatments compared to the control treatment at the Safi Abad Agricultural Research Center.

Table 5.6. Total amount of water applied, reduction of water consumption cf. the control treatment, and irrigation efficiency based on the calculated crop water need.

Treatment	Amount of irrigation water applied (m^3/ha)	Reduction in water consumption cf. the control treatment (%)	Irrigation efficiency – based on ETc (%)
CT	14,464		37
VF	11,538	20	46
DRP	14,500		37
BC-shift	12,227	15	44
BC	9,725	33	55
Drip	6,998	52	75

The number and dates of the surface and drip irrigation application are presented in Table 5.7. The furrow bed culture treatment resulted in a 58% increase in water productivity as compared to the control treatment, while the use of cultivar 602 resulted in a 17% increase in seed yield and subsequently, in the water productivity seed performance.

Conclusions and recommendations

- In Dasht-e Evan region, a major cause of low water productivity and corn yields is over-irrigation
- It is recommended to use high-yielding corn varieties, such as cultivar 602, to replace the presently popular cultivar 704 in the region. The grain yield of cultivar 602 was found to be 17% higher than that of the commonly grown cultivar
- Under the farmers› management practices in Dasht-e Evan, planting corn seed at the bottom of the furrows resulted in a 20% to 30% decrease in the amount of irrigation water consumed. This resulted in an increased efficiency of use of the irrigation water based on crop ET. Similar studies conducted in the Safi Abad Agricultural Research Center revealed that planting at the bottom of the furrows leads to a reduction of about 33% in the amount of irrigation water consumed and is accompanied by an increase of 58% in irrigation water productivity. Therefore, this practice can be recommended.

Table 5.7. Number and date of irrigation at the experimental farm.

Irrigation systems	**Drip irrigation date**	**Surface irrigation date**
	29 Jul	28 Jul
	1 Aug	2 Aug
	3 Aug	8 Aug
	6 Aug	15Aug
	9 Aug	21 Aug
	12 Aug	
	16 Aug	
Total irrigations in month 1	7	5
	21 Aug	27 Aug
	25 Aug	1 Sep
	27 Aug	7 Sep
	31 Aug	15 Sep
	4 Sep	
	7 Sep	
	10 Sep	
	12 Sep	
	15 Sep	
	18Sep	
	21 Sep	
Total irrigations month 2	11	4
	24 Sep	22 Sep
	28 Sep	1 Oct
	1 Oct	6 Oct
	5 Oct	14 Oct
	8 Oct	
	10 Oct	
	13 Oct	
	16 Oct	
	19 Oct	
Total irrigations month 3	9	4
Total irrigations	27	13

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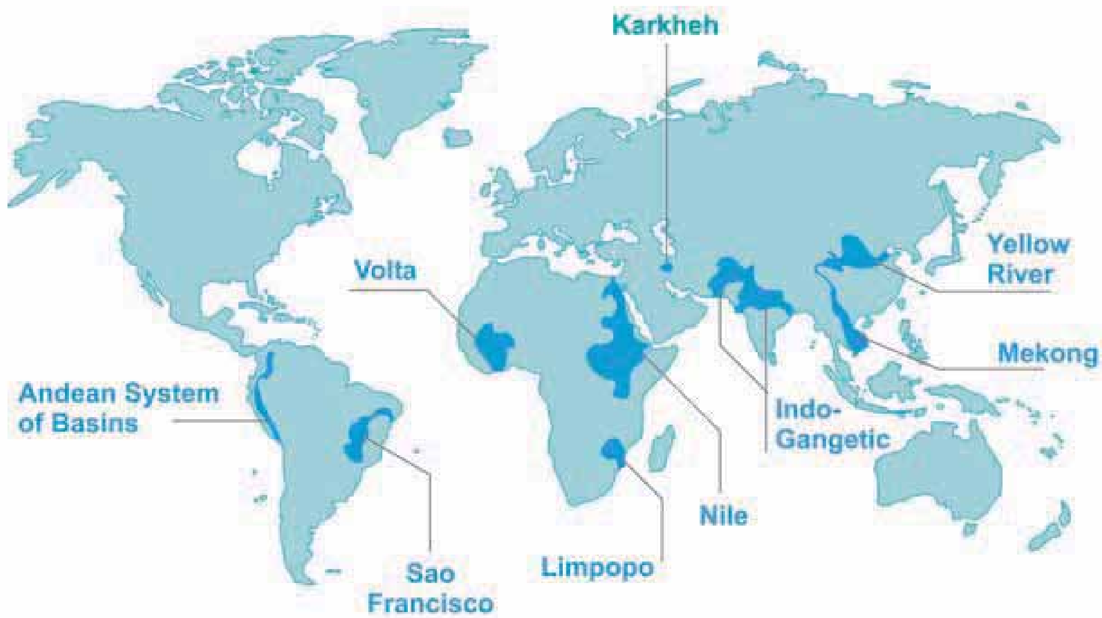
CGIAR Challenge Program on
WATER & FOOD

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.

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