CGIAR Challenge Program on
WATER & FOOD

Proceedings of the International Workshop on:

Improving Water Productivity and Livelihood Resilience in Karkheh River Basin

September 10-11, 2007, Karaj, Iran

Editors:
H. Farahani, T. Oweis, H. Siadat, F. Abbasi, A. Bruggeman,
J. Anthofer and F. Turkelboom

Organized by:

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

2

Strengthening Livelihood Resilience in Upper Catchments of Dry Areas by INRM Project (CPWF PN 24)

ICARDA
International Center for Agricultural Research in the Dry Areas

AEERO
Agricultural Extension, Education and Research Organization

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Contents

Foreword

Water in the Karkheh River Basin (KRB) of the Islamic Republic of Iran is limited and becoming scarce as population and demand are increasing. The productivity of rainfed agriculture is low; conventional irrigation management is poor; cropping systems are sub-optimal; and policies and institutions have room for improvement. However, Iran's agricultural strategy identifies water productivity improvement as a top priority. The KRB reflects in many aspects the problems of water management in other basins in the region. Accordingly, it is intended to link the work in KRB with the Euphrates and Amu Darya river basins.

The aim of the CGIAR's Challenge Program on Water and Food (CPWF) on "Improving On-Farm Agricultural Water Productivity in the Karkheh River Basin (KRB)", (PROJECT REFERENCE NO: PN8) is to help the resource-poor communities in the basin to sustainably improve their income and livelihoods. The specific objectives are to improve farm and basin water productivity and the sustainable management of the natural resource base; develop appropriate policies and institutions; and enhance the capacity of National Agricultural Research Services (NARS).

Means and activities needed to achieve this goal include:

- Options for sustainable improvement of water productivity in irrigated and rainfed systems
- Farmers' adoption of the new recommendations and technologies
- Progressive policies and suitable institutional arrangements
- Capacity building of NARS and community leaders, and
- Assessment of water productivity and institutional and policy structures

The work is conducted in partnership between two CGIAR centers (ICARDA and IWMI), the main umbrella NARS in Iran, the Agricultural Extension, Education and Research Organization (AEERO), and its research institutes such as the Agricultural Engineering Research Institute (AERI), Seed and Plant Improvement Institute (SPII), and Dryland Agriculture Research Institute (DARI), University of California, Davis, USA, and most importantly, the farmers and extension staff in the basin.

A two-day international workshop on "Improving Water Productivity and Livelihood Resilience in Karkheh River Basin" was jointly organized by ICARDA and AREO 10-11 September, 2007 in Karaj, Iran, and the presentations are compiled in the proceedings. The presentations at the workshop focused on integrated and participatory approach to technology development in addressing water productivity and livelihood resilience. It underscored the importance of sustainable development without endangering the ecological assets of fragile ecosystems in this region.

The workshop concluded, based on the research results presented and the discussions held, that agricultural water management occupies an important role in the efforts to improve the livelihoods of rural communities in the basin. It is also clear that achieving the objective of improving water productivity will positively affect farmers' production and income and contribute to sustainable agriculture in the basin. There is a great potential for increasing water productivity in agriculture and the farmers resilience in the future as water will become more scarce and climate change is expected to aggravate that with prolonged drought and other extreme events.

The success of the project, and particularly this workshop, is due to the dedication of all the partners- the research leaders and teams of various institutions- of the two projects and the strong support of the officials in AEERO. The support provided by the CPWF is highly appreciated.

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CHAPTER 1

Water Productivity and Technologies in Upper Karkheh River Basin (KRB)

Role of Transfer of New Technologies to Improve Water Productivity of Major Rainfed Crops in KRB

