CPWF Project Report

Improving On-farm Agricultural Water Productivity in the Karkheh River Basin (KRB)

Project Number 08

T. Oweis, H. Siadat, F. Abbasi
with contributions from the project team

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This paper presents findings from PN08 "Improving Water Productivity in Karkheh river Basin", a project of the CGIAR Challenge Program on Water and Food.

Program Preface:

The Challenge Program on Water and Food (CPWF) contributes to efforts of the international community to ensure global diversions of water to agriculture are maintained at the level of the year 2000. It is a multi-institutional research initiative that aims to increase the resilience of social and ecological systems through better water management for food production. Through its broad partnerships, it conducts research that leads to impact on the poor and to policy change.

The CPWF conducts action-oriented research in nine river basins in Africa, Asia and Latin America, focusing on crop water productivity, fisheries and aquatic ecosystems, community arrangements for sharing water, integrated river basin management, and institutions and policies for successful implementation of developments in the water-food-environment nexus.

Project Preface

Improving On-farm Agricultural Water Productivity in the Karkheh River Basin (KRB)

Improving On-farm Agricultural Water Productivity in the Karkheh River Basin (KRB) was a CPWF project that aimed at enhancement of agricultural water productivity (WP) under irrigated and rainfed conditions in Karkheh River Basin. It was launched in Iran through the partnership of ICARDA and the Iranian NARES under the Agricultural Extension, Education, and Research Organization.

The project lasted for more than four years between 2004 and 2008. Whereas capacity building was an important part of the agenda, PN8 was a participatory, multi-disciplinary, and action-oriented project that carried out mostly on-farm trials. Findings included existing crop water productivity, suitable technologies for their improvement, interactions between the upper and lower KRB, and a review of the prevailing water policies and institutions.

CPWF Project Report series:

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PROJECT HIGHLIGHTS

Agro-ecological zoning of KRB. As a joint activity with PN24, the agro-ecological zones map of KRB was prepared for the purposes of benchmark site selection and out-scaling project findings.

Capacity building of the NARES and other stakeholders. Technical and financial support were provided for two national colleagues to pursue their PhDs. Many training workshops were organized jointly with PN24 on participatory research approaches, participatory technology development, water productivity (WP) assessment methodology, GIS application, and crop modelling. Participation of many project colleagues in related national and international scientific gatherings was facilitated.

Promoting participatory research. Project trials were carried out on farmers' fields with their full participation, enhancing interactions between the farmers and researchers, and narrowing the prevailing gap. The project also promoted multi-disciplinary research and cooperation between different NARES institutions, resulting in the increased number of institutions joining the activities during the project and continuing to the end. Also, AREEO, as the NARES umbrella organization, started developing a similar project in which many institutes, including ones working with this project, are actively cooperating. This project is the first of its kind in AREEO.

Assessing water productivity in irrigated and rainfed agriculture. Water productivity under farmers' conditions was assessed in rainfed areas in the upper KRB and in fully irrigated fields under non-saline and saline conditions. These assessments revealed great potential for increasing WP in these areas.

Determination of technological options for improving water productivity. Trials were conducted to determine the best practices for improving water productivity for rainfed and irrigated crops under saline and non-saline conditions. Supplemental irrigation in rainfed areas, improved crop varieties, and proper planting and irrigation methods, resulted in significant increases in crop yields and water productivity.

Review of water policies and institutions in the basin. This study assessed prevailing water policies and institutional arrangements and suggested reforms of policies and institutions to give due attention to environmental sustainability, gender issues, food security, poverty and water pricing.

Evaluation of interactions between upper and lower KRB. Potential areas for expanding supplemental irrigation were mapped and the possible consequences on the quantity and quality of downstream flow were evaluated.

Assessing the role of economic factors on water use efficiency. Studies carried out in the lower KRB assessed the role of economic factors on water use efficiency in irrigated cereals.

Dissemination of project findings through documentation. At local and regional levels, dissemination was carried out through the production of a comprehensive series of publications. At the international level, dissemination was achieved by preparing and delivering research papers, and presentations at conferences such as IFWF2, where a special session was also organized for KRB.

Up-scaling through policy recommendations. The following policies were formulated and presented to agricultural policy and decision makers at IFWF2:
- Promote the utilization of supplemental irrigation in rainfed agricultural systems of the upper Karkheh River Basin.
- Provide incentives for adopting improved practices and new cropping patterns to increase water productivity and farm income in irrigated areas of the lower KRB.
- Implement agricultural drainage and salinity management technologies in salt-affected areas of the lower KRB.

EXECUTIVE SUMMARY

The Karkheh River is the third longest river of Iran with an annual flow rate of more than 5 km^3. It rises in the Zagros Mountains and flows southward to the southwestern parts of the country. The Karkheh River Basin (KRB) is between 30º58'-34º56'N and 46º06'-49º10'E, a very important agricultural zone with two major agricultural production systems: rainfed production upstream of the newly built Karkheh Dam, and fully irrigated production downstream of the dam. Both systems suffer from low water productivity (WP), the basin has been facing water scarcity and frequent droughts. This situation has had adverse effects on the livelihoods of the farmers. Therefore, water productivity has become an important development issue and the recent National Development Plans of Iran have identified the enhancement of water productivity in agriculture as a top priority.

In order to assist the country in its development plan, the CPWF program approved project PN8 with the hypothesis that water productivity in the KRB could be substantially increased by optimizing supplemental irrigation, improving on-farm irrigation management, introducing proper irrigation methods, introducing new crop varieties, and integrating appropriate agronomic practices in the crop production system with suitable institutional arrangements and policies. The key to the realization of the hypothesis was the involvement and participation of farmers and local communities as well as the full cooperation of the official organizations. Therefore, the project was launched with the following objectives:
1. Strengthening the capacity of NARES for improving water productivity.
2. Assessment of on-farm water productivity in the KRB.
3. Development of options for sustainable improvement of water productivity in irrigated and rainfed areas.
4. Review of water institutions and policy structures in the KRB and development of progressive policies and suitable institutional arrangements.
5. Out-scaling project findings to improve awareness by farmers' in the target environments and improve adoption of the new technologies.

Capacity building of the NARES was given high priority in order to ensure effective progress for the project and its sustainability after completion. Different activities were carried out in this regard including provision of technical and financial support for two national colleagues of the project to pursue their PhDs. Additionally, many training workshops were organized jointly with PN24 on different subjects related to both projects. Among these, training on Participatory Research Approaches and Participatory Technology Development were organized earlier in the project and were highly appreciated by the NARES staff as well as farmers. Technical workshops on water productivity assessment methodology, GIS application and agro-ecological zoning, and crop modeling were also successfully organized. The project also facilitated participation of many of its colleagues in a number of national and international scientific gatherings.

For the field studies, the first step was to select benchmark sites. This was achieved by field surveys and the preparation of an agro-ecological zones map of the basin. Later, four catchments were selected that represented the agro-ecological diversity of the KRB. These were Honam (33º49'N; 48º15'E; elev. 1567 m) and Merek (34º20'N; 48º19'E; elev. 1351 m) in the upper KRB, and Sorkheh (also called Evan) Plain and Azadegan Plain (31°04'-31°51'N and 47°46'-48°35'E) in the lower KRB., The project then used a participatory research approach consisting of on-farm trials and field surveys. Farmers were encouraged to cooperate with the national experts in conducting the research activities planned for the selected sites. Supplemental irrigation studies were carried out in the rainfed areas of the upper KRB, while the fully irrigated production systems under saline and non-saline conditions were studied in the lower parts of the basin. The project research activities were divided into six major components: (1) water productivity assessment in rainfed areas and improving (rain)water productivity with supplemental irrigation in the upper KRB, (2) water productivity assessment and improvement under fresh water conditions, (3) water productivity assessment and improvement under saline conditions, (4) review of water policies and institutions in KRB, (5) interaction between upper and lower KRB in response to the possible expansion of supplemental irrigation, (6) economic factors affecting water use efficiency (WUE). Some of the major research component included sub-components that were scientifically more focused.

In the selected rainfed areas of the upper KRB, project research showed that by applying limited amounts of supplemental irrigation, significant improvements can be achieved in both crop yield and water productivity. In Merek and Honam watersheds, early crop sowing with single 75 mm supplemental irrigation increased wheat and barley yields by over 50%, while applying an additional 75-100 mm of water in the spring more than doubled yields. Consequently, water productivity was also increased by 50% to 100%. It might be noted that, in another component of the project research, it was concluded that about 2000 km^2 of lands in the upper KRB are suitable for this practice. This shows the enormous potential for increasing wheat and barley production in the KRB.

In Sorkheh (Evan) Plain in lower KRB, results of project studies over two years showed that the average irrigation water productivity for wheat was 0.84 kg/m^3, with a maximum of 1.3 kg/m^3 in a farm that had access to both well and network water. The overall mean grain yield for the farms under study was 4700 kg ha^{-1}. Generally, farms irrigated by water from the irrigation network consumed more water, while grain yield was more in farms that had access to both well and water from the network. Also, wheat water use efficiency was more following corn than fallow. In this study, the growing period most sensitive to drought stress was from heading to grain ripening. To avoid drought stress during this stage, three or four irrigations (50 mm each) are recommended during the first half of the spring, from 15 March - 20 April.

In the same area, average WP for maize was 0.42 kg/m^3 of water used. The highest yield was achieved in fields with a density of 75,000 plants/ha. It was also observed that a short interval of about 4 days between the first and second irrigations gave better results. In later irrigations, a weekly interval was recommendable. Measurements of inflow and outflow in several farms showed that although farmers over-irrigated their fields, crop water requirement was not met due to deep percolation and/or runoff losses. The study indicated that improved management, could enhanced irrigation efficiency by about 50%.

Project experiences in Sorkheh (Evan) Plain indicated some Best Management Practices (BMP) for irrigated wheat. One BMP is to reduce the presently common seeding rates by about 25% to 50%, aiming at a density of 400 $seeds/m^2$. For land preparation, BMP is the use of a corn stem chopper prior to planting wheat following corn, to increase soil organic matter and to facilitate irrigation water advance in the field. Another BMP is corrugation irrigation in border strips. Various experiments conducted on farmer's fields showed that irrigation water use efficiency increased by an average of 45% compared with farmer's present practice. It is also advisable to use furrows in irrigation strips in the farms with a soil salinity level of 2 dS m^{-1} or more. Row planting on flat land is appropriate when the field has a relatively steep slope and has no salinity limitations.

Over-irrigation was identified as a major cause of low water productivity and low yields of corn fields. Under farmers' management in Evan Plain, planting corn seeds in the bottom of the furrows led to a saving of 20-30% in irrigation water consumption and an increase in WP based on crop ET. In similar studies conducted in the Agricultural Research Center of Safiabad, planting corn in the bottom of the furrows led to about 33% reduction in irrigation water consumption and 58% increase in WP. This could be recommended as a BMP in the area. Also, planting the high yielding corn cultivar 602 increased grain yield by 17% compared to the commonly planted cultivar 704.

Project studies in Azadegan Plain, i.e. the southern parts of the lower KRB, showed soil salinity as the major cause of low yields and water productivity (WP). The main cause of soil salinity was the high water table. Variability in irrigation WP was high, ranging from 0.1 to 2.1 kg/m^3. Four main sources of inefficiencies were identified: (i) socio-cultural problems e.g. low farming skills and low motivation for investing in irrigation management, (ii) inadequate farmers' control and authority over irrigation intervals and availability of agricultural inputs, (iii) technical and infrastructure limitations, and (iv) farmer managerial problems and limitations associated with irrigation such as flow control, irrigation and land preparation methods, and improvements in water intake structures.

Results of studies on drainage water reuse indicated that the option of using drainage water as irrigation water, especially with cyclic application of the latter, was feasible during different growth stages, without considerable yield losses. This could help improve the WP of wheat, particularly during periods of water scarcity and drought spells. Also, the basin irrigation method was more adaptive to the socio-cultural conditions of the area.

In the same area, comparative trials on wheat varieties showed that Bam, Sistan and Kavir varieties were more productive than Roshan, Akbari, and the local cultivars; therefore, they could be considered as potential substitutes for the present varieties grown under saline and water-logging conditions of the lower KRB. Also, in similar trials with barley and sorghum varieties and lines, some promising genotypes were identified for these conditions.

Supplemental irrigation (SI) is applied in rainfed systems to alleviate soil moisture stress for improved crop yields and water productivity. However, SI developments upstream have impacts on the amount and quality of water flowing downstream. Runoff in the upper Karkheh River Basin in Iran was assessed using a simple water balance in a GIS framework. The potential flow changes under SI strategies were assessed at the upstream sub-basin scale. Water demand and runoff maps were then simulated for a range of rainfall and irrigation scenarios. Three runoff/flow scenarios were considered: average rainfall, average rainfall with an environmental flow allocation (15% of the mean annual runoff) and low rainfall were considered. The water requirement for SI was assessed under different irrigation scenarios including a single irrigation for early sowing (75 mm in autumn); a single irrigation in spring, and two irrigations in spring (150 mm total). A FORTRAN program was prepared to calculate the water allocations for the upstream sub-basins. The impacts of the different scenarios on stream-flow were evaluated for each sub-basin and subsequently at the basin scale by comparing the flow with and without the SI scenarios, for the three flow/runoff situations. The results indicated that early sowing SI allocation in an average rainfall year will decrease downstream flow by about 15% annually, while full spring SI under dry conditions will reduce the amount by about 10%, if all potential areas for SI are developed.

A review was undertaken to assess the impact of water policies and institutional arrangements on irrigation water use and the consequences for water allocation and productivity in rainfed and irrigated regions of KRB. Several indicators were defined to assess current policies and institutions in relation to environmental, social, economic, and political dynamics. The indicators were food security, economic growth, environmental sustainability, poverty reduction, gender issues, water pricing and technology, water allocation, and research activities. A questionnaire was used to analyze these indicators at selected sites. The results suggested that water governance, management, and use, were characterized by a kind of pluralism complex that leads to the overlapping of rules and responsibilities of different organizations and competition between actors; therefore, water governance and water use should not be treated independently.

In an economic study on WP, 166 individual farmers were interviewed using a comprehensive questionnaire. Socio-economic characteristics of the farmers, profitability index, and WP of irrigated cereals and maize rotational production systems were recorded. Under non-saline conditions, the share of water and irrigation costs for wheat and maize were 21% and 25% of the total cost and each unit sale, i.e. each Rial or Dollar obtained in selling of wheat and maize had 56.5% and 51.7% net profit, respectively. Average irrigation WP for wheat (0.58 kg/m^3) was nearly double that of maize (0.38 kg/m^3). Under saline conditions, average yields were reduced by half and each unit sale of wheat and barley had, respectively, only 22.7% and 4.5% net profit, with irrigation WP values of 0.39 kg/m^3 and 0.34 kg/m^3, respectively. An overwhelming number of farmers emphasized irrigation development as an important factor in increasing production and income.

During the project, many reports were prepared and submitted, including quarterly, six-monthly, and annual progress reports, and reports of field missions, Steering Committee meetings, and some workshops. In addition, many papers and presentations were prepared and presented at national and international workshops, including the recent IFWF2 in Ethiopia. Some publications were also printed and distributed including "A Compendium of Review Papers", "Proceedings of the International Workshop on Water Productivity and Livelihood Resilience in KRB", and "Agro-ecological Zones of KRB". Several final reports of the different project activities are being edited and are forthcoming. The project also had joint activities with PN24 on participatory technology development (PTD) as a means for dissemination of knowledge and technology.

At the completion of the project, a half-day session was organized jointly with PN24 for policy and decision makers. The project formulated three policy recommendations: (1) promote the utilization of supplemental irrigation in rainfed agricultural systems of the upper KRB, (2) provide incentives for adopting improved practices and new cropping patterns to increase water productivity and farm income in irrigated areas of the lower KRB, and (3) implement agricultural drainage and salinity management technologies in salt-affected areas of the lower KRB. Printed flyers of these recommendations including explanations and justifications were distributed among participants for up-scaling the results.

The project involved partnerships with NARES including three specialized research institutions, four agricultural and natural resource research centers, and three provincial agricultural organizations. Team work between these institutions was greatly enhanced. Also, capacity building activities of the project, including two PhDs, were highly appreciated by the partners. Project introduction and promotion of participatory research and technology development was popular among farmers and extension agents. On the management issues, formation of

"Steering Committee" and "Project Technical Committee" proved to be a successful means for coordination and monitoring of the project activities.

Further research in the above mentioned activities as well as out-scaling and up-scaling of the project findings are recommended.

INTRODUCTION

The Karkheh River Basin (KRB) was selected as one of the nine benchmark basins of the CGIAR Challenge Program on Water and Food (CPWF) to address appropriate interventions for the improvement of on-farm water productivity, thereby enhancing livelihood resilience. The basin is located between 30º58'-34º56'N and 46º06'-49º10'E and is a very important agricultural zone in Iran with two major production systems: rainfed production upstream of the newly built Karkheh Dam and fully irrigated production downstream of the dam. While both of these systems suffer from low water productivity (WP), the basin has been facing water scarcity and frequent droughts. This situation has had adverse effects on the livelihoods of the farmers. Therefore, water productivity has become an important development issue and the recent National Development Plans of Iran have identified the enhancement of water productivity in agriculture as a top priority.

In the KRB, wheat is the dominant crop, especially in rain-fed conditions. Other crops are barley, chickpea, pulses, maize, alfalfa and vegetables. Orchards are also an important feature of the basin and include fruits such as apple, nuts, pear, olive, citrus, pomegranate, figs, and grapes. The average grain production in rain-fed areas is rather low: 920 kg/ha for wheat, 950 kg/ha for barley and about 500 kg/ha for chickpea. Rain water productivity of these crops ranges from 0.3-0.5 kg/m^3, far lower than the regional average values of 0.7-0.8 kg/m^3.

As agriculture in this area is susceptible to weather conditions, especially rainfall, some experts consider livestock production as being more reliable for livelihood than crop production. Indeed, livestock production is very popular and widespread throughout the basin and constitutes the main source of income for many farmers.

Whereas the basin displays a wide spectrum of bio-physical and socio-economic conditions, agricultural problems in the KRB are also diversified and complex. An important point to be considered in any development program for this basin is that the cultivated area is almost at a maximum, and the possibility of increasing water resources is very limited. Therefore, to meet the food demands of the increasing population, additional crop production will have to be accomplished mainly through increasing the productivity of the existing land and water resources. This necessity clearly calls for extensive research and extension works and emphasizes the urgency for doing so. Such research could also contribute to the enhancement of farmers' livelihoods by increasing their income and would help in better management and sustainability of the natural resources.

The present project was approved by CPWF for implementation in the KRB and was carried out jointly by the International Center for Agricultural Research in the Dry Areas (ICARDA) and the Iranian Agricultural Extension, Education, and Research Organization (AEERO). The objectives of the project were to enhance the capacity of the partner institutions in developing technological options to improve the farm and basin level water productivity and to assess the prevailing policies and institutions and recommend appropriate policies and institutions needed for supporting the project interventions to help the poor communities for the improvement of their income and livelihoods. Moreover, the project aims at general strengthening of National Agricultural Research and Extension Services (NARES) of Iran.

OBJECTIVES

1. Strengthening of the capacity of NARES.
2. Assessment of on-farm water productivity in KRB.
3. Development of options in integrated packages for sustainable improvement of water productivity in irrigated and rainfed areas.
4. Review of institutional and policy structures in KRB and development of progressive policies and suitable institutional arrangements.
5. Out-scaling project findings to improve awareness by farmers in the target environments and to improve adoption of the new technologies.

1. Strengthening the capacity of NARES

In order to ensure the efficiency of the project implementation and its sustainability after completion, capacity building programs were started after the project launch in June 2004 and were continued almost throughout the four years of its operation.

Methods

Capacity building needs of the partner NARES institutions were usually discussed and decided upon in the project technical committee and the CP-KRB projects joint Steering Committee. Selection of the candidates was based on the performance and cooperation of the experts collaborating with the project. All candidates also had to qualify according to the rules and regulations of their respective institutions. For the PhD candidates, initial selection was made by an interview conducted by the project management team. The candidates who passed the interview had to take entrance examinations of the local universities and secure acceptance for registration.

Results and discussion

Many activities were carried out in this regard including provision of technical and financial support for two national colleagues of the project to pursue their PhD at local universities. Additionally, many training workshops were organized jointly with PN24 on different subjects related to both projects. Among these, training on Participatory Research Approach and Participatory Technology Development were organized earlier in the project and were highly appreciated by the NARES staffs as well as the farmers. Technical workshops on water productivity assessment methodology, GIS application and agro-ecological zoning, and crop modelling were also successfully organized. In addition, the project facilitated participation of many of its colleagues in the national and international scientific gatherings. Table 1 shows a summary of the capacity building activities.

Table 1-1- Capacity building activities of PN08

Category	Name	Achievements
PhDs		Finished the course works and is close to defending dissertation
	Moayeri Mansour	Topic: Study on the Impacts of Advanced On-farm Management on Agricultural Water Productivity for Maize in Evan Plain (Karkheh River Basin). Winter 2010.
		Finished the course work and is working on dissertation
	Alireza Tavakoli	Topic: Improving Rainwater Productivity with Supplemental Irrigation in Upper Karkheh River Basin of Iran. Fall 2010
NARES	38 NARES staff	Two weeks training for Participatory Diagnosis (joint with PN24)
	24 NARES staff	One-week workshop on Farmers' Innovation and Innovators (joint with PN24)
	28 NARES staff	One-week workshop on "Principles of PTD (participatory technology development, joint with PN24)
	22 NARES staff	English Classes (joint with PN24)
	2 NARES staff	Two one-week workshops for application of GIS for agro-ecological zoning (joint with PN 8)
	10 NARES staff	One-week workshop on elementary GIS (joint with PN24)
	3 NARES staff	One-week workshop on" Water Productivity survey and economic analysis" in Aleppo, Syria
	7 NARES and NGO staff	Impact Pathway analysis in Iran (joint with PN 24)
	7 NARES staff	Practical familiarization with Participatory Technology Development in Syria (joint with PN24)
	11 NARES staff	One-week workshop on PTD in Aleppo (joint with PN24)
	21 NARS staff	One week on advanced PTD for field experimentation in Iran (joint with PN24)
	1 NARES staff	One week training for uploading CPWF-KRB Website (joint with PN24)
	2 NARESS staff	One-week workshop on economic analysis of WP
	2 NARESS staff	One-week workshop on upper/lower KRB interaction studies.
	6 NARES staff	Two-week training workshop on "Water management in Dry Areas with Special focus on Water Productivity" and modelling using AQUA CROP
	2 NARES staff	One –week workshop on "Reverse simulation of WP using AquaCrop, starting with biomass and

Category	Name	Achievements
		weather data, and up-scaling to watersheds".
	20 Project colleagues and NARES staff	Attended quarterly, mid-annual, and annual workshops of the project (joint with PN24) and participated in the discussions and scientific decision making.
	2 NARES staff	Attended CPWF Forum (1st IFWF) held in Vientiane, Laos
	10 NARES staff	Attended an international workshop in Aleppo on "Assessment of Basin Water Productivity"
	80 NARES and project colleagues of PN8 and PN24	Attended International Workshop on "Improving Water Productivity and Livelihood Resilience in Karkheh River Basin". (Joint with PN24).10-11 Sep 2007, Karaj, Iran and presentations of 14 papers.
	2 NARES staff	Attended the 9th IDDC in Cairo (7-10 Nov, 2009) and presenting a paper on "Assessment of supplemental irrigation at upstream sub-basin of Karkheh River Basin on water quantity and quality of Karkheh Dam" upper/lower KRB interaction
	14 NARES staff	Attended 2nd IFWF in Addis Ababa and organized the Karkheh River Session (jointly with PN 24) and presented their findings.
	90 NARES staff, , stakeholders institutions, and project colleagues	Attended the "Final workshop of the CP WF projects in Karkheh River Basin". Karaj, Iran. 2-3 March 2009. 28 scientific presentations based on the projects research findings and survey activities. (Jointly with PN24)
Farmers	About 250 farmers	Farmers participated in the project on-farm trials on supplemental irrigation and agronomic studies in the upper and lower KRB
		Some participated in PTD activities carried out jointly with PN24.
		Some attended Farmers Day organized by the project alone or jointly with PN24.

2. Assessment of on-farm water productivity in the KRB

2-1-Assessment of wheat water productivity[1]

Methods
These trials were conducted in Sorkheh district of Avan Plain in the lower KRB during 2005-07 seasons. The plain has a semi-arid climate with average rainfall of about 350 mm. It has a Mediterranean type climate and lacks summer rainfall. This study was carried out during the 2005-7 growing seasons. In the study area, seven irrigation zones or units, each consisting of several farms with similar sources of irrigation water, were identified as follows: two units using only wells, three units receiving water from irrigation network canals where water delivery is on a variable rotational basis and depends on the operation of the pumping station feeding the network from the river, one unit pumping water directly from the river, and one unit using both network and well water. In each irrigation unit, three farms were selected with regard to variables such as distance to water source, method of water supply, crop cultivar, management of irrigation, and farming practices. The following information was collected for each field:

1- Physical and chemical soil properties, including soil texture, (pH) reaction and salinity of its saturation extract (EC_e), and soil testing for N, P, and K in each farm, through sampling before cultivation season.
2- Volume of irrigation water by measuring inflow and outflow using cutthroat flume, area of the fields, furrow length, land slope, and water salinity.
3- Daily climatic data used with crop factors to estimate crop evapotranspiration
4- Crop variety, rate of seeding, calendar of farm management practices, crop growth stages, yield and yield components.

In each farm, total yield was calculated from the amount of grain harvested by a combine and area of the field. Also, plants in three 6 m^2 sample areas were cut at the soil surface for measurement of plant density, grain yield, and total dry matter. Finally, using the collected data, water productivity (WP) of each farm was determined as the ratio of crop yield (kg) to the volume of water used (m^3).

Results
1. Average irrigation water productivity for wheat in Dasht-e Avan is 0.84 kg/m^3, and it can be increased to 1 kg/m^3.
2. Mean of measured yields was 4700 kg/ha with 550 mm of applied water.
3. Farms irrigated by water from the network consumed more water but had lower grain yields.
4. Grain yields of Chamran, Veirinak, and Dez varieties were similar in the first year of study, but the Dez cultivar had a higher yield in the second season.
5. Wheat yields and water use efficiency were higher in fields following corn than fields following fallow, possiblye due to the effect of residual fertilizers in the soil after corn harvest, and/or positive impacts of the chopped corn residues.
6. The most efficient unit inflow in terms of irrigation water productivity was 3.5-4 lit/s/m.
7. There were indications that the most sensitive stage to drought stress is heading stage until grain ripening. Therefore, three or four irrigations (each 50 mm) are recommended during early spring.
8. Assuming a fixed yield resulting from the application of proper irrigation practices and/or utilization of irrigation systems with higher application efficiency, the irrigation water efficiency can be enhanced by about 30%.
9. Organic matter contents of the soils in our study were low.

[1] Reference: Moayeri, et al. 2009. Final Report of assessment of WP under non-saline conditions in lower KRB. Chapter 2: Assessment of Wheat Water Productivity. Forthcoming.

Complete results and discussion will be presented in the forthcoming final report. Tables 2-1-1 and 2-1-2 summarize results from the 2005-6 and 2006-7 seasons.

Table 2-1-1-Water productivity of irrigated wheat (2005-6).

Field No.	Variety	Seed rate kg/ ha	No. of irrig.	Border length m	Average irrig. depth mm	Grain yield kg/ha	WP_{ET} kg/m^3	WP $_{Iri+R}$ kg/m^3
1	Chamran	250	3	255	79	5089	1.605	1.183
2	Vierinak	300	3	212	87	4807	1.393	1.190
3	Vierinak	300	4	262	89	4674	1.355	0.940
4	Dez	280	3	470	121	5769	1.949	1.039
5	Dez	280	3	362	198	3514	1.220	0.448
6	Dez	280	3	472	59	4189	1.454	1.141
7	Chamran	300	4	480	73	4846	1.434	1.249
8	Vierinak	350	4	360	74	5493	1.807	1.128
9	Chamran	250	4	275	90	4003	1.321	0.771
10	Dez	300	5	200	93	4208	1.362	0.642
11	Dez	154	4	410	70	4611	1.441	0.931
12	Dez	185	4	300	48	3652	1.159	0.902
13	Vierinak	250	4	383	65	5736	1.625	1.554
14	Chamran	270	3	315	56	4720	1.543	1.311
15	Chamran	270	3	270	96	4447	1.482	0.930
16	Chamran	180	3	235	111	4865	1.378	1.098
17	Chamran	280	8	230	77	3385	1.095	0.411
18	Vierinak	250	7	235	42	4509	1.266	1.034
19	Vierinak	250	7	240	34	2914	0.819	0.765
20	Vierinak	280	4	242	98	3869	1.135	0.771
21	Vierinak	280	4	358	87	3241	0.950	0.709
22	D-79-18	300	3	375	99	4953	1.452	1.220

Table 2-1-2- Water productivityof irrigated wheat (2006-7).

Field No.	Variety	Seed rate kg/ha	No. of irrig.	Border length m	Average irrig. depth mm	Grain yield kg/ha	WP_{ET} kg/m^3	WP $_{Iri+R}$ kg/m^3
1	Sheva	290	5	208	80	4734	1.449	1.027
2	Sheva	330	5	270	48	4690	2.023	1.595
3	Sheva	330	5	235	68	4690	1.909	1.202
4	Dez	300	12	290	101	2269	2.015	0.174
5	Sheva	280	10	365	111	3896	2.164	0.338
6	D-79-18	300	10	480	87	1549	1.285	0.168
7	Vierinak	300	5	275	165	2505	2.254	0.287
8	D-79-18	280	7	150	212	3072	1.528	0.200
9	D-79-18	290	6	220	107	3840	1.929	0.552
10	Star	140	6	238	114	4606	0.752	0.593
11	Star	160	5	243	129	2899	1.455	0.415
12	Vierinak	185	5	239	155	5144	1.453	0.622
13	Vierinak	220	5	311	64	5678	1.971	1.522
14	Vierinak	220	5	270	138	4470	2.211	0.603
15	Vierinak	220	5	335	123	3366	2.123	0.504
16	Chamran	240	6	253	86	3818	1.553	0.634
17	Vierinak	250	6	229	104	2238	1.463	0.345
18	Vierinak	250	6	181	103	4006	1.946	0.627
19	Vierinak	250	5	357	147	2384	1.580	0.304
20	Dez	270	5	275	122	3747	1.929	0.569
21	Dez	280	5	380	104	6134	1.622	1.080

2-2- Assessment of maize water productivity[2]

Method
This study was also carried out during the 2005-7 seasons, as for wheat. The methodology was the same as described for wheat in the preceding section.

Results
Average irrigation water productivity in 2006 and 2007 was 0.54 and 0.57 kg/m^3, respectively; the number of irrigations in both years was about 9 (range 6-17). Taking into consideration average daily evaporation of 10 mm from late July to mid September, and allowing 70 mm cumulative evaporation from Class A pan between irrigations, an average weekly irrigation interval seems appropriate, i.e. 7-8 irrigations, which suggests that most crops were over-irrigated. Results show that irrigation water productivity can be increased by up to 50 % by adopting improved irrigation practices and/or utilization of more efficient irrigation systems.

1. Average irrigation WP for maize in Dasht-e Avan is 0.42 kg/m^3.
2. The highest yield is achieved with 75000 plants/ha.
3. The most effective interval between the first and second irrigations is 4 days.
4. Despite over application of water, the water need of the crop is not satisfied.
5. Irrigation is applied more frequently than the recommended rate of 7 days.
6. Assuming a fixed yield, use of improved irrigation practices and/or utilization of irrigation systems with higher application efficiency can increase irrigation water productivity by about 50%.
7. Average soil organic matter content is low.

Table 2-2-1- – Results of measurement of maize WP in 2006.

No. of Field	Plants /ha	No. of irrig.	ET	Grain yield * kg/ha	WUE	WP_{ET}	WP_{Irri}
1	70000	11	671	6836	0.303	1.019	0.373
2	62963	10	701	5268	0.460	0.752	0.522
3	63704	11	701	4425	0.306	0.631	0.259
4	57037	11	711	3990	0.471	0.561	0.282
5	72222	10	653	3899	0.589	0.597	0.420
6	58148	9	572	5748	0.546	1.005	0.720
7	47037	10	644	2096	0.528	0.325	0.204
8	55926	14	663	3573	0.599	0.539	0.441
9	58519	12	554	3124	0.451	0.564	0.415
10	91111	15	771	5967	0.424	0.774	0.421
11	51852	6	536	3013	0.521	0.562	0.332
12	48519	12	770	2791	0.488	0.363	0.225
13	50000	8	637	2854	0.616	0.448	0.300
14	70741	13	769	3211	0.655	0.418	0.513
15	55185	10	663	3883	0.633	0.586	0.678
16	99259	11	637	5863	0.515	0.920	0.895
17	70370	13	741	4936	0.736	0.666	0.724
18	51852	13	771	2596	0.959	0.337	0.456
19	61481	11	693	4057	0.389	0.585	0.313
20	78148	9	697	4495	0.564	0.645	0.458
21	76296	8	644	3774	0.416	0.586	0.288

* Average of the whole field as harvested by a combine.

[2] Reference: Moayeri, et al. 2009. Final Report of assessment of WP under non-saline conditions in lower KRB. Chapter 3:Assessment of maize water productivity. Forthcoming.

Table 2-2-2– Results of measurement of maize WP in 2007.

No. of Field	**Plants /ha**	**No. of irrig.**	**ET**	**Grain yield * kg/ha**	**WUE**	**WP_{ET}**	**WP_{Irri}**
1	71667	11	845	4608	0.733	0.545	0.400
2	71111	12	906	5211	0.646	0.575	0.371
3	82222	12	906	5705	0.665	0.629	0.419
4	58333	12	827	5716	0.682	0.692	0.472
5	57778	10	725	5899	0.656	0.814	0.534
6	48889	10	640	4465	0.733	0.698	0.512
7	95556	17	809	2893	0.461	0.358	0.165
8	86111	17	809	3479	0.500	0.430	0.215
9	92778	17	827	7594	0.404	0.919	0.372
10	-	10	817	5854	0.298	0.716	0.213
11	96667	10	946	4641	0.380	0.491	0.186
12	-	10	918	6965	0.368	0.759	0.280
13	68889	11	817	7726	0.445	0.945	0.420
14	72222	11	809	9295	0.403	1.149	0.463
15	62222	12	802	3464	0.674	0.432	0.291
16	60556	12	792	4858	0.385	0.614	0.236
17	36111	10	669	2189	0.483	0.327	0.158
18	60556	10	772	7584	0.703	0.982	0.691
19	55000	10	764	7721	0.678	1.011	0.686
20	57222	10	687	6321	1.145	0.920	1.054

* Average of the whole field as harvested by a combine.

2-3-Assessment of water productivity (WP) under saline conditions in Dasht-e-Azadegan (DA)[3]

In the lower KRB, heavy soil texture, low infiltration rates, and recharge from upstream areas are conducive to water logging that is aggravated by low irrigation efficiency. Salinity, water-logging, low soil organic matter and low infiltration rate are the main factors limiting crop production in the irrigated lands of lower parts of KRB. The main objective of this research was to determine and evaluate water productivity of irrigated wheat, a major cultivated crop in DA.

Methods

The research was conducted in 14 selected farmers' fields, typical of the farms in the region, during cropping years of 2006-07 and 2007-08 (7 farms in 2006-07 and 7 farms in 2007-08). These fields were under the supervision and support of Yasamin Agricultural Cooperative and Valfajr Rural Services Center. Some information about these farms is given in Tables 2-3-1 and 2-3-2.

[3] Reference: N. Heydari1, S. Absalan, M. Qadir, F. Abbasi, T. Oweis. 2008. Assessment and evaluation of water productivity in the Dasht-e-Azadegan. CHAPTER II, in: Cheraghi, S.A.M., N. Heydari, et al. (Editors). 2008. Final Report: Improving On-farm Agricultural Water Productivity in Saline Areas of the Lower Karkheh River Basin.

Table 2-3-1- Some soil (0-30 cm) and water characteristics of the selected farms before planting (2006-07).

Farmer's name	Farm code	Area (ha)	Topsoil texture	Topsoil salinity (dS/m)	Depth to water table (cm)	Ground water salinity (dS/m)
Saleh Marei	F1	1.05	SiL	26.4	105	8.8
Rahim Hamoodi	F2	1.47	SiCL	10	205	39
Jalil Mashmashavi	F3	4.49	CL	52.6	180	71.5
Saleh Sakini	F5	3.44	C	17	195	31
Bashir Booazar	F6	1.73	C	21.5	182	48
Motalleb Hamoodi	F7	0.46	SiC	21.3	173	46
Mohammed Hamoodi	F8	5.24	C	10.5	213	8.7

Table 2-3-2- Some soil (0-30 cm) and water characteristics of the selected farms before planting (2007-08).

Farmer's name	Farm code	Area (ha)	Topsoil texture	Topsoil salinity (dS/m)	Depth to water table (cm)	Ground water salinity (dS/m)
Naji Frisat	F1	3.79	SiL	51.4	207	34
Abdolkazem Hardani	F2	4.86	SiCL	17.8	193	48
Abdolhossein Maree	F3	3.71	SiC	16.2	153	19
Abbas Hamoodi	F4	6.92	SiC	15.9	205	88
Rahman Hamoodi	F5	1.17	SiC	21.6	172	15
Adnan Hemadi Nia	F6	1.93	CL	16.8	213	98
Masoud Jalali	F7	23.5	C	81.3	186	24

The selected farms were typical of the farms in the region, during cropping years 2006-07 and 2007-08. The crop cultivated in these farms was wheat. For determination of WP, the rainfall data was obtained from the closest weather stations. The measured parameters were inflow and outflow of irrigation water using WSC (Washington State College) flumes, salinity (EC) of the inflow and outflow waters, soil texture, soil salinity, pH, soil organic matter, P, K, Fe, Mn, Zn, Cu of the soil prior to planting and during cropping season, depth and quality (EC) of ground water during cropping year, and crop yield.

For measurement of crop yield, 20 random field samples were taken in an area of 1 by 1 meter in the field. The fields were harvested at roughly 14% moisture. The irrigation intervals were the same as practiced by the farmers. Irrigation WP was calculated by dividing grain yield by the total amount of irrigation water.

Results and discussions
Tables 2-3-3 and 2-3-4 show a summary of results obtained in the study seasons.

Table 2-3-3- Summary of the results of measurements (season 2006-07).

Farm	**Yield (kg/ha)**	**Irrigation amount (m^3/ha)**	**WP (kg/m^3)**
F1	2392	3110	0.77
F2	1021	3460	0.30
F3	1336	2060	0.65
F5	1453	3790	0.38
F6	3032	3530	0.86
F7	4851	2310	2.10
F8	1431	5930	0.24

Table 2-3-4-Summary of the results of measurements (season 2007-08).

Item/Farm	**Yield (kg/ha)**	**Irrigation amount (m^3/ha)**	**WP (kg/m^3)**
F1	2573	3705	0.69
F2	1317	2188	0.60
F3	1617	2282	0.71
F4	1699	2518	0.67
F5	2094	3496	0.60
F6	1088	3142	0.35
F7	468	4636	0.10

There was a wide range in irrigation amount, crop yield, and irrigation WP. According to the latest national agricultural statistics, Iran produced 67 million tonnes of agricultural products from 84 BCM of water consumed. Therefore, currently the country's average irrigation WP is almost 0.8 kg/m^3 , which seems quite low compared with the world's average value around 1.5 kg/m^3 (Heydari et al. 2006). Previous results of field studies conducted in three provinces in Iran, namely, Kerman, Golestan, and Khuzestan, indicated that the irrigation WP for the farmer managed irrigated wheat was in the range of 0.56-1.46 kg/m^3 (Heydari et al. 2006). The range of WP is generally wide and, for wheat, it varies between 0.6-1.7 kg/m^3.

There were no clear correlations between irrigation WP and initial soil salinity, ground water depth, groundwater salinity, farm size, and the number of irrigation events. However, in some farms with deeper groundwater and smaller farm sizes, WP was higher. It is possible that in smaller farms the size of water flow is small and, therefore, management of water is easier and more efficient.

The lack of a relationship between initial soil salinity and irrigation water productivity may be related to the dynamic nature of salinity in the region. Soil salinity changes greatly with fluctuation of the water table and irrigation with the fresh Karkheh river water. Because of the shallow and variable depth of the impermeable layer below the soil surface, the water table rises rapidly as a result of percolation from irrigation, hence contributes to the soil surface salinity changes. The highest values of soil salinity are normally seen at the beginning of the cropping season following the fallow period. But following the first irrigation most of the salts are washed to the deeper layer. In addition to the highly temporal variability of soil salinity, spatial variability is also high due to poor land leveling and distribution of water, and the variable groundwater salinity and depth. Cheraghi (2008) monitored the soil salinity and depth of shallow water table November 2003 to April 2004 in the Dasht-e-Azadegan region, concluding that there was a large variation in salinity of groundwater ranging between 4 dS/m to 100 dS/m leading to high variation in surface soil salinity. Karma (2002) also noted that alluvial plains in Iran and especially those in Khuzestan Province, including LKRB, are highly stratified and accurate identification of the impermeable layer in these sols is very difficult. Therefore, there is not a simple and direct relationship between soil salinity and irrigation WP in the Dasht-e-Azadegan region. However, it is clear that salinity and water logging are major sources of low WP in this region.