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ABSTRACT

Most of the agricultural area in the upper Karkheh River Basin (KRB) is rainfed and a large part of the region's rural livelihood is based on dryland farming systems. The average water productivity (WP) values for dryland crops range from 0.3 to 0.5 kg m^{-3}. This is in spite of the fact that the upper catchments in the KRB are some of the most suitable rainfed zones of the country, with long-term annual precipitation of 350 to 500 mm. Single irrigation is a proven and efficient technology to increase yields of main dryland crops (wheat, barley, chickpea) especially when combined with other improved agronomic management practices. On-farm experiments during the 2005–07 winter cropping seasons of wheat and barley were conducted at multiple farms across the two benchmark watersheds of Merek (Kermanshah province) and Honam (Lorestan Province) in the upper KRB. The goal of this strategy is to ensure adequate crop establishment and soil moisture prior to winter to maximize the effectiveness and productivity of rainfall. Under farmers' practice at rainfed areas of Merek site, grain production for a local barley variety, an advanced barley variety (Sararood1), local wheat variety and an improved wheat variety (Azar2), were 1000–2100, 2100–2900, 800–2000, and 2000–2700 kg ha^{-1}, respectively. Early planting with the help of a single irrigation (about 50 mm) increased production to 3500–3700 for barley and 1800–3100 kg per ha for wheat. Similar results were obtained at the Honam site. The value of rain water productivity (RWP) for the major crops of interest i.e., wheat, barley, and chickpea, were 0.3 to 0.5, 0.3 to 0.6, and 0.1 to 0.3 kg m^{-3}, respectively. The results of this study showed that a single irrigation application at sowing or spring time (during heading to flowering stage) increased total water productivity (TWP) of wheat and barley from 0.4–0.48 to 0.45–0.8 kg m^{-3}. The irrigation water productivity (IWP) of wheat and barley reached to 1.11–3.74 kg mm^{-3} by using a single irrigation at sowing or spring time. 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.

Keywords: Water productivity, Rainfed, Single irrigation, Sowing date, Yield, KRB

INTRODUCTION

In the KRB, rain water productivity (RWP) is not only low, but also highly variable due to many factors, including the poor field management and availability of improved farm machinery, insufficient extension support, and the inherent variability in rainfall patterns and amount. Increasing and stabilizing the productivity of the limited and erratic rainfall could substantially improve farmers' income and thus regional prosperity. Under this harsh climatic and economic background, more efficient, yet simple, water management techniques must be adopted and combined with other agronomic management practices to improve livelihoods and sustainability. New ways and methods of production should be sought and adopted in order to increase and stabilize crop production in these areas.

Winter cereals are the main crops sown on the rainfed lands of the KRB. In this area, yields are low and strongly dependent on the highly variable and erratic rainfall. Current water productivity (WP) values for dryland crops range from 0.3 to 0.5 kg m^{-3}. These productivity levels achieve an income of less than $50 per ha. This is in spite of the fact that the upper catchments in the KRB are some of the most suitable rainfed zones of the country, with long-term annual precipitation of 350 to 500 mm. The expectation is that under the prevailing rainfall regimes and with improved agronomic practices, WP should nearly double. However, due to fluctuations in rainfall, both within and between seasons, as well as the variations in agro-climatic conditions and lack of appropriate management measures, the productivity is far from potential.

Research has shown that the risks associated with lack of soil moisture profile during fall planting can be significantly reduced by supplemental irrigation. Supplemental irrigation is a proven and efficient technology to increase yields of main dryland crops (wheat, barley, chickpea), especially when combined with other improved agronomic management practices. Research also shows that the risks associated with late planting in the fall and erratic rainfall can be significantly reduced by planting early with the help of a single irrigation. Exploring the potential of supplemental irrigation at early planting of dryland crops is of particular interest in this research.

These preliminary results confirm the potential of single irrigation and early planting as an effective method to enhance productivity. Other potentially useful agronomic factors which could increase RWP are also under investigation, including land preparation, use of improved machinery, optimum seed rate and planting depth, altered sowing date and seed quality, fertilizer management, and harvest operation. This paper discusses means to optimize these factors, thus additionally promoting the use of improved agronomic management practices along with the supplemental irrigation at planting.

With its large population in the future, Iran cannot maintain food security without irrigation. In the rainfed areas of Iran where natural rainfall cannot match crop water requirements, supplementary irrigation is used to increase yields and provide the food needs of the nation. However, excessive-use of diverted river and dams flows and groundwater has caused severe environmental problems. In the rainfed areas of Iran, groundwater, seasonal rivers, springs and small dams are the main source of water for supplemental irrigation.
Moreover, inefficient use of water is a notorious phenomenon in irrigation systems at irrigated areas. It is estimated that about half of the water is lost due to leakage during transfer to farmers' fields (Keshavarz and Sadeghzadeh, 2000). Of the water reaching the field, losses of water are also substantial. In China, flood irrigation is predominant and more efficient irrigation systems such as sprinklers and drip irrigation is rarely used (Deng *et al.,* 2006).

Iran's population will increase by one million people annually over next half a century. To support this growing population, food production has to be based on improving water use efficiency and further expansion of irrigation. Given the severe shortage of water resources in Iran, the expansion of irrigated land is expected to be limited. Therefore, increasing water productivity in both irrigated agriculture and promoting dryland farming through water conservation and efficient use of rainfall will play significant roles in maintaining food security.

Tallie and Sayadyan (2000) reported that for Kermanshah condition, located in the west of Iran, single irrigation at seed development stage had the highest effect on increasing grain yield and irrigation water productivity was 5.9 kg mm^{-1}. An on-farm experiment carried out by Tallie (2005) at farmer's field of Kermanshah province, showed that single irrigation of rainfed new advanced barley variety (Sararood1) at early May (during heading to flowering stage) increased 1204 kg ha^{-1} grain yield compared with rainfed condition. This increase of barley grain yield by single irrigation was highly significance. On the basis of Kermanshah farmer's condition, irrigation water productivity was between 12–50 kg mm^{-1}.

This paper reviews the current status of rain water productivity at rainfed agriculture in KRB and highlights further improvement in agricultural WP in rainfed areas of Kermanshah (Merek site) and Lorestan (Honam site) provinces by using a single irrigation, sowing date and new advanced wheat and barley varieties under on farm scales. The goal of this strategy is to ensure adequate crop establishment and soil moisture prior to winter to maximize the effectiveness and productivity of rainfall. This combined irrigation and planting time practices may well prove to be a key solution in the realization of potentials of the dryland areas in the production of food for the future.

Materials and Methods

Experimental site

KRB is located in the western Iran and represents semi-arid and arid areas of the region. KRB is located between 30° 57' to 34° 57' northern latitudes and 47° 30' to 50° 45' eastern longitudes. Two major agricultural production systems prevail in the KRB. The rainfed cropping prevails in the upstream of the newly built Karkheh Dam and the fully irrigated areas are mainly located in the downstream of the Dam. The total area of KRB is 5.08 million ha (M ha), out of which only 1.07 M ha is irrigable and 0.9 M ha is suitable for dry farming agriculture.

The experiments were conducted in 2005–07 cropping season. Weather data was collected from the nearest meteorological station. Precipitation, maximum and minimum temperatures, air humidity and wind speed were measured on a daily basis. In upper KRB area, frost begins at the end of November and can continue to March. The coolest months are December–February. Snow cover of 2–4 months is common, which protects the crop in winter.

The soil of the experimental site was clay-loam with a pH of about 7.5 and a composition of 12% sand, 42% silt and 46% clay. Organic matter content varied from 0.8 to 1.35%, available potassium and phosphorus values ranged from 305 to 520 and 10 to 20.2 at 0–20 cm depth, respectively.

In 2005-07 seasons, wheat and barley were drilled in mid October at 15–20 cm row spacing. The plot sizes varied from 0.2 to 1 ha, of which three samples (1*1 m) were harvested for yield components. The treatments were randomly assigned to each block and replicated two times (two farmers). Irrigation was applied at on-farm scale based on SI treatment (except the rainfed part). The amount of applied water was determined in such a way to ensure that the root zone moisture is near field capacity.

The climate and farming systems in KRB

Dominated by a continental monsoon climate, precipitation in rainfed areas of KRB is generally low and concentrated in a few months of the year. Mostly, annual precipitation is in the form of rain and snow in the months of December, January, February, March, April and May, and there are two critical stages in early and late crop season, when there are not sufficient precipitation. Winter wheat and barley are the staple crops in the rainfed areas of KRB, where the annual rainfall is about 350–500 mm. The total annual rainfall on first cropping season at Honam and Merek sites were 460 and 574 mm, and on second cropping season at Honam and Merek sites were 569 and 503 mm, respectively, inadequate rainfall for emergence in October and sufficient, but late rainfall in November. Winter wheat and barley are usually rotated with fallow, legumes and cereals each year. In farmers' condition wheat and barley are usually planted after the first effective precipitation (November) and harvested in early July. The annual rainfall is not enough to support crops during early crop season and end of crop season and therefore single irrigation is necessary for wheat and barley at early planting time (at least one month before first effective precipitation) and during spring and early summer, during heading to flowering stage (Oweis and Hachum, 2001; Ilbeyi *et al.,* 2006; Tavakoli, 2004, 2005 & 2007; Tavakoli and Oweis, 2004, Tavakoli *et al.,* 2005). In the rainfed areas of KRB, the soil is usually plowed before sowing.