Overall, based on findings obtained during the field works with the farmers, the sources of inefficiencies and factors causing low values of irrigation WP in the southern part of the lower KRB can be classified into four main categories as follows:

- Socio-cultural problems associated with the farming communities leading to low motivation among the farmers for individual or joint-investment with the Government in irrigation management and on-farm improvement activities.
- Limitations that are out of farmer's management control and authority, e.g., irrigation intervals and rationing of the canal network, and shortage of agricultural inputs (fertilizers, other agrochemicals, machinery, etc.).
- Technical and infrastructure limitations and problems (e.g., inadequate drainage and reclamation, and incomplete irrigation and drainage networks) that need extensive planning and investments and which should be supported by the government.
- Farmer management problems and limitations whose solutions are simple and do not need much investment, and which can be accomplished easily e.g., flow control, irrigation and land preparation methods, improvements in water intake structures, growing improved varieties, fertilizer and weed control management, etc.

The results indicated that these limitations vary depending on the farmer and location of the farm. Some of these limitations are:

- Traditional common irrigation in the area is a mixture of border-basin irrigation method. The long borders (up to 400 m, 12-15 m wide) are divided into small basins (30-60 m length). Every basin receives its water from the previous (upstream) basin. Water is ponded for a long time in the upper basins in the sequence until the bottom basin has been irrigated, damaging the seed in the upper basins due to prolonged water logging. The high inflow rate at the top also results in erosion and exposure of the seeds. As there is not enough control on cutoff time, large amounts of water accumulate in the lower parts and create surface water logging. It is recommended to irrigate via a farm ditch alongside the border and a proper intake into each basin.
- Problems in water intake and conduct of water into the irrigation plots due to lack of proper constructed intake structures. This problem leads to much time and effort spent by farmers to control irrigation flow (start and terminate the flow to the plot). This directly leads to extra runoff, deep

percolation losses, and poor water management in the field. Construction of temporary and low-cost intake structures (gates, etc.) to facilitate water intake and improve water management are recommended.
- Improper leveling and slope of the fields causes non-uniform distribution of water in the plots.
- Improper land preparation and agronomic practices (weed control, planting date, etc.).

Conclusions and recommendations
The main objective of this research was to find cost effective and short-term solutions for solving these problems and to improve irrigation WP of wheat in the salt-prone areas of lower KRB. We determined irrigation WP in farmers' fields. Water logging and soil salinity are major threats to the productivity and sustainability of agriculture in the lower KRB. Soil salinity is the major cause of low yields and water productivity in this region. In general, the main cause of soil salinity is the high water table, varying between 1.2-3.0 m below the soil surface.

Variability in irrigation WP was high, ranging from 0.1 to 2.1 kg/m^3. There were four main sources of inefficiencies: (i) socio-cultural problems e.g. low farming skills, low motivation for investing in irrigation management and on-farm improvement activities, and low motivation for participatory works, (ii) limitations out of farmers' control and authority e.g., irrigation intervals and rationing, and shortage of agricultural inputs, (iii) technical and infrastructure limitations and problems, and (iv) farmer managerial problems and limitations associated with irrigation, e.g., flow control, irrigation and land preparation methods, improvements in water intake structures, that can be overcome easily and which do not need much investments.

Considering the above limitations and problems, the following solutions are recommended to improve WP in the saline area of the lower KRB:
- Conversion of traditional and locally common irrigation methods to proper basin/border methods.
- Construction of fixed and low-cost water intake structures on farm ditches.
- Proper land leveling and bedding according to farm slope.
- Application of on-farm management improvement instructions provided by rural extension services.
- Farmers training and supervision by irrigation experts for guidance, and enhancement of irrigation management.
- Preparing the required condition and enabling environment for volumetric allocation of water to the farmers through extension services.
- It is recommended that this survey be continued in the future with a higher number of farms in order for the results to include wider changes and variations of the factors affecting WP, especially the spatial and temporal changes in the salinity of soil and water in the southern part of the lower KRB.

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3. Options for improving water productivity (WP)

3-1- Improving WP of rainfed wheat and barley by supplemental irrigation[4]

Methods

The on-farm trials were carried out in different farms and fields in Merek and Honam. Local cultivars and improved varieties of wheat and barley were sown in 2005-07 seasons in mid October (early sowing) at 15-20 cm row spacing. The plot sizes varied from 0.2 to 1 ha, depending on the farmers' consent and field conditions. The treatments were randomly assigned to each block and replicated two times (two farmers) and included two main management methods: Advanced Management (AM) including improved varieties mechanized land preparation and planting, proper fertilizer management, weed, and disease control and Traditional Management (TM) including local cultivars and traditional practices such as planting by manual broadcasting. In separate fields, improved varieties of winter bread wheat (Azar2) and winter barley (var. Sararood1) grown with AM or TM were subjected to the following supplemental irrigation (SI) treatments:(1) early sowing with 50 mm single irrigation at planting time, (2) 50 mm single irrigation at spring time (at heading-flowering stage), (3) 75 mm single irrigation at planting time + 50 mm single irrigation at spring time, (4) only rainfed i.e. no SI. Similar treatments were conducted for traditional sowing dates At the end of the season, three samples (1 m^2) were taken from each plot for measurement of yield components i.e. grain and biomass yields, thousands kernels weight (TKW), grain per spike, and harvest index (HI). Statistical analysis was performed by using t-Test statistical software.

With regard to the different definitions of water productivity, calculations were carried out by using the following equations, in which volume of water used refers to irrigation, rainfall and or sum of irrigation and rainfall amounts (m^3), RWP is rain water productivity (kg/m^3), IWP is irrigation water productivity(kg/m^3), GIWP is taken as the ratio of increase in grain yield to the gross depth of irrigation

$$RWP = \frac{Yield}{rain} \qquad TWP = \frac{Yield}{irr. + rain}$$

$$IWP = \frac{Yield}{irr.water\ \ use} \qquad GIWP = \frac{Yield_{irr} - Yield_{rainfed}}{irr}$$

Results

During 2005-06 season in both catchments, rainfall was inadequate for emergence at the optimum time (October). In Merek, total seasonal rainfall amount was 505 mm and first and last effective rainfall were 31 mm and 18.2 mm on 16-17 November 2005 and 5-6 May 2006, respectively. In 2006/2007 season, adequate rainfall fell in October immediately after sowing with a total seasonal amount of 552 mm. The first and last effective rainfalls were 8.6 mm and 18.5 mm on 16-17 October 2006 and 32.3 mm on 15-17 May 2007, respectively. In Honam, total seasonal rainfall during 2005-06 was 544 mm, the first effective rainfall amounts were 7.2 mm and 24.4 mm on 21 October and 6 November 2005, respectively, and the last effective rainfall amounts were 37.7, 7.4 and 12.3 mm on 6-7, 17-18 and 25-27 April 2006, respectively. However, during the 2006-07 season, Honam had adequate rainfall in October immediately after sowing with a total seasonal amount of 573 mm. The first and last effective

[4] Reference: Tavakoli1, A.R., T. Oweis, S. Ashrafi and A. Liaghat. 2008. Improving water productivity of rainfed wheat and barley by supplemental irrigation in Northern Karkheh River Basin.

rainfalls in this catchment were 15.6 mm and 31.9 mm on 16 October 2006 and 16 May 2007, respectively.

The treatment involving rainfed farming (no SI) with advanced agronomic management outyielded traditional management at both sites in both years, by up to 60%. RWP under AM (0.26-0.39 kg/m3) increased by about 15-33% compared to TM.

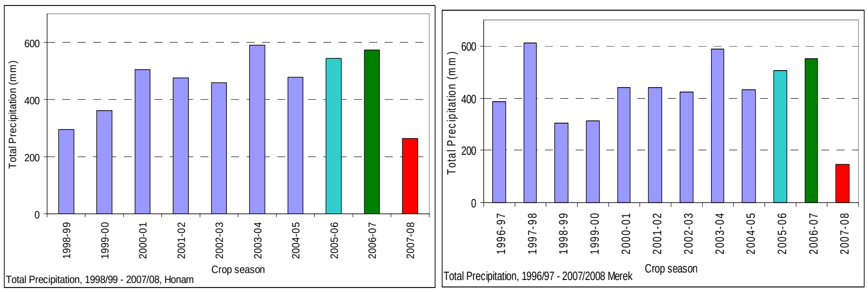

Fig. 3-1- Mean crop season annual rainfall for Honam (left) and Merek (right) sites

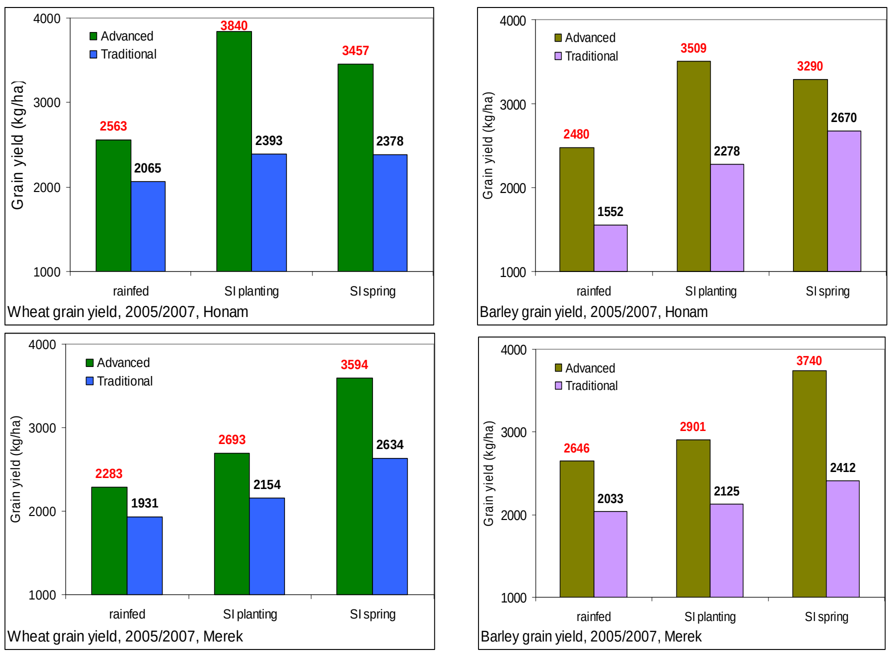

Fig. 3-2- Wheat grain yield under different SI treatments at Honam and Merek sites

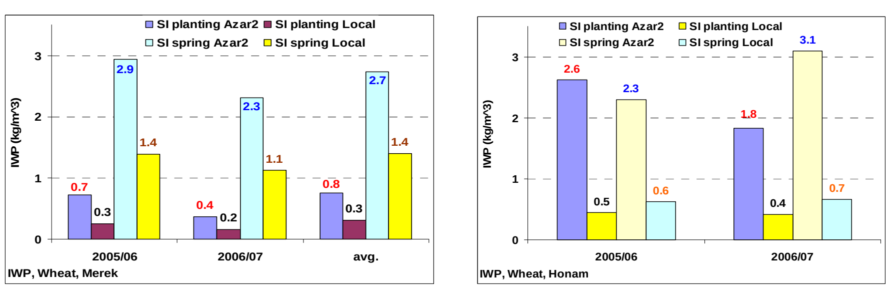

Fig. 3-3- Irrigation WP under different SI treatments at Honam and Merek sites

The results of this study showed that a single irrigation at sowing or spring time (during heading to flowering stage) increased TWP of wheat from 0.53 kg/m^3 to 0.75 kg/m^3.

The irrigation water productivity (IWP) of wheat reached 0.7-3.1 kg/m^3 with a single irrigation at sowing or spring time (Fig.3-3). Low RWP (and yield) in farmer practices were mainly due to suboptimal agronomic management practices. These preliminary results confirm the potential of single irrigation and early planting as an effective method to enhance productivity, and that the biggest gains are to be made by combining supplementary irrigation with improved varieties and management.

Discussion

Yields of wheat and barley substantially increased with SI and proper agronomic management practices (Fig 3-2). While many of the previous studies in the dryland Mediterranean zone have focused on individual components of cereal cropping, few have integrated these components into a technology package with potential for adoption. However, even when this technology package is applied, some year to year yield ceilings may occur due to factors such as cold and fungal disease, which are difficult to control (Tavakoli and Oweis, 2004).

In Honam, single irrigation at sowing or in spring increased yield effectively; however, in Merek, SI at planting was not effective, while SI at spring i.e. during heading–flowering stage, increased yield (Fig 3-2). This reflects their climatic condition: Honam has a cold climate that starts early; therefore, SI at early planting helps the crop grow before winter frosts occur, while Merek is a cold-temperate region where cold temperatures occur later and not as low as Honam.

Early sowing with single irrigation allowed early crop emergence and development of good stand before being subjected to the winter frost. As a result, the crop used rainwater more efficiently. Single irrigation in spring also increased yield significantly, but with reduced irrigation water productivity. Early emergence of the crop as a result of irrigation at sowing produced higher straw and grain yields and plant height in the two sites.

Conclusion

The most dramatic implication from this study was the large increases in yield by combining supplementary irrigation with improved varieties and management. In most cases, applying a single irrigation with new advanced varieties doubles yield compared with rainfed conditions (Tavakoli et al. 2005). Such yield increase clearly supports the findings of Stewart and Musick (1982), Tavakoli and Oweis (2004) in favor of the potential for supplementary irrigation in semi-arid regions.

Among the management parameters, date of sowing plays a special role under rainfed conditions. In cold winter environments (such as Honam condition), an adequate plant stand before the dormant frost period (end of November till March) is essential for a high crop yield (Fig.3-2). This may not be attained in the growing seasons when the first adequate rainfall occurs later than November. However, where irrigation water is available, early germination and emergence can be ensured by applying a small (30–40 mm) irrigation after sowing (Oweis and Hachum 2004; Tavakoli and Oweis 2004; Tavakoli et al. 2005; Ilbeyi et al. 2006). Oweis et al. (2001) reported substantial increases in wheat yield, in a similar highland environment in the Central Anatolian Plateau of Turkey, as a result of a 50 mm irrigation at early sowing time. Further SI in the spring can improve yield and water productivity but to a lower degree.

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3-2- Assessment of potential upstream-downstream impacts of supplemental irrigation in KRB[5]

Although supplemental irrigation (SI) is a highly efficient water-use practice, the consequences of using the water upstream on the developments downstream should be assessed. The objective of this work is to examine the potential consequences of SI implementation in rainfed areas on the downstream flow.

Methods

Runoff mapping

Monthly flow records for the years 1975-2004 were extracted from the Tamab Database. Gauging stations operating over the entire period were selected, yielding a set of 53 stations. The ArcHydro extension (Maidment 2002) in ArcGis9 was used to derive the drainage patterns of the Karkheh catchments from the digital terrain model. Raster analysis was performed to delineate the gauged watersheds. Some watershed boundaries were corrected manually using 1:25,000 topographic maps. Given a grid of precipitation values and a grid of watersheds (defined with the same cell size), a table of the mean precipitation in each watershed was determined. Based on computed 30 year mean flows for each station, the net measured inflow for each of the 53 watersheds was computed, and the net measured inflow was normalized by the watershed area and expressed in mm/year. The average runoff per unit area (mm) versus average rainfall (mm) for all delineated watersheds was calculated. Information from the outlying points was used to create a map of actual runoff. Using the inference of scale-independence, the expected runoff function was applied to the

[5] Reference: Hessari, B, F. Abbasi., M. Akbari, A. Bruggeman, T. Oweis, and E. De Pauw. 2008. Proceedings of IFWF2. Addis Ababa.

precipitation grid to create a spatially distributed map of expected runoff. A grid of actual runoff was created by combining net runoff information at the watershed scale.

Supplemental irrigation iso-potential mapping
De Pauw et al. (2008) presented a methodology for using GIS tools and expert criteria to identify potential areas for SI in Syria. The assumptions used are that such areas: are basically rainfed; are characterized by the presence of arable soils; have non-constraining slopes; and are within the proximity of existing irrigation schemes that do not require substantial investment in irrigation infrastructure. The method is based on the assumption that the irrigation water discharge (from either surface or groundwater) available in existing irrigated schemes, that is currently used to fully irrigate summer crops, could instead (or in addition) be used fully or partially in winter for SI of winter crops. Since the water requirements for SI of winter, rainfed crops are a fraction of that for non rainfed fully irrigated summer crops, the areas that could be irrigated in winter, using same amount of water, are much larger than the areas currently used for summer full irrigation. The method uses a simple model to calculate the additional rainfed area that can be irrigated by shifting from spring/summer fully-irrigated crops to supplementary-irrigated winter/spring crops. The potential SI area is identified by combining with a water allocation procedure for the surrounding rainfed areas based on suitability criteria. In this research, the method used in Syria was applied to the KRB.

Slope classes determine the suitability land for different types of irrigation. Figure 1. shows slope classes in two sub-basins of the KRB. The slopes used for different irrigation methods are: surface (less than 5%), sprinkler (5-8%), and trickle (8-12%). The most common and easily accessible water supply are from rivers in the KRB, where flow data is recorded. Buffers of 1000 m for were imposed around the streams lines. This is based on expert estimates of the maximum distance for economically conveying water in the region. The stream buffer area layer is overlaid on the rainfed area slope classes for the 53 sub-basins, from which the iso-potential map for SI is derived. The monthly irrigation requirement for each sub-basin is calculated based on the SI map. In this research, the long term monthly stream flow data of gauge stations along the river were considered as the available water for allocation to SI.

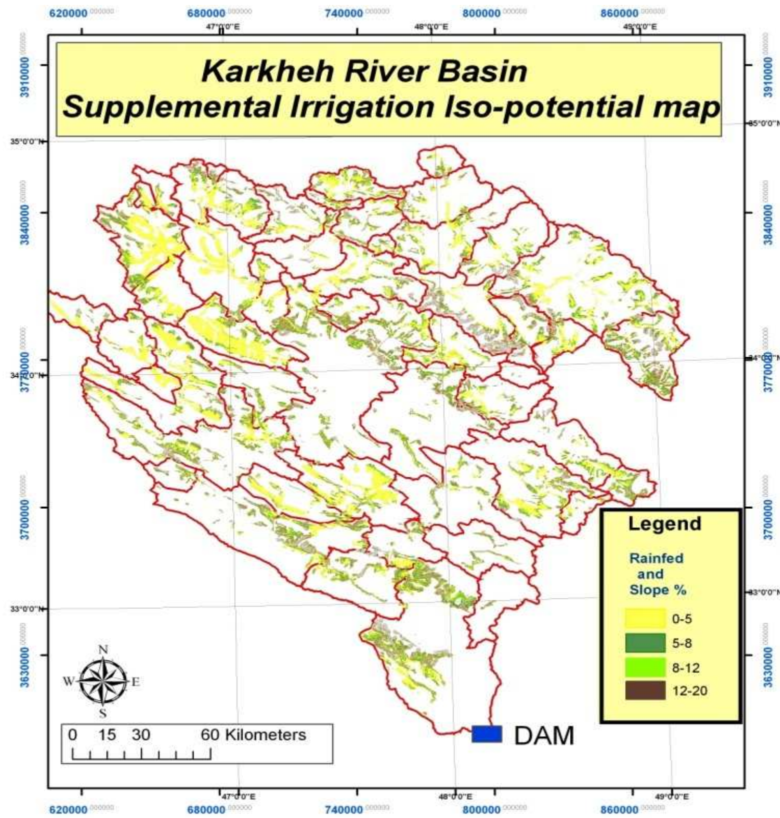

Figure 3-2-1. Rainfed cultivation areas with different slope class in two sub-basins of the KRB

Water resource requirements (system, SI and environmental flow)
Available stream flow is allocated for SI in autumn and spring. Water requirements include: existing needs (irrigation, industry, domestic), new supplemental irrigation and environmental flow requirements (EFR). At gauge stations excess water is recorded, thus if water is allocated according to recorded gauge stream flow data, all existing needs are considered already . Strategies of SI are: (i) a single irrigation (100 mm) in autumn; (ii) two irrigations (each 75 mm) in spring. Available water in each sub-basin is based on daily and monthly base flow of the stream in addition to available groundwater resources. Discharge data variation and the wet and dry thresholds of surveyed sub-basins and base flow in sub-basins determine the water available for allocation. The challenge is to determine the amount of water, and its quality, that should be allocated for the maintenance of the ecosystems through an "environmental flow allocation" and water that can be allocated for agriculture, industry, and domestic services (Ramsar Convention Secretariat 2007). Methods for estimating EFR include: hydrological methods, hydraulic rating, habitat simulation and holistic methods (Mazvimavi et al. 2007). In this research, 15% of the mean annual runoff was used as an EFR. By subtracting EFRs from monthly flow data, available water for allocation to SI areas of all sub-basins was determined.

Water allocation
Allocation of water is made according to location, planting calendar and available water in sub-basins. In this study, long term monthly flow data of gauge stations along the river were used to estimate the available water for SI in suitable rainfed areas. One scenario of allocation water for SI will be drought situation. A higher level of water stress was considered, with the (river) resource availability set at 80% of the occurrence probability as a drought condition. A FORTRAN program

was developed to calculate the available and required water volumes for each sub-basin based on the suitable area for each slope class and to route the remaining water from the upper sub-basins to the Karkheh dam. The program first calculates the potential available flow for each sub-basin by subtracting all current downstream uses computed from the observed incoming and outgoing flows (gauge data) of each sub-basin.

Results and discussion

The outflow estimation before and after applying SI strategies allowed evaluating: i) the impacts of different SI strategies on stream flow; ii) assessment of the water demand at each sub-basin; iii) the water allocation pattern; iv) the response of each sub-basin to SI intervention; and v) the available and allocated water based on each strategy. Tables 1 and 2 present the impacts of implementing the three SI scenarios on the areas and the flows downstream, respectively. Allocations of water may be adjusted based on water availability and priorities and the comparative benefits among various uses within the basin. The critical factors affecting water management are the temporal and spatial characteristics as associated with the national objectives of the upstream-downstream development. Figure 2 shows results of comparison of the 3 rainfall/flow conditions and the potential supplemental areas. Expected reductions in the downstream flows under the average, average with environmental flow and dry conditions are 9-15%, 9-16% and 5-10% of the available flow, respectively. Thus the results indicate that implementation of SI in the rainfed areas does not substantially reduce the average annual flow to the Karkheh reservoir significantly. At the same time, SI provides considerable benefits for yield and water productivity in the upper KRB according to ongoing research on selected sites. In addition to environmental flow there are left-over flow from most sub basins then 15% of mean annual runoff as the minimum EF will be sufficient.

Table1. Suitable irrigation areas and developable irrigated areas of SI.

Scenario	Areas (km^2) in different slope classes			
	0-5%	0-8%	0-12%	0-20%
	Suitable SI areas (km^2)			
	3559	4802	5945	7361
	Actual SI areas (km^2)			
Average stream flow	1259	1572	1833	1945
Average stream flow with environmental flow	827	1053	1234	1362
Dry conditions (low stream flow)	432	628	793	975

Table2. Available flow and outflow after of SI Scenarios

Slope %	Condition	*Average stream flow*					*Average with env. flow*					*Dry*				
		oct	nov	Apr	may	annual	oct	nov	apr	may	annual	oct	nov	mar	apr	annual
	available flow (m^3/s)	57	115	421	284	177	30	89	394	257	151	42	67	205	225	90
0 -5	outflow with SI (m^3/s)	17	107	408	167	162	6	80	381	144	137	28	59	205	212	86
	Reduction of downstream flow (%)	-71	-7	-3	-41	-9	-79	-10	-3	-44	-9	-33	-13	-6	-11	-5
0 -8	outflow with SI (m^3/s)	10	101	400	133	158	3	75	373	113	133	26	53	205	204	85
	Reduction of downstream flow (%)	-82	-12	-5	-53	-11	-90	-16	-5	-56	-12	-38	-21	-9	-13	-6
0 -12	outflow with SI (m^3/s)	6	96	391	106	154	2	69	364	86	130	26	48	205	195	83
	Reduction of downstream flow (%)	-90	-17	-7	-63	-13	-93	-22	-8	-67	-14	-39	-29	-13	-15	-8
0 -20	outflow with SI (m^3/s)	6	88	380	82	150	2	62	354	72	127	26	41	205	184	82
	Reduction of downstream flow (%)	-90	-23	-10	-71	-15	-93	-30	-10	-72	-16	-39	-40	-18	-15	-10

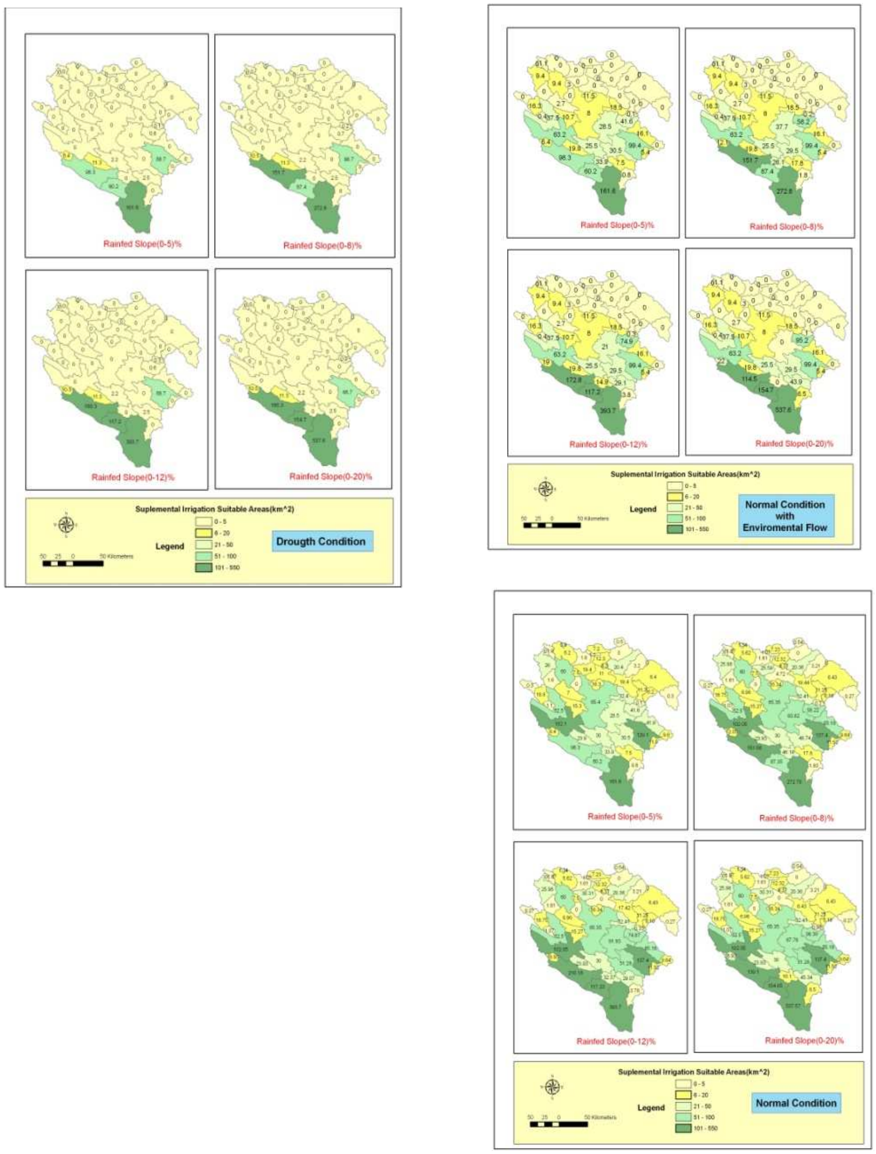

Fig 3-2-2- Potential supplemental irrigation under normal, normal with environmental flow, and drought conditions in the KRB of Iran.

Conclusions and recommendations

The results indicate that implementation of SI in the rainfed areas does not substantially reduce the average annual flow to the Karkheh reservoir, while providing considerable yield and water productivity benefits. We recommend the use of SI in spring, or a single irrigation in autumn with early sowing, to maximize water productivity in upstream KRB. Environmental flow for maintaining the ecosystem should not be neglected with 15% of mean annual runoff as the minimum allocation. Further research should be made to solve EF allocation with left-over considerations of complex river system of KRB with 53 sub basins . A detailed soil map can be very useful to help allocate SI water more precisely. The methodology, the criteria and the scenarios may be refined further by including socioeconomic factors. In particular, the predicted changes in farm incomes under the proposed options may help influence policies for the reallocation of available water resources.

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3-3-Improving wheat and maize water productivity[6]

The objectives were to study effects of field management and agronomic practices on the water productivity of two major irrigated crops, wheat and maize, in the lower KRB.

Methods
Trials were also conducted in Sorkheh district, where two rotations are quite common: maize-wheat and fallow-wheat. The study conducted for fallow-wheat cropping system had the following treatments:(TW1) disking, broad casting, corrugation irrigation, (TW2) 3 rows on 60 cm-wide raised bed i.e. flat top ridges, furrow, (TW3) flat land sowing, 12.5 cm row spacing, flood irrigation, and (TW4) farmers' practice i.e. disking, seed broad cast, border irrigation. For wheat after maize, treatments were:(TW5) use of corn chopper then combined planter, (TW6) use of corn chopper then seed broadcasting, disking, corrugation irrigation, and (TW7) = flat land sowing, 12.5 cm row spacing, flood irrigation + corn residue. The farmer system (control) for both cropping system was border irrigation with broadcast seeding and disking. Wheat was sown at the rates of 165 kg/ha.

For maize, four field management systems were compared with traditional practice (control) at Sorkheh, in farmers' fields. The treatments were all irrigated by furrows spaced at 75 cm and consisted of the followings: (TM1) plant row spacing 75 cm, alternate furrow irrigation, (TM2) 2 plant rows spaced 25cm on furrow ridge, full furrow irrigation (TM3) single plant row inside furrow, full furrow

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6 Reference: Moayeri, M., H. Dehghanisanij, A.F. Nato, H. Siadat, T. Oweis and H. Farahani.2008. Increasing field water productivity of irrigated crops in the lower Karkheh River Basin. Unpublished draft.

irrigation (TM4) 2 plant rows inside each furrow, full furrow irrigation, and (TM5) farmers' practice: single plant line, full furrow irrigation All the furrows were with 130 m length. Each treatment was conducted in three replications in full sized field (130 m length) where they received the same amount of applied irrigation water. The in-flow and out-flow was measured using a calibrated cut-throat flume. A variance analysis (ANOVA) was used to compare treatments effects on yield and water productivity.

Data collection included: soil characteristics, soil fertility analysis, water quality (salinity), land leveling (slope), size of fields, irrigation amount and runoff, number of irrigation events, crop varieties, cropping calendar (time of planting, harvest, etc.), crop yields (by sampling from 1 m^2 area), tillage and cultivation practices, crop growth stages, timing and amount of inputs including fertilizers and pesticides, seeding rate and climate parameters to estimate crop water requirements. The following definition of crop WP was used:

$$\text{WP (kg/m}^3\text{)} = \frac{Ya}{I+R} \qquad (1)$$

Where WP is crop water productivity based on the irrigation water (I) plus rainfall (R) entering the field, and Ya is defined as the marketable part of the total above ground biomass production. Here, however, we considered Ya as the total grain yield for both wheat and maize.

Results and discussion

Mean wheat water productivity was 1.46 kg/m^3 in improvement fields (Table 3-3-1). There was significant difference between the wheat yields in improved technololgy fields after fallow or maize compared with farmer practice. In average the mean wheat yield was slightly higher (by 300 kg/ha) after fallow compared to after maize. However, the amount of input (irrigation plus rain) water was less in the fields after maize, mainly due to the later sowing and shorter wheat growth period after maize. The net result was that wheat WP was higher in the fields after maize compared to those after fallow. Wheat WP was significantly higher in TW5 (improved treatment after maize) compared to the improved treatments after fallow (TW1, TW2, and TW3) and controls (TW4 and TW7). In the improvement fields after maize, border irrigation with combined planter (TW5) showed higher impact on wheat WP (1.84 kg/m^3) compared to furrow irrigation with combined planter, broadcasting and corrugating after planting (TW2) (1.48 kg/m^3). In the improvement fields after fallow, impact of TW1 and TW3 treatments on wheat WP were similar to each other and close to the value obtained for the control treatment.. However, both (TW1 and TW3) were lower compared to the full furrow irrigation, with raised-bed system and sowing using local furrower (Hamedani Barzegar type). Overall, TW5 had the highest WP of 1.84 kg/m^3 among all treatments and TW2 had the maximum WP value of 1.4 kg/m^3 in the wheat fields planted following fallow.

Table3-3-1-Wheat yield and water productivity under different treatments.

Treatments	**I+R (m^3/ha)**	**Yield (kg/ha)**	**Water productivity (kg/m^3)**
After fallow			
TW1	4820	6466^{b}	1.34^{ce}
TW2	4880	7134^{a}	1.46^{b}
TW3	5000	5836^{d}	1.17^{e}
TW4 (farmer practice)	4921	5124^{e}	1.12^{e}
After maize			
TW5	3470	6369^{c}	1.84^{a}
TW6	4390	6480^{b}	1.48^{b}
TW7 (farmer practice)	4377	4694^{f}	1.11^{e}

The maize plant density in our farmers' practice treatments in farmers' fields ranged between 45,000 to 100,000 per ha in Sorkheh. We applied a seeding rate corresponding to 75,000 plants/ha.

Maize grain yield of TM1 and TM2 was similar to control. However, measured maize grain yield in furrow bed system (TM3) was significantly lower than other improvement and control treatments. Irrigation applications were highest in TM4 where furrow bed systems with double planting line inside the furrow was applied and that was and lowest in TM3. The significant lower irrigation amount for the furrow bed system with a single planting line (TM3) compare to that for double planting line could be attributed to the furrow bed system and higher water advance rate in furrow with a single planting line. As a result, maize water productivity in all improvement systems was significantly higher than that in control. Maize water productivity in TM2 improvement treatment was 0.58 kg/m^3, significantly higher than other improved treatments and control (Table 3-3-2).

Table 3-3-2. Maize yield and water productivity following treatments,. 2006.

Treatments	Irrigation (m^3/ha)	Grain yield (kg/ha)	Water productivity (kg/m^3)
TM1	11620	6361^b	0.55^b
TM2	10920	6367^b	0.58^a
TM3	9760	5283^c	0.54^b
TM4	13360	6514^a	0.49^c
TM5 (farmer practice)	14360	6118^c	0.43^d

Conclusions

In the Karkheh river basin, low irrigation water productivity (WP) is one of the main issues in agricultural production, mainly due to poor field water management and agronomic practices. The recommended seeding rates for both maize and wheat are less than that applied by farmers, but gave higher yields in combination with other improved management practices. The WP of maize was increased with both (i) furrow irrigation with broadcasting, disking, and corrugating, and (ii) full furrow irrigation, with raised-beds and sowing using a local furrower. For wheat, input water productivity of wheat in the maize-wheat cropping was higher than in the fallow-wheat cropping system, despite slightly lower yields. The mean wheat input WP was improved by 43% by improved management practices. The highest maize WP measured in the fields was faced deficit irrigation at least partially. The mean maize water productivity improved 20% by improved field management, especially by raised beds with 75 cm bed width and full furrow irrigation. Results indicate that the mean wheat and maize input water productivity with farmer practice was 1.02 and 0.40 kg/m^3 which were subsequently improved to 2.32 and 0.52 kg/m^3 when improved practices were applied at the farms.

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3-4-Improving wheat water productivity (WP) under saline conditions

Improving water productivity in the Dasht-e-Azadegan (DA)[7]

In the southern part of lower KRB, mainly Dasht-e Azadegan (DA) or Azadegan Plain, available data and information show that the problem of soil salinity is intensified due to inadequacy of farmers' skills and unavailability of new and improved farming practices. The main objective of this research was to find out cost effective and short-term solutions to increase wheat water productivity in the DA. Accordingly, the following targets were identified in this research:

- Development of simple management practices for improving agricultural WP.
- Investigation of traditional vs. improved border-basin irrigation method.
- Investigation of the impact of different cultivation/sowing methods on wheat WP.

Methods

The research was conducted in a farmer's wheat field in DA during the seasons 2006-07 and 2007-08. The farm is located in 31°26′39.6″N and 48°17′45.2″E. The source of irrigation water was the Karkheh River. Six improved irrigation and planting methods were compared with farmer practice (Tc):

- $T_{1=}$ modified border irrigation +sowing by centrifugal broadcaster followed one pass disc
- $T_{2=}$modified border irrigation + sowing by seed drill machine (Taka type)
- $T_{3=}$ modified border irrigation + sowing by three rows bed seeder (Hamedani type)
- $T_{4=}$ modified basin irrigation + sowing by centrifugal broadcaster followed one pass disc

[7] *Reference:* Heydari, N., S. Absalan, E. Dehghan,, F. Abbasi, M. Qadir and T. Oweis. 2009. Management practices for improving water productivity in the Dasht-e-Azadegan. In: Cheraghi, S.A.M., N. Heydari, M. Qadir, G.H. Ranjbar and T. Oweis (eds.). Final Report: Improving On-farm Agricultural Water Productivity in Saline Areas of the Lower Karkheh River Basin. CPWF-ICARDA-AEERO. Pp 48-84. (Forthcoming).

- $T_{5=}$ modified basin irrigation + sowing by seed drill machine (Taka type)
- $T_{6=}$ modified basin irrigation + sowing by three rows bed seeder (Hamedani type)
- $T_{c=}$ irrigation and sowing managed by farmer traditional method (as control).

The dimensions of the modified border were selected as 160 m x 10 m (T1, T2, T3) and for the modified basins as 40 m x 10 m (T4, T5, T6). These dimensions were optimal sizes and were based on SCS recommendations. The traditional method of irrigation (control) was similar to a combination of basin and border irrigation. Farmers chose borders length according to their farm dimensions (usually 100-400 m) and then divided borders to several basins with 30-70 m length, depending on their field topography. During irrigation, they fill the first basin and then transfer water to the second one, and so on thereafter. The width of such borders was usually between 5 to 14 m.

Chamran wheat variety was sown in all the treatments. Seeding rate was 250 kg/ha in treatments sown by centrifugal broadcaster (T_1, T_4). In the other treatments, seed drill (TAKA) and three rows bed seeder (Hamedani), the rate was 180 kg/ha. In the control treatment (T_c) sown by centrifugal broadcaster and managed by the farmer, the seed rate was 350 kg/ha. Other farming practices (e.g. irrigation interval) were the same for all treatments.

Plant density and grain yield were measured by sampling from 1 m^2 sampling frames at random locations in each plot before harvest. Irrigation water was measured by WSC flumes. The number of irrigations and interval between irrigations were the same as practiced by the farmers.

The reuse of drainage water for irrigation was also investigated. The main objectives of reuse are to reduce irrigation amount and lower the water table. In the first year, this trial was conducted in small experimental plots, but in the second year it was done in large plots beside the farmer's field. Treatments of this study are shown in Table 3-4-1.

Table 3-4-1: Treatments for drainage water reuse experiment.

Year 2006-07		Year 2007-08	
Treatment	**Explanation**	**Treatment**	**Explanation**
T1	Application of Saline-Saline-Fresh water	T1	Cyclic application of water (Saline-Saline-Fresh-Fresh)
T2	Application of Fresh-Fresh-Salinewater	T2	Cyclic application of water (Fresh-Fresh-Saline-Saline)
T3	Application of Fresh-Saline-Fresh water	T3	Cyclic application of water (Fresh-Saline-Fresh-Saline)
Tc	Canal (fresh) water (Control)	Tc	Canal (fresh) water (Control)

Results and discussion

At the study site, soil texture was silty clay loam to silt-loam, average soil pH was 7.8 and average soil salinity at depth of 0-30 cm was 15 dS/m. However, the soil salinity values in the region vary greatly temporally and spatially. The EC of the groundwater and canal water was 11.3 and 1.4 dS/m, respectively. Groundwater depth at the beginning of the growing season was 237 cm and in winter, following recharge from irrigation, it rose to 35 to 98 cm from soil surface. Figure 3-1 depicts a wide range of variation in water table depth in the selected field during the growth seasons. Deep percolation losses of irrigation during this period cause water table to rise, with the peak rise in February.