Most of the agricultural area in the upper KRB is rainfed and a large production of the region's agricultural livelihood is based on dryland farming systems. KRB is a water short area and droughts are becoming a permanent feature of this region. In the dry areas, water, not land, is the most limiting resource for improved agricultural production and thus maximizing rain water productivity (RWP), for instance the amount of yield per unit of effective rainfall, is a sound strategy. In the rainfed conditions, late sowing is a common practice. Late planting is one of the major causes of poor crop stand prior to dormancy and increased damage and susceptibility by the cold winter. This lack of early vegetation also leads to less effective use of rainwater during early season. Late planting of winter crops is risky as it could lead to significant loss of yield potential, resulting in low rainwater productivity and limited economic sustainability.

Treatments and experimental design

The on-farm scale experiments were carried out at Merek and Honam sites of Kermanshah and Lorestan provinces (Eastern of Iran). A cultivar of advanced winter bread wheat (Azar2 cultivar) and a cultivar of advanced winter barley (Sararood1 cultivar) were subjected to the following treatments: early sowing with about 50 mm irrigation at planting time, normal sowing with about 50 mm irrigation, early sowing with about 50 mm irrigation at during heading – flowering stage, normal sowing with about 50 mm irrigation at during heading – flowering stage, early sowing with about 50 mm irrigation at planting time + 50 mm irrigation at during heading – flowering stage. These treatments compared with local wheat and barley cultivar. Grain, straw and biomass yields, thousands kernels weight (TKW), grain per spike and harvest index (HI) were measured and analysis performed by T-Test Graphpad statistical software.

Results

Present rain water productivity
At Honam site, based on data collected from 60 different fields of major rainfed local crops (wheat, barley, chickpea and lentil). The average grain yields were 800–2000, 1000–2900, 300–750 and 200–700 kg ha^{-1}, while rain water productivity varied from 1.7–4.3, 2.6–6.3, 0.7–2.2 and 0.4–1.5 kg mm^{-1}, respectively. At Merek site average grain yields were 900–2400, 1000–1800, 300–900 and 700–1100 kg ha^{-1}, and rain water productivity ranged between 1.6–4.2, 1.7–3.1, 1.2–1.9 and 0.5–1.6 kg mm^{-1}, respectively.

Mean grain yield

Honam (2005–06)

- Results showed that early establishment of the wheat, using SI at sowing, increased grain yield from 2216 kg ha^{-1} to 4088 kg ha^{-1} and so increased grain yield to 3292 kg ha^{-1} by applying single irrigation at spring time (Table 1).
- Similar results obtained for barley by using SI at sowing, increased grain yield from 2109 kg ha^{-1} to 2963 kg ha^{-1}. Single irrigation at spring time increased grain yield to 3008 kg ha^{-1} (Table 2).

Merek (2005–06)

- Results showed that early establishment of the wheat, using SI at sowing,

increased grain yield from 2300 kg ha^{-1} to 2800 kg ha^{-1}. Single irrigatin at spring time increased grain yield to 3500 kg ha^{-1} (Table 1).
- Similar results were obtained for barley by using SI at sowing; grain yield increased from 2600 kg ha^{-1} to 2900 kg ha^{-1} and applying single irrigation at spring time increased grain yield to 3700 kg ha^{-1} (Table 2).

Honam (2006–07)
- Results showed that early establishment of the wheat, using SI at sowing, increased grain yield from 2515 kg ha^{-1} to 3227 kg ha^{-1} and applying single irrigation at spring time increased grain yield to 3430 kg ha^{-1} (Table 3).
- Similar results were obtained for barley; grain yield of local and Sararood1 barley varieties were 1490 and 2930 kg ha^{-1} to 2963 kg ha^{-1}, respectively and grain yield increased 3240 kg ha^{-1} by applying single irrigation at planting time (Table 4).