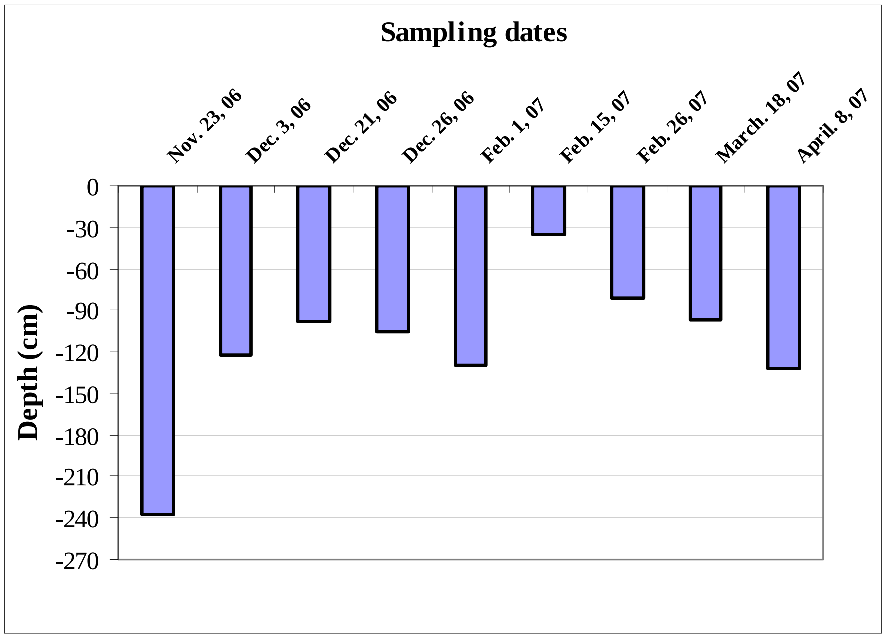

Fig. 3.1: Variation of the groundwater depth (average of three points) during growth season (2006-07)

The recommended modified border and basin designs with shorter length of run gave considerable reductions in the volume of irrigation water and greatly increased irrigation and input water productivity compared with farmer practice (Tables 3-4-2, 3-4-3 and 3-4-4). Border irrigation with centrifugal and Hamedani sowing methods (T1, T3) had the highest irrigation water productivities in 2006-07 and 2007-08, being 1.60 kg/m^3 and 1.88 kg/m^3, respectively. Averaged across sowing methods, the modified (recommended) border irrigation had the maximum irrigation water productivity (1.36 and 1.74 kg/m^3) in 2006-07 and 2007-08, respectively, was more than double that of the farmer managed treatment.

Agronomic measurements and data analysis are presented in Tables 3-4-4 and 3-4-5. Statistical analysis showed that the recommended treatments i.e. T1 through T6, had positive effects on crop germination, yield, and seeding rate in comparison to the control. Results from 2006-07 and 2007-08 are presented in Tables 3-4-6 and 3-4-7, respectively.

There was no significant difference (α=0.05) in yield between the recommended treatments and the control treatment in the first year (2006-07). This indicates that the effects of the recommended treatments were on water saving and increasing irrigation application efficiency rather than increasing yield. However, in the second year of the experiments, due to the severe drought in the area, the treatments had a pronounced effect on water savings and, hence, higher yields were obtained in comparison to the control and the difference was significant. Although the seed rate used with Taka and Hamedani sowing machines was 50% less, seed germination percentage was more than with the centrifugal method.

Tables 3-4-8 and 3-4-9 show the grain yield obtained under different cyclic applications of fresh and saline drainage water for the two years of the experiments. Drainage water had EC values of 17.3 dS/m and13.9 dS/m as measured on Nov 2006 and Feb, 07.

In summary, both the modified basin and border irrigation methods can save considerable volume of irrigation water and enhance WP in the Lower KRB. Also, using drainage water for irrigation of wheat, especially with cyclic application of fresh and saline water during different growth stage, is feasible without considerable yield losses and it will help to improve wheat irrigation WP.

Table 3-4-2- Amount of applied water, yields, and water productivities under different irrigation management treatments (2006-07).

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

Table 3-4-3- Amount of applied water, yields, and WP for different treatments (2007-08).

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

Table3-4-4- Values of WP of different treatments with the inclusion of rainfall**

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

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

Table3-4-5- Agronomic data for different treatments (2006-07).

Irrigation method	Sowing method	Seeding rate (kg /ha)	Number of plants per m^2	Germination (%)	Yield (kg /ha) Planting treatment	Yield (kg /ha) Irrig.n treatment
Basin-border (farmer)	Centrifugal	350	247	34	1953	1953
Modified border	Centrifugal	250	341	56	2590 n.s.	2308
	Taka	180	262	60	2434 n.s.	
	Hamadani	180	286	65	1901 n.s.	
Modified basin	Centrifugal	250	387	63	2730 n.s.	2483
	Taka	180	332	75	2521 n.s.	
	Hamadani	180	353	80	2198 n.s.	

n.s.: Statistical difference not significant

Table3-4-6- Agronomic data for different irrigation management treatments (2006-07).

Irrigation method	Sowing method	Seeding rate (kg/ha)	Plants per m^2	Germ. (%)	Yield (kg /ha)	
					Planting treatment	**Irrigation treatment**
Basin-border (farmer)	Centrifugal	350	270	31	1940	1940
recommended border	Centrifugal	250	290	47	2144 n.s.	2338
	Taka	180	302	61	2471 n.s.	
	Hamedani	180	316	64	2400 n.s.	
recommended basin	Centrifugal	250	320	52	2251 n.s.	2474
	Taka	180	321	65	2606 n.s.	
	Hamedani	180	352	71	2564 n.s.	

Table3-4-7- Agronomic comparison between irrigation management treatments (2007-08).

Irrigation method	Sowing method	Seeding rate (kg/ha)	Plants per m^2	Germination percentage (%)	Yield (kg /ha)
					Planting treatment
Basin-border (farmer)	Centrifugal	350	305	35	1940
recommended border	Centrifugal	250	335 n.s.	54**	2198 n.s.
	Taka	180	344**	70**	2538 **
	Hamedani	180	336**	68**	2482**

ns: no significant ; *, **: Significant at 5%,and 1% respectively

Table 3-4-8- Grain yield (kg/ha) in cyclic use of drainage water for irrigation (2006-07).

Treatment/ Replication	**T1***	**T2**	**T3**	**Tc**
R1	3523	3358	3466	3963
R2	3025	3880	3026	4088
R3	3355	3528	3045	3839
Average	3301	3589	3179	3963
Change to the control (%)	16.7	9.5	19.8	-

*:T1: Saline-Saline-Fresh water; T2: Fresh-Fresh-Saline water;
T3: Fresh-Saline-Fresh water; Tc: Fresh-Fresh-Fresh water

Table3-4-9- Grain yield (kg/ha) in cyclic use of drainage water for irrigation (2007-08).

Water treatment		**Grain yield**	
		kg/ha	**t/ha**
Tc	Fresh-Fresh-Fresh (Control)	2698	2.70
T2	Fresh-Fresh-Saline	2118	2.12
T3	Fresh-Saline-Saline	1710	1.71
T4	Saline-Saline-Saline	1501	1.50

Conclusions and recommendations

The basic approaches to solve salinity and water logging problems in DA would be the construction and completion of modern irrigation and drainage networks, and managing the system based on integrated and scientific programs. But such programs are costly and time consuming. Therefore, research activities related to water-table management, soil salinity control, irrigation water management, selection of suitable crop varieties, and improved agronomic practices are needed to improve agricultural water productivity and farmers' livelihood without heavy investments.

According to the present research, both improved basin and border irrigation methods can be recommended for the enhancing WP in the study area. However, basin irrigation is more compatible with the socio-cultural conditions of the area. Improvement of traditional surface irrigation methods in the saline and waterlogged areas can also help amelioration of the situation and improve crop water productivity

Using drainage water as irrigation water, especially with cyclic application of fresh and saline water during different growth stage, is feasible without considerable yield losses and it will help to improve wheat irrigation WP.

3-5-Introduction of salt tolerant plant varieties in saline areas of KRB[8]

Salinity is a major problem in irrigated areas of the lower Karkheh River Basin (LKRB), where high groundwater level has compounded the situation. Use of salt-tolerant genotypes, such as high yielding salt-tolerant wheat, barley and sorghum varieties, is a potential short-term method to address the growing salinity problem in the area. Considering that the majority of the cereal planted area in this region has an average yield of 2 t/ha, introduction of high-yielding salt tolerant varieties could bear a positive impact on total crop production and water productivity.

Methods

This study was conducted at Dasht-e Azadegan in Khuzestan province during 2005-2008. Dasht-e Azadegan is located in the lower KRB between 31^{o}04'35"-

[8] Reference: Ranjbar, G.H., S.A.M. Cheraghi, A. Anagholi, G. L. Ayene , M.H. Rahimian and M. Qadir. 2008. Introduction of salt tolerant wheat, barley and sorghum varieties in saline areas of KRB. IFWF. Addis Ababa, Ethiopia.

31°51'39"N and 47°46'34"-48°35'12"E. Wheat, barley and sorghum genotypes were examined in separate experiments.

Wheat crops were grown in 4 m × 7 m plots with each plot containing 18 rows of each genotype. The rows were spaced 0.2 m apart. Prior to sowing triple super phosphate was mixed into the top 0.25 m of soil at a rate of 115 kg P/ha. To assure adequate N fertility throughout the experiment urea was added at the rate of 150 kg N/ha. Herbicides were applied to control weeds whenever necessary. The salt tolerant genotypes were Bam, Akbari, Sistan, Kavir and Roshan. The local wheat cultivars were Chamran and Verinak.

The treatments for barley experiments were two cultivars (Afzal and Reyhan) and four barley lines (Karon × Kavir, M80-9, M-81-19 and On-4). Barley rows were spaced 0.2 m apart with sowing density of 350 seeds/m^2. Each plot was 4.0 m × 6.5 m, so that 18 rows of each genotype were sown in every plot. Wheat and barley genotypes were sown in November 2005, 2006 and 2007. To determine grain and straw yield of wheat and barley genotypes, a 3 m^2 area was harvested from the center of each plot.

In the sorghum experiment, the treatments included four hybrid variety namely Speed feed, Sugar graze, Jumbo and Nectar and four pure lines namely KFS_1, KFS_2, KFS_3 and KFS_4. Each plot was 6.0 m long and 1.8 m wide and contained 6 rows, which were spaced 0.3 m apart.

At four occasions during the experiments (i.e. planting, stem elongation, flowering, grain filling) soil samples were taken to a depth of 0.9 m for salinity measurement of saturated extracts. All experiments were laid out in a randomized complete block design with three replications. The data collected were subjected to variance analysis using SAS software. Statistical differences among the means were determined using Duncan's new multiple range test.

Results and discussions

Root zone salinity

Crops were irrigated during the growing season with water diverted from Kharkheh river. Salinity of the river water was around 1 dS/m. The relatively good quality irrigation water leached the salts, which were deposited in the soil during the fallow season as a result of high evaporative demand and high water-table level. As shown in Fig.3-5-1 crops were exposed to high salinity during the growing season (in addition to water logging and end of season heat stress).

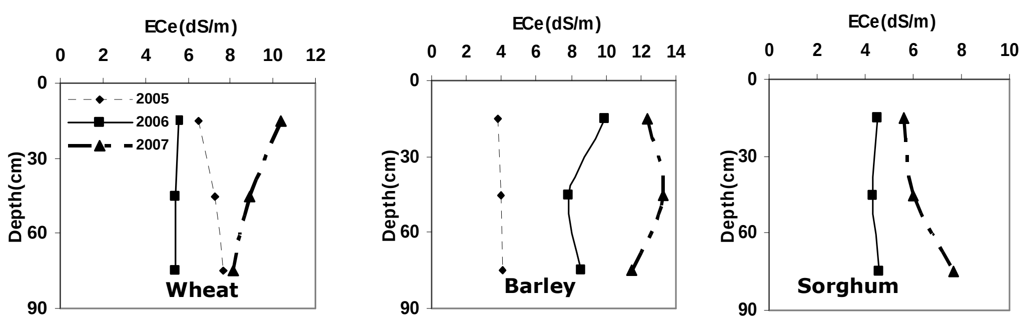

Fig.3-5-1- Average soil salinity for different growing seasons in wheat, barley and sorghum experiments

Wheat

Statistical analysis of combined grain yield for 3 years showed that performance of the genotypes varied significantly. Among the genotypes, Sistan and Verinak consistently produced the highest and lowest grain yield, respectively. The mean grain yields of Sistan, Kavir, Bam, Chamran, Roshan, Akbari and Verinak were 4.7, 4.5, 4.4, 4.3, 4.1, 3.9 and 3.2 t/ha, respectively. Sistan produced the highest grain yield in 2 years, and equal highest in 2005-2006 (Table 3-5-1). The mean grain yield of Sistan for the whole experiment was 11 and 47% more than Chamran and Verinak (local varieties), respectively. Verinak showed the lowest grain yield compared to the other varieties for the three years. From the present study it appears that all genotypes have the same main stem leaf number, and the same phonology except for Verinak (data not shown). In spite of this, Sistan, Kavir and Bam showed higher yield than the others. There are many genetic factors which affect grain yield under saline conditions, such as the number of tillers and leaf area duration (Hay and Walker 1989). The number of tillers/plant for Sistan, Kavir, Bam, Chamran, Roshan, Akbari and Verinak was 4.0, 3.0, 3.5, 2.2, 4.1, 3.7 and 2.0, respectively. In fact, salt tolerant genotypes produced more tillers than the local varieties. Roshan produced the most tillers during the growing season, but it lodged at the end of the season and its grain yield was markedly reduced. The other very important factors affecting grain yield under stressed conditions are leaf area and the duration of the grain filling period. Field observations showed that varieties like Sistan, Bam and Kavir had the highest ground cover and longest grain filling period. This allows for more mobilization of soluble carbohydrates from other parts of plant to the developing grains. Short grain filling period could be a factor causing low yield in some varieties like Verinak

Barley

Combined analysis of variance showed that, regardless of the year, On-4 and Afzal produced the highest and lowest grain yields, respectively. The mean grain yields of On-4, Reyhan, M80-9, M81-19, Karon x Kavir and Afzal were 3.3, 3.1, 2.8, 3.0, 2.9 and 1.7 t/ha, respectively (Table 3-5-2). Barley genotypes produced different grain yield each year, particularly Afzal variety. High yielding barley varieties are always tall plants. Thus, a variety that has a strong stem and does not lodge in the field can produce the highest grain yield (Hay and Walker, 1989). Field observations showed that lodging percentage for On-4, Reyhan, M80-9, M81-19, Karon x Kavir and Afzal were 0, 20, 3, 0, 10 and 55, respectively. Therefore, based on the results of grain yield and lodging percentage, On-4 and M81-19 could be considered as new barley genotypes for the LKRB.

Table3-5-1- Comparison of mean grain yield for wheat genotypes, 2005-2008.

Genotypes	**2005-2006**	**2006-2007**	**2007-2008**
Kavir	4.1a	3.9^{ab}	5.4^{ab}
Roshan	3.8ab	3.7^{ab}	4.6^{bc}
Bam	4.5a	4.2^{a}	4.6^{bc}
Akbari	3.2bc	3.2^{bc}	5.4^{ab}
Sistan	3.9ab	4.3^{a}	5.7^{a}
Chamran	3.8ab	4.0^{a}	5.0^{b}
Verinak	2.7c	2.9^{c}	4.1^{c}

Means followed by the same letter at each columns were not significantly different (Duncan's 5%)

Table 3-5-2- Yield comparison of barley genotypes during 2005-2008.

Genotypes	**2005-2006**	**2006-2007**	**2007-2008**
Reyhan	3.3a	3.6a	2.5ab
M80-9	2.6b	2.9ab	3.0a
M81-19	3.4a	3.4a	2.3bc
On-4	3.6a	3.3a	3.1a
Karon × Kavir	3.2ab	2.9ab	2.7ab
Afzal	1.0c	2.2b	1.7c

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

Sorghum
KFS_4 produced the maximum fresh matter of 100.7 t/ha in 2006, followed by KFS_2 and KFS_1, with 92.7 and 86.3 t/ha respectively, which were not significantly different. A minimum of 66.9 t/ha fresh matter was observed for KFS_3 in 2006 (Table 3-5-3). Again, in the second year (2007), the maximum fresh matter was measured for KFS_4, with 107.7 t/ha.

For hybrid varieties, Speedfeed produced the maximum fresh matter yield of 117.0 t/ha in the first year followed by Sugargraze, Nectar and Jumbo which were in the same Duncan's group with 89.3, 81.9 and 70.2 t/ha, respectively (Table 3-5-3). In the second year, Jumbo produced the highest fodder yield with 130.4 t/ha followed by Speedfeed and Sugargraze, with 124.6 and 120.7 t/ha, respectively, which were not significantly different. Nectar had the lowest fodder yield in the second year. The highest dry matter yield of 23.6 t/ha was measured for KFS_4, followed by KFS_2 and KFS_1, with 22.8 and 20.6 t/ha, respectively in first year, which were not significantly different. KFS_3 produced minimum dry matter of 17.0 t/ha among lines in first year KFS_4 produced the highest dry matter yield of 30.1 t/ha in the second year again followed by KFS_3 (27.7 t/ha) with no significant difference.

Dry matter production of Speedfeed, Sugargraze and Jumbo hybrid varieties differed significantly in the first year (Table 3-5-3). The highest total dry matter yield of 28.3 t/ha was measured for Speedfeed variety. Sugar graze and Nectar produced the next highest dry matter of 22.3 and 18.7 t/ha, respectively. Both varieties' total dry matter was not significantly different in the first year. Jumbo had the lowest hybrid dry matter yield of 17.1 t/ha in 2006, and the highest yield of 32.6 t/ha in the second year. Combined analysis of dry matter showed that Speedfeed produced the highest dry matter yield for the two years by 30.5 t/ha (data not shown).

Table 3-5-3: Comparison of fresh and dry matter yield for sorghum lines and hybrids.

	First year(2006)		**Second year(2007)**	
Line	**Fresh matter yield (t/ha)**	**Dry matter yield (t/ha)**	**Fresh matter yield (t/ha)**	**Dry matter yield (t/ha)**
KFS_1	86.3 [a]†	20.6 [ab]	83.2 [c]	23.9 [c]
KFS_2	92.7 [a]	22.8 [a]	100.2 [ab]	27.4 [b]
KFS_3	66.9 [b]	17.0 [b]	95.4 [b]	27.7 [ab]
KFS_4	100.7 [a]	23.6 [a]	107.7 [a]	30.1 [a]
Hybrid				
Speed feed	117.0 [a]	28.3 [a]	124.6 [a]	32.6 [ab]
Sugar graze	89.3 [b]	22.3 [b]	120.7 [a]	30.1 [bc]
Jumbo	70.2 [b]	17.1 [c]	130.4 [a]	34.7 [a]
Nectar	81.9 [b]	18.7 [bc]	96.0 b	27.5 [c]

†Means comparison were made separately for lines and hybrid.

Conclusion and recommendations
Crop production in the lower areas of Karkheh river basin is impaired by highly saline soil and water resources and water logging. At present, the crop varieties used by farmers are not adapted to the prevailing soil conditions and significant improvements in production could be realized by introducing salt-tolerant varieties. Based on the results of this study varieties like Bam, Sistan and Kavir for wheat, and On-4 and M81-19 for barley and KFS4 and Speed feed of sorghum were found to be more tolerant than the others and could be considered as potential substitutes for the present varieties under saline and water logged conditions of LKRB.

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3-6-Effects of economic factors on wheat and maize profitability and water productivity in KRB.[9]

In the management of water demand, economic measures such as water pricing are used for water saving and increasing water productivity. Due to the importance of water saving in arid and semi-arid regions, optimal and economic use of water is vital. The objective of this study was to assess effects of economic factors on WP of irrigated wheat, barley, and maize under farmers' conditions in the lower KRB. This includes socio-economic characteristics of sample farmers and target regions, determination of profitability indexes in irrigated cereals and maize production, determination of average irrigation WP for the sample farmers, and estimation of production value for one Rial[10] worth of irrigation water use in the Azadegan (DA) and Sorkheh plains (DS) in the lower KRB.

Methods

The study was implemented in the DA and DS plains in the L-KRB for cereals crops including: wheat, barley and maize, during 2006-2007. Two methods were

[9] Reference: Asadi. H., K. Shideed, M. Niasar, A. Abbasi, A. Ayeneh, N. Heydari. F. Abbasi. H. Farahani, F. Mazraeh and M. Gamarinejad. 2008. Effects of economical factors on profitability and water productivity of irrigated cereals and maize in the Karkheh River Basin. Unpublished.

[10] 1 US$= 9320 Rials

used for data collection. In the first step, library studies were conducted to collect basic information from previous research on the subject. Then, 166 farmers were selected in the two locations by stratified random sampling method. Average productivity was calculated as total production divided by water use. Profitability indexes were calculated using Microsoft Excel. Average WP, profitability, cost ratio and sale of return indexes were determined using, respectively, the following equations:

WP = Total product / water use (1)
Cost ratio = (Total cost / Gross income) * 100 (2)
Sale return = (Net profit / Gross income) * 100 (3)

Results and discussion

Socio-economic characteristics of sample farmers in DA and DS plains were studied, with results, respectively,of: distance of farms from villages: 4.1 and 2.6 km; farmers' age: 45.1 and 44.7 years; number of children: 5.1 and 6.1; number of children active in farms: 2 and 1; experience in agriculture: 25 years and 24.3 years; participation in extension programs: 7% and 52%; and contribution of irrigated crops to household income: 96.9% and 78.3%.

In DS, the average planting area for wheat and maize production were 19.1 and 13.3 ha, respectively. The means of seeding, urea, phosphate, and potassium fertilizer rates used for wheat were 255, 323, 158 and 81.5 kg/ha, respectively. Average irrigation water use for wheat and maize were 7323 m^3/ha and 14,889 m^3/ha. In the DA, means of planting area for wheat and barley were 18.6 and 9 ha, respectively. The means of seeding, urea and phosphorus rates for wheat were 283.1 kg/ha, 215.3 kg/ha and 121.4 kg of DAP/ha, respectively. Average irrigation water use for wheat and barley were 6570 m^3/ha and 5464 m^3/ha. The means of seeding, urea, and phosphate rates for barley were 208.8 kg/ha, 180.2 kg/ha, and 109.3 kg of DAP/ha, respectively.

Net profit and profitability

As shown in Table 3-6-1, in the DS and DA, means of wheat gross income are estimated at, respectively, 8.7 million Rials/ha, and 5.2 million Rials/ha, with estimated means of net profit at 4.9 million Rials/ha and 1.2 million Rials/ha. Results also showed that, 43.5% of wheat gross income is spent for fixed and variables costs of production (cost ratio = 43.5%). Meanwhile, for one Rials of sale, the profit was 56.5% i.e. sale return= 56.5%. The mean yield of improved maize was 5711 kg/ha with a mean gross income of about 9.3 million Rials/ha. Mean net profit of maize was estimated at 4.8 million Rials/ha. while fixed and variable costs of production constituted 48.3 % of its gross income i.e. cost ratio= 48.3% and sale return (as defined in eq.3) was 51.7% i.e. for one Rial of sale, the net profit was about 0.52 Rial.

Table 3-6-1: Means of net profit and profitability indexes in irrigated cereals.

Item	**Azadegan plain (DA)**		**Sorkheh plain (DS)**	
	Wheat	**Barley**	**Wheat**	**Maize**
Yield (kg/ha)	2575	1856	4147	5711
Gross income (1000 Rials/ha)	5238	3372	8706	9252
Total costs (1000 Rials /ha)	4051	3221	3783.2	4469.6
Net profit (1000 Rials /ha)	1187	151.3	4923	4782
Cost ratio (%)	77.3	95.5	43.5	48.3
Sale return (%)	22.7	4.5	56.5	51.7

Table 3-6-2: Average WP (kg/m^3) and value of production for one Rials of irrigation water used (Rials/Rials) in the DA and DS plains.

Item	Azadegan plain (DA)		Sorkheh plain (DS)	
	Wheat	**Barley**	**Wheat**	**Maize**
Average WP (kg/m^3)	0.39	0.34	0.58	0.38
Value of production for one Rial water use (Rials/Rials)	4.1	3.44	10.74	8.35
Water cost ratio	0.24	0.29	0.10	0.12

In the DA, mean yield of improved wheat was 2575 kg/ha. Mean wheat price was 2034 Rials/kg and fixed and variable costs of production constituted 77.3% of its gross income (cost ratio = 77.3%). Meanwhile, sale return of wheat in this area was 22.7% i.e. for one Rial of sale, profit was 22.7%. Mean yield of improved barley yield was 1856 kg/ha. In the case of barley, mean price was 1817 Rials/kg with a mean gross income of 3.37 M.Rials/ha. Results showed that, fixed and variables costs of barley production constituted 95.5% of its gross income (cost ratio=95.5%) and its sale return was 4.5%, i.e. for one Rial of sale, profit was 4.5%. Mean irrigation WP of wheat and maize were 0.58, and 0.38 kg/m^3. The value of production of wheat, and maize for one Rials of water used was 10.7, and 8.3 Rials, respectively. Water costs accounted for about 10 and 12% of the gross income of wheat and maize, respectively. In the DA plain, mean WP of wheat, and barley were 0.39 and 0.34 kg/m^3 respectively. The value of production of wheat, and barley for one Rials of water used were 4.1, and 3.4 Rials, respectively. Water costs accounted for about 24% and 29% of the gross income of wheat and barley.

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Objective 4- Review of institutional and policy structures in the KRB

4-1-Assessing policies and institutional arrangement in Karkheh River Basin[11]

This study was conducted to review the policies and institutional arrangements on irrigation water use and to assess the consequences for water allocation and productivity in selected sites of Sorkheh and Azadegan in the lower KRB, and in Merek in a rainfed part of the basin.

Methods
The methods involved review of available policy documents as well as secondary and stakeholder survey data to assess water and related policies and institutions influencing water use in KRB. Data included: food security, economic growth, ecosystem consideration and environmental sustainability, poverty reduction, gender inequity, water pricing, water use technology, water allocation and related criteria, and research activities. The study is divided into the following sections: description of the farming system of the KRB and its importance, natural resources of the basin, and review of water and related policies and institutions involved in water management in the KRB.

Results

Water Institutions

The two ministries of Energy (MoE) and Jihad-e Agriculture (MoJA) are the main institutions responsible for the management of water in Iran. The MoE is responsible for storage and supply of water for different consuming sectors, i.e., agriculture, industry, and domestic. In the agricultural sector, which is the biggest consumer of water in Iran, MoJA is responsible for improvements in water productivity and development of irrigation system technologies. From a network point of view, the responsibilities in MoE and MoJA are mainly with, respectively, the water board authorities and the office of the deputy minister on soil and water. For the management of water resources, these two ministries also receive help from research institutes, consultant engineers, and the universities.

In Iran there are 49 research and or educational institutes related to water, 14 institutes specifically on water research, 25 societies on water or agriculture, 47 consulting engineering firms in water, and 178 manufacturing and/or design companies in irrigation (especially in pressurized irrigation systems).

In KRB, with its vast water and soil resources, the exigency of utilizing these resources necessitated extensive and thorough studies to be carried out in the region. In 1960, the National Parliament and Senate passed a bill by which the Khuzestan Water and Power Authority (KWPA) was officially established in order to carry out the projects in the Khuzestan Province, where the lower part of KRB is located. The KWPA is the sole custodian of water resources in the province and, therefore, responsible for the allocation, operations and protection of water resources with the ultimate goal of its optimal development and operation.

Water management in KRB is characterized by some types of complex, overlapping, and sometimes competing networks of actors, rules, functions, and organizations. Multiple actors and organizations involved in water-related decision making at different levels have caused a situation where a farmer cannot receive

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[11] Reference: Keshavarz, A., H. Dehghanisanij, and M.Mousavi. 2008. Assessing policies and institutional arrangement in Karkheh River Basin. IFWF 2.

water at the right time and in the right amount. Accordingly, agricultural fields are facing over-irrigation or deficit irrigation during the crop growing season. Such complexity and pluralism where different organizations and authorities with different opinions are competing for water require multiple reform strategies. However, policies for agricultural water management have tended to adopt "simplifications". Moreover, standardized approaches and solutions are usually problematic, especially in farm level under irrigation network.

Water Policies

The law of "Equitable Distribution of Water" is one of the important national acts on water policy in Iran and was first approved by the parliament in 1982 and slightly modified later on. It consists of five chapters, 52 articles and 27 notes. The main chapters are: (i) Public and national ownership of water, (ii) Ground water resources, (iii) Surface water resources, (iv) Duties and authorities, and (v) Penalties and regulations. Since its approval in 1990, the following actions have been taken for the execution of this law; (i) preparation of a law for "fixing agricultural water price" and its approval by the parliament in 1990; based on this law, water price for a crop season varies between 1-3% of the value of the crop yield, depending on the type of water resources (regulated or non-regulated) and type of irrigation network (modern and traditional), and (ii) determination of "oversight charging" for water in pumping systems (groundwater) and its approval by the "Economic Council" of the government in 1992. The purpose is to prevent over-exploitation and improve management of groundwater resources. The oversight charge varies between 0.25-1.00% of the economic return of the cultivated crop, depending on crop type and crop yield. For yields higher than average, the charge reduces proportionally, and for yields double the average, there is no charge. In this regard, the MoE prepared action plans to equip all the wells in the country with water meters.

Improvements in water supply and water productivity programs have been among the most important government policies during the past 22 years. In this regard, different rules have been set and different technical infrastructure (including executive, research, and consultative) in both public and private sectors have been developed. Indeed, in addition to the establishment of special laws and regulations, certain articles and objectives of the national development programs have paid attention to this issue as well.

During the past 22 years, and especially in the first, second, and third five-year national development acts, many attempts and actions have been somewhat non-regular and or non-systematic. However, huge investments were made on the construction of dams and new irrigation and drainage networks. Unfortunately, most of the projects were development-oriented and less attention was given to operation and maintenance of the projects. This factor, in addition to increased costs, gradually reduced the performance of irrigation networks and led to land drainage and salinization problems. In the case of KRB, the irrigation network under Karkheh dam was mainly developed for food security and economic growth, while less attention was paid to environmental sustainability, gender inequity, poverty reduction, and water pricing issues.

Conclusions and recommendations

Even though several water policies, strategies, laws, and regulations exist, effective water resource development is yet to be achieved. Examples of deficiencies are:

- Inadequate water resource development projects, despite high investment, especially for secondary canals

- Low irrigation water productivity at both national (0.9 kg/m^3) and KRB (0.54 kg/m^3) levels
- Depletion of groundwater, and negative water balance in some basins
- Simultaneous soil and water resources degradation
- Less-than-fully successful achievement of projected provisions of the first, second and third mid-term development plans on water allocation, productivity, and water resource management

Accordingly, water governance, management and use cannot be treated as separate issues. There was lack of consideration of environmental issues in the past versions of the Karkheh irrigation network objectives. The Karkheh irrigation network objectives for water allocation, cropping pattern system, and environmental issues have been revised in two scenarios where environmental issues are considered seriously. To contribute to poverty reduction, environmental sustainability, gender inequity, and water pricing, reforms are needed which should create a framework for development of relationships among the key governance actors, nongovernmental organizations, civil society, private sector and farmers to identify the most effective resource uses and management modalities. Because incentives are lacking to engage poor people in the governance of water resources, the state needs to use its authority to enhance their voice and benefits.

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Objective 5- Out-scaling project findings to improve awareness

5-1-Agroecological zones of the Karkheh River Basin

With respect to out-scaling PN8 results, the project used an on-farm participatory approach in conducting its field studies during the whole study period. For future out-scaling, an agroecological zones map (AEZ) map is an essential tool. This is also very helpful for agricultural planning since, by integrating the key components of the agricultural environments, it offers a bird-eye view of internal diversity, and agricultural potentials and constraints that decision-makers find easier to understand than a pile of single-theme maps.

Methods

This study has several major components, (i) an assessment and mapping of the agricultural environments in the entire Karkheh River Basin (KRB), (ii) the setting of the selected benchmark sites for the two Challenge Program projects in relation to these environments, and (iii) the mapping of the possible out-scaling domains (from a biophysical perspective) at the level of the Karkheh River Basin, Iran and the CWANA region. To support these objectives, two methodologies have been designed for application in a GIS environment.

The agricultural environments of the KRB were mapped using the concept of agroecological zones (AEZ), integrated spatial units arising from the integration of climatic, topographic, land use/land cover and soil conditions. The AEZ were derived by the following six-step procedure:

- Generating raster surfaces of basic climatic variables through spatial interpolation from station data;
- Generating a spatial framework of agroclimatic zones (ACZ);
- Simplifying the relevant biophysical themes (agroclimatic zones, land use/land cover and landform/ soils);
- Integrating the simplified frameworks for agroclimatic zones, land use/land cover and landforms/ soils (soilscapes) by overlaying in GIS;
- Removal of redundancies, inconsistencies, and spurious mapping units;
- Characterization of the spatial units in terms of relevant themes.

Using this methodology the entire Karkheh River Basin (50,764 km^2) was classified into 46 unique AEZ, of which only five occupy nearly 60% of the basin (see map). On the basis of major differences in climatic conditions, land use patterns and terrain-soil characteristics, three major agricultural regions, the Northern, Middle and Southern Agricultural regions, are distinguished and described. In addition, an overview is provided of the biophysical conditions that prevail in the four benchmark sites selected in the basin. The AEZ present in the benchmark sites occupy 90% of the KRB, hence on this criterion the benchmark sites are highly representative, even though some of the AEZ may occupy only a small area in the benchmark sites. On the other hand, with the exception of a few small areas in Merek, the oak forest belt, which is characteristic of the Middle Karkheh Agricultural Region, is not present in the benchmark sites. Neither are the badlands, which occupy substantial areas in the Middle and Southern Karkheh Agricultural Regions, and the sand dunes of the Southern Karkheh Agricultural Region.

A methodology was developed to assess where the technological, institutional and policy options for the farmers and communities developed in the benchmark sites have application possibilities in areas outside these sites. The methodology is based on assessing the similarity in conditions between each of the benchmark sites and different target areas for out-scaling (the KRB, Iran and CWANA). The approach taken is confined to the biophysical domain only and involves several stages of assessment. In the first stage climatic similarity in biophysical conditions is assessed using temperature and precipitation as indicators and similarity indices for quantification. In further stages the climatic similarity index is combined with a landform similarity index and a land use/cover similarity index. Soil type, a potentially important indicator, was not considered because of inadequate soil information at the level of the benchmark sites, but soil type can be brought into the similarity assessment at a later stage when such information becomes available.

Results
Many different maps were prepared in this study and are presented in the report of De Pauw, et al. (2008). The agroecological map and its legend are shown in Figures 1 and 2, respectively, and further detail is available in De Pauw et al. (2008).

Reference
De Pauw, E., A. Mirghasemi, A. Ghaffari and B. Nseir. 2008. Agroecological zones of Karkheh River Basin. CPWF-AEERO-ICARDA publication No.3.

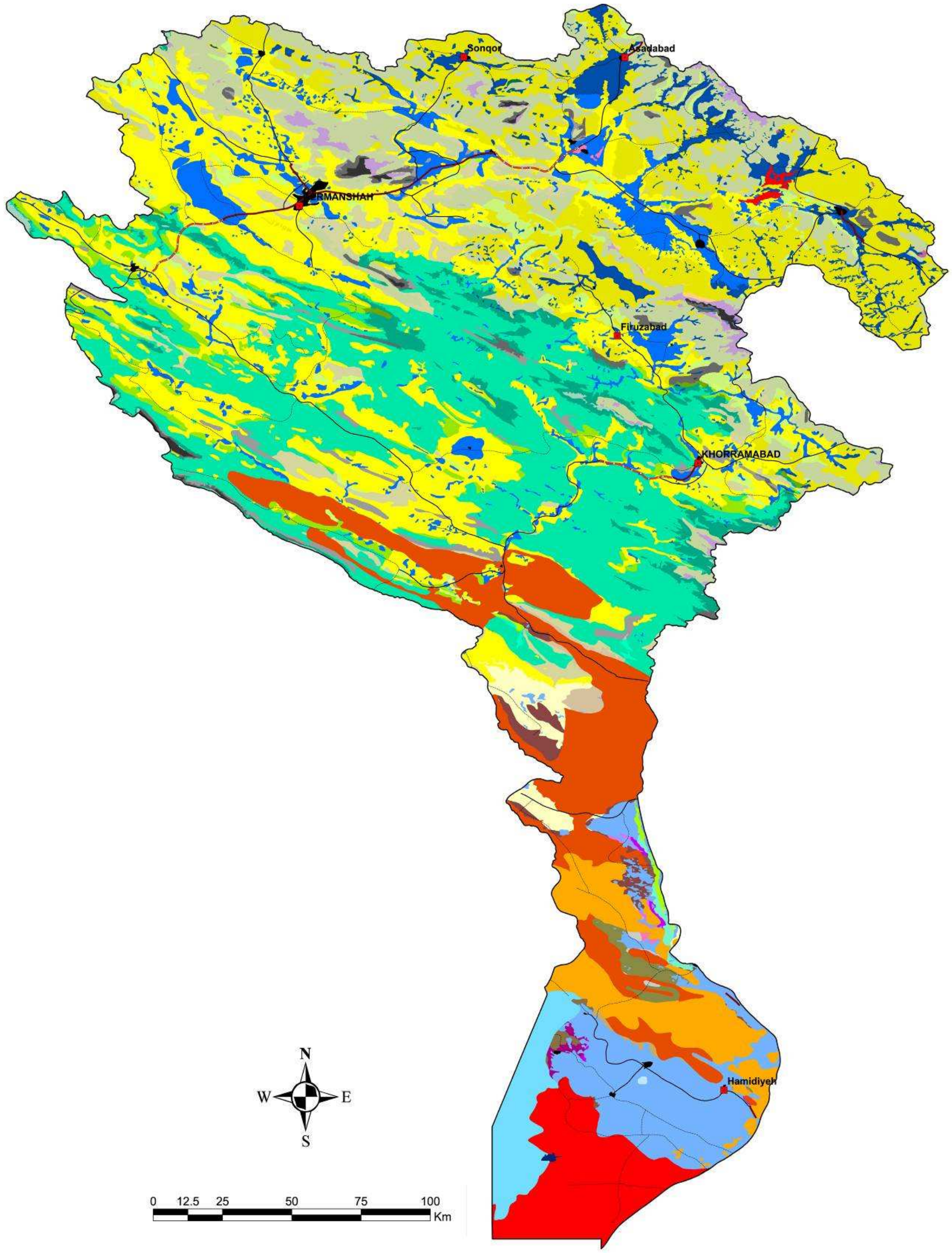

Fig. 5-1-Agroecological zones of the Karkheh River basin. The legend is presented in Fig.2.

Fig. 5-2-Legend of agroecological zones mao of the Karkheh River basin.

International public goods

While PN8 had many national public goods as reflected in the previous sections of this report, the following can be considered as its international public goods:

- A methodology was developed for assessment of basin level water productivity based on readily available data using relatively simple calculations and AQUACROP model.
- A methodology was developed and applied for preparing the map of agroecological zones of the basin. This map is of great help in site selection for pilot projects and out-scaling research results and is also an effective tool for agricultural planning. The methodology can be applied in basins around the globe.
- A methodology was developed and applied for studying the impacts of different scenarios of supplemental irrigation (SI) expansion in the upstream areas on the quality and quantity of downstream flow. The method consisted of, first, mapping the areas suitable for expansion of supplemental irrigation on the basis of slope, soil, and availability of water resources. Secondly, different scenarios of SI that included time and amounts of irrigation were considered in these areas and the impacts on downstream flow were simulated. GIS techniques and a simple Fortran program were used in this study. The methodology is recommended for water resources development projects in similar river basins.
- The findings of the project with respect to early planting of wheat and barley with supplemental irrigation can be adopted by rainfed farmers in cold areas with great reliability. Additionally, in the spring time when rainfall deficits threaten rainfed crop maturity and yield, use of single supplemental irrigation was found to be very effective in stabilizing and even increasing yield, thereby resulting in high water productivity.
- The inflow-outflow measurement of water for assessing on-farm water productivity proved as a simple and reasonably reliable method and can be recommended for adoption in other basins.
- The project tested new varieties or genotypes of wheat and barley, for rainfed as well as fully irrigated conditions, some of which became very popular among the farmers of the selected sites. Also, responses of different maize varieties were compared in a warm semi-arid condition and the one with higher yield was identified. These genotypes could be used in similar situations in other parts of the world.
- Under saline conditions, with or without high water table, the project tested the performance of some wheat, barley and sorghum varieties and genotypes and identified those with relatively higher yields.
- The project adopted an on-farm research approach that enhanced the development of community level participatory research. This was welcomed by the farmers and the NARES and is highly recommended for other areas, particularly the CWANA countries.
- The project developed a management style consisting of two committees. First, a "steering committee" where high level decisions concerning administrative and financial issues as well as general progress of the project were discussed among different stakeholders in charge of the project and due decisions was taken. Secondly, a "project technical committee" was formed consisting of top national and international experts of the project that over sighted the technical activities of each research from the design stage to the end. This management style proved successful and can be adopted for other similar situations.