Merek (2006–07)
- Results showed that early establishment of the wheat, using SI at sowing, increased grain yield from 2625 kg ha^{-1} to 2900 kg ha^{-1}. Grain yield increased to 3768 kg ha^{-1} by applying single irrigation at spring time (Table 5).
- Similar results were obtained for barley by using SI at sowing, increased grain yield from 2273 kg ha^{-1} to 2533 kg ha^{-1}. Grain yield increased to 3426 kg ha^{-1} by applying single irrigation at spring time (Table 6).

Water productivity

Honam (2005–06)
- TWP of new wheat and barley variety (Azar2 and Sararood1, respectively), under rainfed and single irrigated treatments showed that using single irrigation at sowing increased from 4.8 and 4.6 kg mm^{-1} to 8 and 5.8 kg mm^{-1} and SI at spring increased to 6.5 and 5.9 kg mm^{-1}, respectively (Table 1).
- IWP of wheat reached to 37.4 and 21.5 kg mm^{-1} by using single irrigation at sowing and spring time respectively and IWP of barley reached to 17.4 and 14.8 kg mm^{-1} by using single irrigation at sowing and spring time respectively, (Table 2)

Merek (2005–06)
- TWP of new wheat and barley variety (Azar2 and Sararood1, respectively), under rainfed and single irrigated treatments showed that using single irrigation at sowing increased TWP of wheat and barley from 4.5 and 5.4 kg mm^{-1} to 4.6 and 5.5 kg mm^{-1} and SI at spring increased to 6.3 and 7.2 kg mm^{-1}, respectively (Table 1).
- IWP of wheat reached to 4.5 and 22.5 kg mm^{-1} by using single irrigation at sowing and spring time respectively and IWP of barley reached to 4.2 and 23 kg mm^{-1} by using single irrigation at sowing and spring time respectively (Table 2).

Honam (2006–07)
- TWP of new wheat variety (Azar2), under rainfed and single irrigated treatments showed that using single irrigation at sowing increased from 4.4 kg mm^{-1} to 5.2 kg mm^{-1} and SI at spring increased to 5.54 kg mm^{-1} (Table 3).
- IWP of wheat reached to 14.24 and 18.3 kg mm^{-1} by using single irrigation at sowing and spring time (Table 4).

Merek (2006–07)
- TWP of new wheat and barley variety (Azar2 and Sararood1, respectively), under rainfed and single irrigated treatments showed that using single irrigation at sowing increased TWP of wheat and barley from 5.21 and 4.52 kg mm^{-1} to 5.24 and 4.58 kg mm^{-1} and SI at spring increased to 6.81 and 6.19 kg mm^{-1}, respectively (Table 5).

- IWP of wheat reached to 5.5 and 22.86 kg mm^{-1} by using single irrigation at sowing and spring time respectively and IWP of barley reached to 5.2 and 23.1 kg mm^{-1} by using single irrigation at sowing and spring time respectively (Table 6).

Single irrigation at sowing was more effective for Honam condition and single irrigation at spring (during heading–flowering stage) was more effective for Merek site. It refers to their climate condition, because Honam and Merek sites have a cold and cold-temperate climate, respectively. 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. Additional single irrigation in spring also increased the yield significantly. Early emergence of crop produced higher straw and biological yields and plant height in the two sites.

Statistical analysis (T-Test)

Statistical analysis (T-Test) was performed for grain and straw yields of wheat and barley in the two studied sites. Results indicated that there were statistically significant differences between sites on grain per spike (at 1% level) under 50 mm single irrigation at spring time treatment (during heading–flowering stage) of new barley cultivar. There are statistically significant differences on plant height, grain per spike, grain and biological yields (at 1% level) and at on straw (at 5% level) under rainfed condition of new barley cultivar.

Results indicated that there were statistically significant differences between two sites on grain per spike, grain and biological yields (at 1% level) and plant height and straw (at 5% level) under single irrigation (50 mm) at planting time treatment of new wheat cultivar. There are statistically significant differences between plant height (at 1% level) and between straw and biological yields (at 5% level) under single irrigation (50 mm) at spring time treatment (during heading – flowering stage) of new wheat cultivar. Finally, there were statistically significant differences between plant height and grain per spike (at 1% level) under rainfed condition of new wheat cultivar.

Table 1: Amounts of TWP and IWP (kg mm^{-1}) of new wheat cultivar (Azar2) under rainfed and single irrigation treatments at Merek and Honam sites, 2005–06

Honam site				Merek site			
	Grain yield (kg ha^{-1})	TWP (kg/mm)	IWP (kg/mm)		Grain yield (kg ha^{-1})	TWP (kg/mm)	IWP (kg/mm)
Farmer: Moradi				**Farmer: Lotfi**			
SI planting	3004	5.9	15.8	SI planting	3003	4.8	14.5
SI spring	2858	5.6	12.8	SI spring	4007	6.4	34.6
Rainfed	1599	3.5	-	Rainfed	2590	4.5	-
Farmer: Belvasi				**Farmer: Azizi**			
SI spring	3684	7.2	29.4	SI planting	2667	4.3	7.8
Farmer's name:Khosravi				SI spring	3250	5.2	19.4
SI planting	4965	9.7	55	Rainfed	1967	3.4	-
SI spring	3212	6.3	19.9				
Rainfed	2494	5.4	-				-
Farmer: Siyah-poosh							
SI spring	3320	6.5	22.1				
Rainfed	2386	5.2	-				
Avg. rainfed	2216	4.8	-	Avg. rainfed	2279	4	-
Avg. SI planting	4088	8	37.4	Avg. SI planting	2835	4.5	11
Avg. SI Spring	3292	6.5	21.5	Avg. SI Spring	3629	5.8	27

Table 2: Amounts of TWP and IWP (kg mm^{-1}) of new barley cultivar (Sararood1) under rainfed and single irrigation treatments at Merek and Honam sites, 2005–06

Honam site				Merek site			
	Grain yield (kg ha^{-1})	TWP (kg/mm)	IWP (kg/mm)		Grain yield (kg ha^{-1})	TWP (kg/mm)	IWP (kg/mm)
Farmer: P. Moradi				**Farmer: Elahi**			
SI planting	2947	5.8	16.8	SI spring	3107	5	9.4
Rainfed	1961	4.3	-	Rainfed	2600	4.5	-
Farmer: S. Moradi				**Farmer: Karami**			
SI spring	3165	6.5	21.1	SI spring	4000	6.4	27.2
Rainfed	2296	5	-	Rainfed	2767	4.8	-
Farmer: Naderi				**Farmer: Mohammadi**			
SI planting	2978	5.8	17.4	SI spring	3383	5.4	14.9
SI spring	2851	5.6	14.8	Rainfed	2550	4.4	-
Rainfed	2070	4.5	-				
Avg. rainfed	2109	4.6	-	Avg. rainfed	2639	4.6	-
Avg. SI planting	2963	5.8	17.1	Avg. SI Spring	3497	5.6	17.2
Avg. SI Spring	3008	5.9	18				

Table 3: Amounts of TWP and IWP (kg mm^{-1}) of new wheat cultivar (Azar2) under rainfed and single irrigation treatments at Honam site, 2006–07

	Grain yield (kg ha^{-1})	TWP (kg/mm)	IWP (kg/mm)		Grain yield (kg ha^{-1})	TWP (kg/mm)	IWP (kg/mm)
Farmer: Gh. Siyahposh				**Farmer: Akbar. Siyahposh**			
SI planting, first quarter	2950	4.5	5.75	SI planting	3610	5.83	19.2
SI planting, second quarter	2760	4.35	4.15	SI spring	3800	6.14	23
SI planting, third quarter	2600	4.2	2.2	Rainfed	2650	4.66	
SI planting, last quarter	2570	4.2	2	**Farmer: Ali Siyahposh (Rainfed)**			
Rainfed	2490	4.4	-	**Rainfed Azar2**	2630		
Farmer: Karamollahi				**Rainfed Local**	2025		
SI planting	2630	4.25	3.6				
SI spring	2910	4.7	9.2				
Rainfed	2450	4.3					
Farmer: Asadollahi							
SI planting	3950	6.34	29.6	**Avg. rainfed**	2515	4.4	-
SI spring	3580	5.78	22.2	**Avg. SI planting**	3227	5.5	14.24
Rainfed	2470	4.34	-	**Avg. SI Spring**	3430	5.54	18.3

Table 4: Amounts of TWP and IWP (kg mm^{-1}) of new barley cultivar (Sararood1) under rainfed and single irrigation treatments at Honam site, 2006–07