- Preparation of several papers and other publications that contain the data collected and the experiences gained in this project. These are available for international use.

Outcomes

As PN8 activities progressed, the NARES interest and involvement increased. This was obvious by the increase in the number of stakeholders, including NARES and farmers that were asking questions about the activities and expressed willingness to participate in the project. Some of them, indeed, joined us in the middle of the project and continued to the end. In this regard, the change of behavior of many farmers in the selected sites was striking: In earlier stages of the project, it was not easy to find farmers who would accept to allocate part of their fields to our on-farm trials. However, after the first season when farmers had observed the benefits of the new technologies, there were "complaints" by some of them as to why the project cannot expand its activities to work on their farms as well!

It is believed that this outcome was the result of the approaches adopted by the project as follows:

- Extensive participation of the national stakeholders: Farmers were mostly consulted about their research needs and explanations were given about the project technological alternatives, while NARES staff were actively involved in all stages of research activities including design, execution, and analysis of the data.
- Organization of numerous capacity building programs that helped a lot in enhancing scientific capacity of the NARES.
- Improvement of the communication skills of the national participants by providing facilities for them to attend English classes and continuously encouraging them to express themselves in English, verbally and in writing.
- Holding of quarterly, six-monthly, and annual workshops with the NARES
- Providing facilities for NARES staff to attend different international workshops.

Other changes were also brought about by the project. For example, the participatory, multi-institutional, and multi-disciplinary approach to the problems of the basin was appreciated by the NARES as evidenced by repeated expressions of interest and appreciation by the national management about their decision to adopt this approach.

Also, the project management underwent some changes. In the beginning, most of the decisions were made by a small group of NARES mangers and the project leaders. However, after launching, a gradual process of "decentralization" of decision making was promoted with the intention of increasing the authority and involvement of the provincial staff. This change improved and expedited progress of the project. In addition, the project adopted a management style consisting of two committees. First, a "steering committee" where high level decisions concerning administrative and financial issues as well as general progress of the project were discussed among different stakeholders in charge of the project and due decisions was taken. Secondly, a "project technical committee" was formed consisting of top national and international experts of the project that over sighted the technical activities of each research from the design stage to the end. This management style proved successful and gained popularity in the NARES.

Impacts

Scientific impacts on NARES:

- One of the main impacts of the project on NARES came about through capacity building. This activity included granting of two PhD opportunities and many training workshops (jointly with PN24 or independently) on technical topics related to the project. The complete list of this activity is presented in this report under the heading of " Activities regarding objective 1: Strengthening the capacity of NARES". The project impact on enhancement of the scientific capacity of the NARES became evident by the project participants' presentations in two international workshops, including IFWF2. In addition to scientific enhancement, the project helped greatly in improving English language of the participants by supporting them to attend English classes and by encouraging them to speak or write in English.
- The multidisciplinary and basin-wide integrated approach of the project enhanced cooperation between different NARES institutions and promoted the spirit of team work.
- As the project proceeded, new NARES institutions joined the project, reflecting the scientific interest raised by the project.

Community impacts through research methodology

- The participatory research approach (PRA) adopted by the project enhanced the community level involvement and raised the interest of both farmers and the NARES researchers in conducting on-farm research and participatory diagnosis of research needs. Local Agricultural Service Centers that are responsible for extension services became actively involved with the project on-farm research.
- Farmers showed enthusiasm for adopting new technologies introduced by the project such as supplemental irrigation, proper irrigation management, and planting new improved seeds.
- The Agro-Ecological Zone map that was prepared jointly with PN24 became a powerful tool for out-scaling project results and could also help local decision makers in planning agricultural development programs.

Impacts on location and scale of research, development

- At the beginning of the project, local Agricultural Service Centers were asked to encourage farmers to participate in the project in order to establish interactive collaboration between researchers, farmers and extension agents. However, as time went on, the farmers themselves were coming directly to the project staff to announce their willingness to join the activities.
- Considering the obvious positive results of supplemental irrigation, it is anticipated that expansion of this technology may be included in future development programs for the basin. Therefore, different scenarios of expanding supplemental irrigation in upstream rainfed areas were simulated and their impacts on quantity and quality of downstream flow were assessed.

Impacts on project management

- The project developed a management style consisting of two committees. First, a "steering committee" where high level decisions concerning administrative and financial issues as well as general progress of the project were discussed among different stakeholders in charge of the project and due decisions was taken. Secondly, a "project technical committee" was formed consisting of top national and international experts that oversaw the technical activities of research from the design stage to the end. This management style proved successful and can be adopted for other similar situations.
- The projects encouraged and promoted the concept of “decentralized management” and enhanced the role of colleagues in decision making.

Partnership achievements

Impacts of the project and its outcomes have been explained in the previous sections of this report.

The project established firm relations with many NARES institutes that were active within the basin. For some of these institutions, working in a joint project was unprecedented and they showed great enthusiasm for working together. A wealth of information regarding the issues related to water productivity and the methods for its improvement have been shared with most of these organizations in different ways, including the workshops that were held in different times during the project implementation period. Also, series of publications prepared by the project have been distributed among the NARES.

The project succeeded in collecting field level water productivity values for irrigated and rainfed areas of the basin under the existing situation and provided strong evidence of the methods and technologies that can improve it significantly. The participatory research methods employed by the project were welcomed by both the NARES and the farmers, hinting that the scientific results will be widely taken up if the project recommended policies are adopted.

Based on the scientific interest raised by the project, the NARES are thinking of continuing the project to the second phase using their own resources and conduct similar projects in other basins of the country.

Recommendations

Thematic and site-specific recommendations of the project are presented at the end of each research activity (sections 1-5). Here, general recommendations for research, extension, policy, and institutions are mentioned in brief:

<u>On research:</u>
- Participatory and multidisciplinary research approach needs to be promoted in AREEO and its institutions. The end users should have their say from the beginning of each research activity.
- The spirit of team work among the experts and scientific members needs to be enhanced by preparing and conducting further joint projects similar to PN8.
- In each basin, before launching a project, a participatory research needs assessment is highly recommended to customize the research activities to the needs of that basin.
- A central databank for research activities and results needs to be established and made accessible to participants of each project to avoid unnecessary repetition of studies and provide a medium for information sharing among different researchers.
- Support research on salt-tolerant varieties of commonly grown crops – wheat, barley, and sorghum – to replace low-yielding varieties
- Further capacity building in scientific writing is needed so as to help in better dissemination of the results.
- Development of the English language among national experts will help smooth scientific communications between partners in a project.

<u>On extension</u>
- Enhancing the capacity of extension services to improve awareness by and technical support to farmers/stakeholders.
- Enhancement of the relations between researchers, farmers, and extension agents cannot be over-emphasized.

- Participatory technology development seems to be the best way for dissemination of research results, introducing of "new" technologies to the farmers and enhancing relations between researchers, farmers and extension agents.
- Involvement of women in all extension activities and programs needs due attention and serious action.
- Implement agricultural drainage and salinity management technologies in salt affected areas of lower KRB.
- Use public support to modify cropping patterns in favor of higher water productivity crops.

On policy

- Promote supplemental irrigation in rainfed agricultural systems in the upper KRB.
- Provide incentives for adopting improved practices and new cropping patterns to increase water productivity and farm income in irrigated areas of the lower KRB.
- Promote the farmer's adoption of improved irrigation systems though facilitation investment and providing credit.
- Develop water regulations and control to encourage deficit irrigation and discourage wasteful use of water.
- Develop and implement a comprehensive strategic plan for combating soil and water salinization in the lower KRB
- Support public investments in agricultural drainage systems and disposal and the reuse of drainage effluents.
- Introduce irrigation water application regulations to decrease drainage volumes and water logging problems.

On institutions

- Institutional reforms are needed to reduce overlapping of organizational responsibilities on water resources and to improve coordination among various institutions in charge of water resources development and supply.
- Encourage the establishment of water user associations and empower them for managing their irrigation water.

Publications

Already printed and distributed

- Oweis, T., H. Farahani, M. Qadir, J. Anthofer, H. Siadat, F. Abbasi and A. Bruggeman (eds). 2008. Improving On-farm Agricultural Water Productivity in the Karkheh River Basin. Research Report No. 1: A Compendium of Review Papers. ICARDA, Aleppo, Syria. iv+103 pp. ISBN: 92-9127-205-9.
- H. Farahani, T. Oweis, H. Siadat, F. Abbasi, A. Bruggeman, J. Anthofer and F. Turkelboom. 2008. Proceedings of the International Workshop on: Improving Water Productivity and Livelihood Resilience in Karkheh River Basin in Iran No. 2. ICARDA, Aleppo, Syria. iv+169pp. ISBN: 92-9127-212-4.
- De Pauw, E., A.Mirghasemi, A. Ghaffari and B. Nseri.2008. Agro-Ecological Zones Of Karkheh River Basin. ICARDA. Aleppo, Syria. viii+96pp.ISBN:92-9127-212-6.

*Forthcoming research reports (**Please also see Appendix 1**)*

- Improving rainwater productivity with supplemental irrigation in the upper Karkheh River Basin of Iran.
- Assessing and improving irrigation water productivity of wheat and maize in the lower KRB of Iran

- Assessment of different scenarios of supplemental irrigation at upstream sub-basins of Karkheh Basin on quantity and quality of flows of Karkheh Dam.
- Assessment and Improvement of Water Productivity under Saline Conditions in the lower KRB.
- Study of the effects of economic factors on water use efficiency in irrigated cereals under farmers' condition in the lower KRB.
- Assessing Policies and Institutional Arrangement in the Karkheh River Basin.

Software

- A FORTRAN program to calculate the available and required water volumes for each sub-basin based on the suitable area for each slope class and to route the remaining water from the upper sub-basins to the Karkheh dam.
- GIS software for agro-ecological zoning.
- GIS software for studying upper and lower KRB interaction.

Policy flyers

- Promote supplemental irrigation in rainfed agricultural systems in the upper KRB.
- Provide incentives for adopting improved practices and new cropping patterns to increase water productivity and farm income in irrigated areas of the lower KRB.
- Implement agricultural drainage and salinity management technologies in salt affected areas of the lower KRB.

Website: http://www.karkheh-cp.icarda.org/karkheh-cp/default.asp

Miscellaneous:

- Quarterly, six-monthly and annual progress reports of the project from the start to the end.
- Field mission reports, workshop reports, and reports of the steering committee meetings.
- Slides of many presentations prepared for the periodical workshops of the project.
- The following 4-page papers prepared for IFWF2:
    - A methodology for the assessment of agricultural water productivity at the river basin level
    - Increasing field water productivity of irrigated crops in the lower Karkheh River Basin
    - Improving water productivity of rainfed wheat and barley by supplemental irrigation in Northern Karkheh River Basin
    - Assessing policies and institutional arrangement in Karkheh River Basin
    - Assessment of potential upstream-downstream impacts of supplemental irrigation in KRB
    - Introduction of salt tolerant wheat, barley and sorghum varieties in saline areas of KRB
    - Effects of economic factors on profitability and water productivity of irrigated cereals and maize in the Karkheh River Basin
- Presenting a paper at the 9th IDDC in Cairo (7-10 Nov,2008) on "Assessment of supplemental irrigation at upstream sub-basin of Karkheh River Basin on water quantity and quality of Karkheh Dam".

Bibliography

These are written at the end of each activity in sections 2-5 of this report.

Project participants

PN8 Participant

Agricultural Extension, Education, and Research Organization (AEERO)	
1.	Dr Porhemmat, DG, AEERO, Head of the project Steering Committee
2.	Dr Kamali, DDG, AEERO, Steering Committee member
Agri. Engineering Research Institute (AERI)	
3.	Dr Javadi, Machinery Expert and DG, Agri. Engineering Research Institute (AERI). Project Coordinator, SC secretary.
4.	Dr Abbasi, Irrigation Specialist and DDG, AERI, acting project oordinator
5.	Dr Heydari, Irrigation and Soils, Basin Coordinator, SC member
6.	Eng'r Moayeri, Irrigation expert, Safi abad Ag. Research Center (ARC)
7.	Dr Dehghani Sanij, Irrigation expert,
8.	Eng'r Hessari, hydrologist and GIS expert
9.	Dr Ashrafi, Irrigation expert
10.	Dr Akbari, Irrigation expert,
11.	Eng'r Absalan, Irrigation expert, Khozestan,
12.	Eng'r Dehghan, machinery expert, Khozestan,
ICARDA Colleagues	
13.	Dr Oweis, Director, IWLM Program, Project Leader, SC member
14.	Dr De Pauw, Senior GIS Expert
15.	Dr Siadat, Project facilitator, editor, SC member
16.	Dr Farahani, Irrigation expert, editor
17.	Dr Bruggeman, Hydrologist, SC member
18.	Dr Manzoor, Salinity expert, editor
19.	Dr Pala, Agronomist
20.	Dr H.Ketata, ICARDA Country Rep. (till 2006)
21.	Dr A.Amri, ICARDA Country Rep (2006-08)
22.	Dr Roozitalab, ICARDA Country Rep, SC member (2008-present)
23.	Dr Shoaei, ICARDA, CO, Technical Coordinator, SC member
National Salinity Research Center	
24.	Dr Cheraghi, Salinity Expert and DG, National, NSRC
25.	Eng'r Ranjbar, Agronomist, NSRC
26.	Eng'r Anagholi1, Soil Scientist, NSRC
27.	Eng'r. Rahimian, agronomist, NSRC
Dryland Agricultural Research Institute	
28.	Dr Ghaffari, Soil scientist and DG
29.	Eng'r Tavakoli, Supplemental Irrigation expert, Kermanshah, DARI
30.	Dr Pourdad, DDG, Kermanshah
Provincial J-e Ag and other institutions	
31.	Eng'r Noori, DG, Kermanshah ARC
32.	Eng'r Keshavarz, Irrigation expert, Consulting Eng'r Firm
33.	Eng'r Asadi, Economist, Seed and Plant Improvement Institute
34.	Eng'r Farhadnato, Agronomist, Safi abad Dezful ARC
35.	Eng'r Rouintan , DG, Kermanshah, J-e-Ag Org.
36.	Eng Nazari, DG, Lorestan ARC
37.	Mr Morad Azizollahi, Extension agent, Lorestan J-e-Ag, Honam
38.	Mr Daei Chini, Ag Service Center (ASC), Merek, Kermanshah.
39.	Mr Azizi, ASC, Kermanshah
40.	Eng'r Ayene, agronomist, Khozestan, ARC

Appendix 1

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

Forthcoming Final Research Reports

Improving Rainwater Productivity with Supplemental Irrigation in the Upper Karkheh River Basin of Iran

A.R. Tavakoli, T. Oweis, H. Farahani, S. Ashrafi ,H. Asadi, H. Siadat and A. Liaghat

Table of Contents

Summary

The Karkheh River Basin (KRB) is located in southwestern Iran. Most of the agricultural area in the upper KRB is rainfed. Current water productivity (WP) values for dryland crops are 0.3-0.5 kg/m^3, mainly due to poor distribution of rainfall and poor agronomic management practices

To study the options for increasing water productivity in the basin, on-farm trials were conducted during the 2005-08 winter cropping seasons of wheat and barley at multiple farms across two benchmark watersheds of Merek (Kermanshah Province) and Honam (Lorestan Province) in the upper KRB. Under farmers practice at rainfed areas of Merek site, grain production for a local and an advanced barley variety (Sararood1), and a local and improved wheat variety (Azar2), were 1000-2100, 2100-2900, 800-2000, and 2000-2700 kg/ha, respectively. Early planting with the help of a single supplemental irrigation (about 75-50 mm), at Merek site, increased production to 3500-3700 for barley and 1800-3100 kg/ha for wheat. Similar results were obtained at the Honam site. The value of present rain water productivity (RWP, defined as rainfed grain yield divided by the total crop season annual rainfall water) for wheat, barley, and chickpea were 0.3-0.5, 0.3-0.6, and 0.1-0.3 kg/m^3, respectively. The results of this study showed that combination of advanced management with a single supplemental irrigation (SI) application at sowing or spring time (during heading to flowering stage) increased total water productivity (TWP, defined as grain yield divided by the sum of total crop-season rainfall and irrigation water) of wheat and barley from a range of 0.3-0.37 kg/m^3 to a range of 0.45-0.71 kg/m^3. The irrigation water productivity (IWP, defined as the ratio of increase in grain yield by supplemental irrigation to the irrigation water applied) of wheat and barley reached a range of 0.55-3.62 kg m^{-3} by using single irrigation at sowing or spring time. These preliminary results confirm the potential of supplemental irrigation and advanced management as effective methods to enhance productivity.

Results of deficit irrigation (DI) studies showed that under DI conditions, crop water productivity for irrigated wheat in the two sites was higher than under full irrigation conditions. Deficit irrigation not only increased water productivity, but also farmers' profits. Under pressurized irrigation, total water productivity under a 25% water deficit was 1.2 times that achieved under normal irrigation.

A soil water and salt balance model (BUDGET) and a crop water productivity model (AquaCrop) were used to simulate grain and biomass yields, soil moisture content and evapotranspiration of winter wheat sown early with single irrigation scenarios, with experimental data from three growing seasons (2005–08). The experimental design incorporates Azar2 bread wheat cultivar tested under three treatments: no irrigation at sowing (rainfed), supplemental irrigation at sowing with 75 mm of water (SI sowing) and irrigation to replenish the total water requirement at 0–90 cm soil profile at spring (about 50 mm of water). Crop input parameters were selected from the model documentation and experimental data. In the first season, experimental data were used for model calibration and the other two crop season data were used for simulation. Results showed that BUDGET (2005) and AquaCrop (2009) were able to simulate grain yield reduction, soil moisture content and evapotranspiration as observed in field experiments.

Economical analyses of different treatments for wheat and barley at Honam show that all treatments, except early planting with SI, were not economic. At Honam, recommended management options are advanced management (AM) + planting SI, AM + SI spring, and AM + rainfed treatments. Traditional management with SI or without SI is not recommended. Similar results with spring SI and early planting SI scenarios are recommended at Merek for both wheat and barley.

Assessing and Improving Irrigation Water Productivity of Wheat and Maize in the Lower Karkheh River Basin of Iran

M. Moayeri, H. Siadat, H. Farahani, T. Oweis, E. Pazira, F. Abbasi, F.Kaveh , H. Dehghanisanij and A. F. Nato

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Summary

Water productivity (WP) of wheat and maize was assessed in Evan Plain (lower KRB), using inflow-outflow measurements of irrigation water in 21 farmers' fields. The two-year average irrigation water productivity for wheat was found to be 0.84 kg/m^3, while in the wet season of 2006 it reached 1 kg/m^3. Mean wheat grain yield obtained was 4700 kg/ha with 550 mm of water (effective rainfall + irrigation). The grain yields of Chamran, Verinak, and Dez cultivars were nearly similar in the first year of the study, but Dez cultivar showed a lower drop in yield in the second relatively dry season. There were indications that the most sensitive stage to drought stress was heading stage until grain ripening. According to these results and assuming a constant yield, a theoretical increase of about 50% can be achieved in water use efficiency of wheat in Evan Plain. For maize crop, average WP in Evan was 0.42 kg/m^3 of water used .Despite the extra use of water, the crop water requirement was not satisfied .Using the two-year average yield of 4773 kg/ha for all farms and considering the two-year mean of ET_c (738 mm), the highest WP_{I+R} is expected to be 0.64 kg for each m^3 of water. According to the data gathered in this study, a major cause of low water productivity and yield of corn fields in Evan Plain is over-irrigation, while its water use efficiency could be enhanced by a theoretical maximum of about 50%, merely by proper water management.

Effects of field management and agronomic practices on WP were also studied for both crops. The study was conducted in two farmers' fields to evaluate methods for improving WP and to determine its potential level. For wheat, the treatments in fields after fallow included :(a) disking, broad casting, corrugation irrigation (b) 3 rows on 60 cm-wide raised bed i.e. flat top ridges, furrow (c) flat land sowing, 12.5 cm row spacing, flood irrigation and (d) farmers' practice i.e. disking, seed broad cast, border irrigation. For wheat after maize, treatments were:(e) use of corn chopper then combined planter (f) use of corn chopper then seed broadcasting, disking, corrugation irrigation and (g) = flat land sowing, 12.5 cm row spacing, flood irrigation + corn residue. Results showed that use of corrugation irrigation was recommendable. Various experiments conducted on farmer's fields, both with and without corn residues, showed that, by improved irrigation practices, water use efficiency of wheat was increased by an average amount of 45% compared with farmer's present practice. For maize, furrow spacing was 75cm in all cases and the treatments consisted of (i) Plant row spacing 75cm, alternate furrow irrigation, (ii) 2 plant rows spaced 25 cm on furrow ridge, full furrow irrigation (iii) single plant row inside furrow, full furrow irrigation (iv) 2 plant rows inside each furrow, full furrow irrigation, and (v) farmers' practice: single plant line, full furrow irrigation. Results indicate that the mean wheat and maize water productivity of 1.02 and 0.40 kg/m^3 were subsequently raised to 2.32 and 0.52 kg/m^3 when improved practices were applied. Under farmers' management, planting corn in the bottom of furrows can reduce water application by 20-30%, increase grain yield, and enhance irrigation water productivity by 50-100%.