	Grain yield (kg ha^{-1})	TWP (kg/mm)	IWP (kg/mm)		Grain yield (kg ha^{-1})	TWP (kg/mm)	IWP (kg/mm)
Farmer: Sabzevari (Sararood1)				**Farmer: Kherollahi (Local)**			
SI planting	3240	5.23	8.2	SI spring	2860	4.62	11.2
Rainfed	2830	4.97	-	Rainfed	2300	4	-
Farmer: Sabzevari (Local)				**Farmer: Nazari (Rainfed)**			
SI planting	1720	2.78	4.6	Rainfed Sararood1	2930	5.15	
Rainfed	1490	2.62	-	Rainfed Local	2110	3.71	
Farmer: Moradi (Rainfed)							
Rainfed Sararood1	3080	5.41					
Rainfed Local	2380	4.18					

Table 5: Amounts of TWP and IWP (kg mm^{-1}) of new barley cultivar (Sararood1) under rainfed and single irrigation treatments at Merek site, 2006–07

	Grain yield (kg ha^{-1})	TWP (kg/mm)	IWP (kg/mm)		Grain yield (kg ha^{-1})	TWP (kg/mm)	IWP (kg/mm)
Farmer: Lotfi				**Farmer: Mahmoodi**			
SI planting	3000	5.42	6	SI planting	2960	5.3	3.2
SI spring	4400	7.96	34	SI spring	3576	6.46	15.5
SI planting + SI spring	4520	7.49	18.2	SI planting + SI spring	4296	7.1	14.9
Rainfed	2700	5.37	-	Rainfed	2800	5.56	-
Farmer: Hoseini				**Farmer: Mousavi**			
SI planting	2755	4.98	6.3	SI planting	2890	5.2	6.6
SI spring	3495	6.95	21.1	SI spring	3600	6.5	20.8
SI planting + SI spring	3852	6.39	14.1	SI planting + SI spring	3930	6.5	13.7
Rainfed	2440	4.85	-	Rainfed	2560	5.1	-
Avg. rainfed	2625	5.21	-	**Avg. SI Spring**	3768	6.81	22.86
Avg. SI planting	2900	5.24	5.5	**SI Planting + SI spring**	4149	6.88	15.24

Table 6: Amounts of TWP and IWP (kg mm^{-1}) of new wheat cultivar (Azar2) under rainfed and single irrigation treatments at Merek site, 2006-07

	Grain yield (kg ha^{-1})	TWP (kg/mm)	IWP (kg/mm)		Grain yield (kg ha^{-1})	TWP (kg/mm)	IWP (kg/mm)
Farmer: Lotfi				**Farmer: Mahmoodi**			
SI planting	2530	4.57	2.8	SI planting	2600	4.7	6.6
SI spring	3530	6.38	22.8	SI spring	3505	6.34	24.7
SI planting + SI spring	3940	6.5	15.5	SI planting + SI spring	3700	6.1	14.3
Rainfed	2390	4.75	-	Rainfed	2270	4.5	-
Farmer: Hoseini				**Farmer: Mousavi**			
SI planting	2450	4.4	7.4	SI planting	2550	4.6	4
SI spring	3210	5.8	22.6	SI spring	3460	6.2	22.2
SI planting + SI spring	3560	5.9	14.8	SI planting + SI spring	3580	5.9	12.3
Rainfed	2080	4.1	-	Rainfed	2350	4.67	-
Avg. rainfed	2273	4.52	-	**Avg. SI Spring**	3426	6.19	23.1
Avg. SI planting	2533	4.58	5.2	**SI Planting + SI spring**	3695	6.13	14.22

Discussion

Yields of wheat and barley can be substantially increased and stabilized with minimal irrigation and agronomic management practices, with higher yield potential. 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).

SI at sowing was more effective in Honam site and SI at spring (during heading –flowering stage) was more effective in Merek site. It refers to their climate condition, because Honam and Merek sites have a cold and cold-temperate climate, respectively.

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. Additional single irrigation in spring also increased yield significantly.

Early emergence of crop produced higher straw and biological yields and plant height in the two sites.

The most dramatic impact observed in this study was application of single irrigation with new advanced varieties compared with rainfed conditions (Tavakoli 2007). Such yield increase clearly supports the findings of Stewart and Musick (1982), Tavakoli and Oweis (2004) and Oweis et al. (1999) in favor of the potential for conjunctive use of irrigation and rainfall in semi-arid regions.