Assessment of Different Scenarios of Supplemental Irrigation at Upstream Sub-basins of Karkheh River Basin on Quantity and Quality of Flows to Karkheh Dam

B. Hessari, F. Abbasi., M. Akbari , T. Oweis and A. Bruggeman

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Summary

The Karkheh River Basin (KRB), with a semi-arid to arid climate, is suffering from low rainfed agricultural productivity. Supplemental irrigation (SI) is recommended in the upper rainfed areas to increase crop yields and water productivity. However, development activities upstream will certainly affect the amount of water flowing to the Karkheh dam downstream. Current runoff in the upstream Karkheh River basin is assessed using a surface water balance in a GIS framework. Potential future situation with SI is assessed by assuming various scenarios at the upstream sub-basins. Water demand and new runoff maps are then simulated. Potential SI at the upstream sub-basins is prepared from intersecting layers method within the GIS. Four priorities of slopes in 53 sub-basins, 3 scenarios of normal condition, normal condition with environmental flow consideration, and drought condition are considered to investigate upstream/downstream interactions. SI scenarios include: full SI (satisfying the deficiency of rainfall), SI for early sowing (75 mm in autumn) and two levels of deficit SI strategies. Results indicate that water allocation to SI in normal situation could decrease downstream flow by 15%, whereas in drought condition, the reduction may amount to 10%, if all potential suitable areas for SI are developed. Water scarcity and salinization are major threats to sustainable irrigation in Iran as well as many other parts of the world.

In addition, a simplified Water and Salinity Basin Model (WSBM) was developed for a quick analysis of supplemental irrigation at upper Karkheh sub-basin on water quantity and quality. First, the model was calibrated and used for current and past water extraction analyses. Despite the simplicity of the model, observed and simulated stream flows and salinity were similar, proving that the model could be used for scenario analyses. The first scenario was setup to analyze the effect of single supplemental irrigation (75 mm) in autumn for about 140000 ha of rainfed areas. As a consequence of this scenario, water salinity will increase, resulting in less water available with higher salinity for downstream users along the Karkheh River. This scenario has no significant effect on water quality and quantity of Karkheh Dam. For the second scenario i.e. a single supplemental irrigation (75 mm) in spring for about 200000 ha of rainfed lands increased water extraction is negligible compared to the annual flows of the river. The third scenario was a combination of scenarios 1 and 2, therefore, the result was similar to scenarios 1 and 2. However, annual water quantity of Karkheh Dam decreased by 5.9%, but water salinity increased 3.9%. For the last scenario, i.e. two supplemental irrigations (of 150 mm) in spring at the heading and milky stages, the result of the supplemental irrigation at the heading stage was the same as the scenario 2. Supplemental irrigation (75 mm) in June (at the milky stage), somewhat decreased water quality and quantity of Karkheh River and branches. By application of this scenario, annual water quantity of Karkheh Dam was decreased by 6.9% and water salinity increased 4.1%. Finally, it was concluded that the methodology and the model developed were useful for a swift and transparent analysis of past, current and future water and salt management, and to perform scenario analyses.

Assessment and Improvement of Water Productivity under Saline Conditions in the Lower Karkheh River Basin

I- Chapter One: Present status of salt-affected and waterlogged soils in Dasht-e-Azadegan and management strategies for their sustainable utilization

S.A.M. Cheraghi, N. Heydari, Y. Hasheminejad, M. Qadir, H. Farahani and T. Oweis

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Summary of chapter 1

The Karkheh River Basin (KRB) is one of the major river basins in the Khuzestan province consisting of two main sub-basins namely Karkheh Olia (upstream) and Karkheh Sofla (downstream). Agriculture in the upstream basin is mainly rain fed, while the downstream basin is mostly irrigated. Dasht-e-Azadegan plain is the terminal basin of the Karkheh river and its entire tributaries end in this basin. The main problems limiting agricultural production in this region are salinity and water logging. Saline-sodic soils constitute a vast area of Dasht-e-Azadegan. About 99% of the area of the region has been faced with salinity or sodicity for a long time. Salinization of land and water resources has been the consequence of both anthropogenic activities and naturally occurring phenomena. Major factors causing the situation include high groundwater table, salt containing layers, inadequate drainage facilities, high evaporation, salt intrusion by wind, and saline groundwater intrusion.

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

II- Chapter Two: Assessment and evaluation of water productivity in the Dasht-e-Azadegan

N. Heydari, S. Absalan, M. Qadir , F. Abbasi and T. Oweis

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Summary of chapter 2

The main objective of this research was to assess and evaluate WP in farmers' fields, find out the sources of wheat production inefficiency, and determine cost effective short-term solutions for solving the soil salinity and water logging problems in the salt-prone areas of the lower KRB. It was realized that the main cause of soil salinity was the high water table, varying between 1.2-3.0 m below the soil surface as a result of intensive over-irrigation in the absence of drainage facilities, heavy soil texture, and recharge of ground water by lateral subsurface flows from upstream irrigated areas .

Variability in irrigation WP was high, ranging from 0.1 to 2.1 kg/m^3. There were four main sources of inefficiency: (i) socio-cultural problems e.g. low farming skills, low motivation for investing in irrigation management and on-farm improvement activities, and low motivation for participatory works, (ii) limitations out of farmers' control and authority, e.g. irrigation intervals, water rationing, and shortage of agricultural inputs, (iii) technical and infrastructure limitations and problems, and (iv) farmer managerial problems and limitations associated with irrigation such as flow control, irrigation and land preparation methods, and improvements in water intake structures that can be overcome easily and do not need much investments.

Considering the above limitations and problems, the following short-term solutions are recommended to improve WP in the saline area of LKRB:

- Conversion of traditional and locally common irrigation method to proper basin-border method.
- Construction of fixed and low-cost water intake structures on farm ditches.
- Proper land leveling and bedding according to the field slope.
- Application of on-farm management improvement instructions provided by rural extension services.
- Farmers training and supervision by irrigation experts for guidance, and enhancement of irrigation management.
- Preparing the required condition for volumetric allocation of water to the farmers through extension services.
- Continuation of this survey to cover higher number of the selected farms in order for the results to take into account more changes and non-uniformities of the factors involved, especially spatial and temporal variations of salinity in the southern part of LKRB.

<u>III- Chapter Three:</u> Management practices for improving water productivity in the Dasht-e-Azadegan

N. Heydari, S. Absalan, E. Dehghan, F. Abbasi, M. Qadir, and T. Oweis

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Summary of chapter 3

In the lower KRB (Dasht-e Azadegan plain, DA) wheat is the main irrigated crop with an average yield of 1.5 t/ha. Heavy soil texture and recharge of ground water by lateral subsurface flows from upstream irrigated areas provide the conditions for water logging and salinity that are aggravated by poor irrigation management. The main objective of this research was to find out cost effective and short-term solutions to increase wheat water productivity in the DA. Accordingly, the following targets were identified: (i) development of simple management practices for improving agricultural WP, (ii) investigation traditional vs. improved border-basin irrigation method, and (iii) investigating impact of different cultivation/sowing methods on wheat WP.

The research was conducted in a farmer's wheat field in DA during cropping seasons of 2006-07 and 2007-08. The irrigation and planting methods were studied using the following factorial treatments: Two irrigation methods (border and basin) x three sowing methods: (i)sowing by centrifugal broadcaster following one pass disc, (ii) sowing by seed drill machine (Taka type), (iii) sowing by three rows bed seeder (Hamedani type). A control treatment consisting of the farmer irrigation and agronomic practices was also part of the study.
Soil samples were taken from the field for different analyses. Chamran wheat variety was sown in all the treatments. Seeding rate was 250 kg/ha in treatments sown by centrifugal broadcaster (T_1, T_4). In the other treatments, seed drill (TAKA) and three rows bed seeder (Hamedani), the rate was 180 kg/ha. In the control treatment (T_c) sown by centrifugal broadcaster and managed by the farmer, the seed rate was 350 kg/ha. Other farming practices were the same for all treatments. Agronomic data were recorded and crop yield and yield components were measured by sampling from 1 m^2 sampling frames before harvest. Irrigation water was measured by WSC flumes. Interval and number of irrigations were the same as practiced by the farmers, but, the difference was in management of water flow on the land and the method of irrigation.
According to the results, both improved basin and border irrigation methods can be recommended for enhancing WP in the area. However, the basin irrigation method is more adoptive to the socio-cultural conditions of the plain.

Reuse of drainage water for irrigation was also studied, in small and large experimental plots. Treatments were: T_c=Fresh water-Fresh-Fresh (Control), T2=Fresh-Fresh-Saline, T3=Fresh-Saline-Saline, T4=Saline-Saline-Saline. Results indicated that the option of using drainage water for irrigation during different growth stages, especially in cyclic application with fresh water, is feasible without considerable yield losses. This will improve wheat WP, especially during water scarcity and drought conditions.

IV- Chapter Four: Comparison of Yield of Local Wheat cultivars in Saline Areas of Lower Part of KRB

G. H. Ranjbar, S.A.M. Cheraghi and G.A.L. Ayene

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Summary of chapter 4

Crop production in the lower areas of the KRB is impaired by high salinity of soil and water resources and water logging conditions. The long term solution to the problem is through control of saline ground water level, which is a time consuming and an expensive task. In short terms, however, production could be improved through selection of suitable crop species or varieties for the area.

Five commercial wheat varieties selected for saline conditions referred to as new varieties and two local cultivars were sown in the plots in November each year. The new varieties were Roshan (a tall variety), Kavir (semi-dwarf variety, released in 1996), Bam, Akbari, Sistan (semi-dwarf varieties, released in 2006). The local wheat cultivars were Chamran and Verinak. In total, the experimental design consisted of seven wheat genotypes replicated three times in a randomized complete blocks design. During the growing season, all plots were irrigated at the same time with the same amount of irrigation water. Three soil cores per block were taken to a depth of 0.9 m for four times during the growing season. The pre-experiment average soil salinities (electrical conductivity of soil saturated paste extract, ECe) for the 0.9 m soil depth were 7.1, 7.0 and 12.9 dS/m in 2005, 2006 and 2007, respectively. Irrigation water for the experimental fields was taken directly from the Karkheh River. The electrical conductivity of river water was less than 1.5 dS/m.

Comparison of mean grain yields for 3 years showed that Sistan and Verinak produced the highest and lowest grain yield, respectively. The mean grain yield of Sistan, Kavir, Bam, Chamran, Roshan, Akbari and Verinak were 4.72, 4.47, 4.42, 4.26, 4.06, 3.93 and 3.25 t/ha, respectively (Fig. 4.1). There were significant differences among local cultivars vs. new varieties (Table 4.2). New varieties produced more grain yield than the local cultivars by 15%. Generally, Sistan, Kavir and Bam produced more grain yield than the other varieties. Among new varieties, Roshan and Akbari produced lower grain yield. Based on the results of this study wheat varieties like Bam, Sistan and Kavir were found to be more productive than Roshan, Akbari and local cultivars and could be considered as potential substitutes for present varieties under saline (also water-logging) conditions of lower Karkheh River Basin. Results also showed that number of kernels per spike was the main yield component that caused yield improvement in new varieties. However, more grain yields for the new varieties were associated with increase in biological yield rather than harvest index.

<u>V- Chapter Five:</u> Comparison of Yield of Local Barley cultivars in Saline Areas of Lower Part of KRB

G.H. Ranjbar, S.A.M. Cheraghi and M.H. Rahimeyan

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Summary of chapter 5

Barley is also an economical crop grown in Dasht-e Azadegan, which is facing the dual problem of salinity and water logging. Native varieties of barley are commonly cultivated in the area, with average yields that is lower than the average of the country. A field experiment was conducted in that area during 2005-2008. The treatments included two barley cultivars (Afzal and Reyhan) and four barley lines (Karon × Kavir, M80-9, M-81-19 and On-4). The experimental design was randomized complete blocks with three replications. Genotypes were sown in the plots in November each year.

Combined analysis of variance showed that On-4 and Afzal produced the highest and lowest grain yields regardless of the year, respectively. The mean grain yield of On-4, Reyhan, M80-9, M81-19, Karon x Kavir and Afzal were 3.33, 3.12, 2.82, 3.01, 2.91 and 1.65 t/ha, respectively. Comparison of mean grain yield in each year showed that barley genotypes produced different grain yield in each year. The highest grain yield was observed for On-4 except for 2006-2007. Generally, Afzal produced the least grain yield in each year. Grain yield of barley genotypes were highly correlated with stem height and biological yield (Table 5.3, $P<0.01$). The same as for grain yield, the highest and lowest plant height was observed for On-4 and Afzal genotypes. Results of this study indicate that germplasm and lines such as On-4 and M81-19 could be considered as new barley genotypes for the lower parts of the KRB.

VI- Chapter Six: Comparison of Yield of Local and Exotic Sorghum Cultivars in Saline Areas of Lower Part of KRB

A. Anagholi and A.A. Rahnema

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Summary of chapter 6

A study on the performance of different sorghum genotypes was conducted at Dasht-e-Azadegan, during spring and summer of 2006 and 2007. The experiment was laid out in randomized complete blocks design with 3 replications. Treatments were 4 hybrid variety namely Speedfeed, Sugargraze, Jumbo and Nectar and 4 pure lines namely KFS_1, KFS_2, KFS_3 and KFS_4. Each plot was 6.0 m long and 1.8 m wide and contained 6 rows that were spaced 0.3m apart. Leaf and stem weight were obtained through destructive sampling on 3 representative plants at harvest time. For obtaining fresh and dry matter yield, 2 square meter plot was harvested from central rows. EC_e was measured by soil sampling during the growing season. All data were analyzed using SAS statistical package. Means found significant were tested using Duncan's test at 5% level of probability.

Fresh matter yield of sorghum pure lines was found to be significantly different in annual analysis at 1% level of probability for two years. KFS_4 produced the maximum fresh matter of 100.67 t/ha in the first year, followed by KFS_2 and KFS_1, with 92.67 and 86.33 t/ha respectively, which were not significantly different. The highest fresh matter obtained for KFS_4 could be due to its maximum plant height. In the second year, the maximum fresh matter was measured for KFS_4, with 107.72 t/ha, again followed by KFS_2, with no significant difference. Dry matter production of the pure sorghum lines was also found to be significantly different on annual analysis at 5% and 1% level of probability in the first and second year, respectively

The highest total dry matter of 28.31 t/ha was measured for Speedfeed variety in the first year. Jumbo produced the highest dry matter of 34.68 t/ha in the second year and Speedfeed produced 32.59 t/ha with no significant differences. Based on the results of this study, KFS_4 and KFS_2 produced highest fresh and dry matter yields among lines. For hybrid varieties, Speedfeed showed the highest fresh and dry matter yields.

According to these results, it could be concluded that for the agro-ecological condition of this area pure lines could well compete with hybrid varieties of sorghum. KFS_4 produced 104.19 and 26.83 t/ha of fresh and dry matter, respectively, which is comparable to those of Sugargraze, Nectar and Jumbo. Also since KFS_2 is considered to be a salt tolerant line, it can compete with Jumbo and Nectar hybrids in Agro-climatic condition of Dasht-e-Azadeghan in the lower KRB.

Study of the Effects of Economical Factors on Water Use Efficiency in Irrigated Cereals under Farmers Condition in Lower KRB in Khuzestan Province

H. Asadi, K. Shideed, F. Shomo, Niasar, A. Abbasi, A. Ayeneh, N. Heydari, F. Abbasi, F. Mazraeh and M. Gamarinejad

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Summary

This study was carried out during 2006-7 in the selected sites in KRB to determine some socio-economic characteristics of sample farmers, different water uses and water price for cereals, agronomic and economical issues related to production of irrigated cereals in the Azadegan (DA) and Sorkheh (DS) plains, and to compare the effects of economical factors on average water use efficiency in saline (DA) and fresh conditions (DS). A total of 166 farmers (136 from DA and 30 from DS) were selected as samples using stratified random sampling method. Required data were collected from sample farmers by questionnaire with the help of experts from the local Agricultural Extension Centers. Models used for estimating of efficiency were:(1) corrected ordinary least squares method (COLS), (2) linear programming method, and (3) stochastic maximum likelihood method. Also, SPSS and Frontier Version 4.1 computer programs were used.

According to the results, in Azadegan plain under saline conditions, estimated net profit for wheat and barley were, respectively, M.Rial 1.2 and M.Rial 0.2 per hectare, with corresponding average water productivity values of 0.39 kg/m^3 and 0.34 kg/m^3. In Sorkheh Plain with non-saline conditions, wheat and maize are grown and the profits were generally higher. Estimated net profit for wheat and maize were, respectively, M.Rial 4.9 and M.Rial 4.8 per hectare, with corresponding average water productivity values of 0.58 kg/m^3 and 0.38 kg/m^3.

For wheat, it was also found that factors of water price, seeding rate, and application rate of urea and phosphate fertilizers had significant effect on water productivity and there was a negative relation between water price and land size with water productivity i.e. when water price and land size are high, water productivity was low. In addition, results indicated that land tenure, water limitation, soil salinity and soil texture had significant effect on water use inefficiency. Based on stochastic maximum likelihood method, relation between water limitation with "technical efficiency" was negative i.e. when water limitation was high, technical efficiency was low. Average technical efficiency of wheat farmers, as obtained from the same model, was 88%. In the case of barley similar relations were found and water price had significant effect on water productivity. There was a negative relation between water limitation and technical efficiency i.e. when water limitation was high, technical efficiency was low. Average technical efficiency of barley farmers was almost 90%. About 77% of farmers believed that irrigation development had positive impacts on household livelihoods and could increase their income and stability of production.

Assessing Policies and Institutional Arrangements in the Karkheh River Basin

A. Kehsavarz

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Summary

This study was conducted to review the policies and institutional arrangement on irrigation water use and to assess the consequences for water allocation and productivity in selected sites of Sorkheh and Azadegan in the lower KRB and Merek in rainfed parts of the basin. The method used is based on review of available policy documents as well as secondary and stakeholder survey data to assess water and related policies and institutions influencing water use in KRB based on some indicators including; food security, economic growth, ecosystem consideration and environmental sustainability, poverty reduction, gender inequity, water pricing, water use technology, water allocation and related criteria, and research activities.

The two ministries of Energy (MoE) and Jihad-e-Agriculture (MoJA) are the main institutions responsible for the management of water in Iran. The MoE is responsible for storage and supply of water for different consuming sectors, while MoJA is responsible for improvements in water productivity and development of irrigation systems technologies. In Iran there are 49 research and or educational institutes related to water, 14 institutes specifically on water research, 25 societies on water or agriculture, 47 consulting engineers firms in water, and 178 manufacturing and or design companies in irrigation (especially in pressurized irrigation systems).

Water management in KRB is characterized by some types of complex, overlapping, and sometimes competing networks of actors, rules, functions, and organizations. Multiple actors and organizations involved in water-related decision making at different levels have caused a situation where farmer cannot receive water in the right time and amount.

The law of “Equitable Distribution of Water” is one of the important national acts on water policies in Iran that was first approved by the parliament in 1982 and was slightly modified later on. It consists of five chapters, 52 articles and 27 notes. The main chapters are: (i) Public and national ownership of water (ii) Ground water resources (iii) Surface water resources (iv) Duties and authorities (v) Penalties and regulations.

Even though several water policies, strategies, laws, and regulations exist, effective water resource development is yet to be achieved. Examples of deficiencies are:

- Less water resource development projects, despite high investment, especially for secondary canals
- Low water productivity at both national (0.9 kg/m^3) and KRB (0.54 kg/m^3) levels
- Depletion of groundwater, and negative water balance in some basins
- Simultaneous soil and water resources degradation
- Less-than-fully successful achievement of projected provisions of the first, second and third mid-term development plans on water allocation, productivity, and water resource management

To contribute to poverty reduction, environmental sustainability, gender inequity, and water pricing, reforms is needed which should create a framework for development of relationships among the key governance actors, nongovernmental organizations, civil society, private sector and farmers to identify the most effective resource uses and management modalities. Because incentives are lacking to engage poor people in the governance of water resources, the state needs to use its authority to enhance their voice and benefits.