A research station experiment carried out by Tavakoli (2007) at Maragheh (East Azarbaijan province) located in the northwest of Iran, showed that the rainwater productivity (RWP) of barley varieties varied between 2.77 and 3.04 kg mm^{-1}. In the dry areas, most of the rainwater is lost by evaporation; therefore the rainwater productivity is extremely low. Single irrigation water productivity (IWP) were between 16.56–31 kg mm^{-1} and total water productivity (TWP) was between 5.2–8.1 kg mm^{-1}. The other research station experiment carried out by Tavakoli (2005) at the same place, showed that the rain water productivity (RWP) obtained between 3.08 to 4.32 kg mm^{-1}. Irrigation water productivity (IWP) were between 7.18–23.94 kg mm^{-1} and total water productivity (TWP) was between 3.63–8.52 kg mm^{-1}. The average grain yield of rainfed wheat during two growing seasons under single irrigation (100 mm, early), single irrigation (100 mm, normal), single irrigation (50 mm, late), and rainfed condition for Azar2 wheat variety were 3017, 3232, 2050, and 1404 kg ha^{-1}, respectively.

The strategy of applying restricted amounts of water at critical growth stages, based on available soil moisture, as practiced in this experiment, is the essence of the concept of single irrigation. The high return for limited irrigation water is another advantage of single irrigation. The WP values obtained with SI of over 20 kg mm^{-1} are not attainable in conventional rainfed wheat and barley. Based on water availability, a relatively small amount of irrigation water applied at strategic times could achieve substantial increases in yield and WP of rainfed wheat and barley (Zhang and Oweis, 1999; Tavakoli, 2000, 2003 & 2004).

Of the management parameters, the date of sowing is more problematic under rainfed conditions. In this cold winter environment (such as Honam condition), an adequate plant stand before the dormant frost period (end of November and March) is essential for a high crop yield. 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 (Tavakoli and Oweis, 2004; Oweis and Hachum, 2001; Ilbeyi *et al.,* 2006; Tavakoli, 2004, 2005 & 2007; Tavakoli *et al.,* 2005). 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.
Optimum level of supplemental irrigation for Sabalan wheat cultivar was 1/3 of full supplemental irrigation with 60 kg N ha^{-1} resulted to maximum water productivity (30.1 kg mm^{-1}). In spite of 20% reduction of yield in this treatment, the maximum net benefit was obtained along with probability of 180% cropping area increasing which can lead to 74% increase in total production grain yield. The limit of benefitability for optimum level of supplemental irrigation was determined as 2857 Rial/m^3 water (Tavakoli, 2004).

Supplemental irrigation and single irrigation are a highly efficient practices with great potential for increasing agricultural production and improving livelihoods in the dry rainfed areas (Tavakoli and Oweis, 2004, 2006). The average rainwater productivity of wheat grains in WANA is about 0.35 kg/m^3 (Oweis and Hachum, 2003 and 2004). However, it may increase to as high as 1.0 kg/m^3 with improved management and favorable rainfall distribution. It was found that one cubic meter of water applied as SI at the proper time might produce more than 2.0 kg of wheat grain over that of rainfed (Oweis and Hachum, 2003 & 2004).

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Effect of *Azotobacter* and *Azospirillum* on the Yield of Wheat (*Triticum aestivum L.*) and Barley (*Hordeum vulgare L.*) in Kermanshah and Lorestan, Iran

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Abstract

To reduce farmers' dependency on mineral fertilizers, to increase water use efficiency and to increase households' incomes, participatory on-farm research trials to test the effect of the inoculums of *Azotobacter* and *Azospirillum* on the yields of wheat and barley were conducted in the upper catchments of Karkheh River, Iran, in 2005–06 and 2006–07. In 2005–06, grain yield of inoculated irrigated wheat increased by 11%, while the yields of rain-fed barley increased by 36% compared to the untreated control.

In 2006–07, inoculation of irrigated wheat significantly increased grain yields from 3,656 to 4,536 kg ha^{-1}. The risk for randomly selected farmers not to obtain a determined yield target was always lower for the inoculation treatment than for the control.

Grain yields of inoculated rain-fed wheat increased by 11% on an average. Adaptability analysis revealed that the yield increase was independent from the farmer's location, hence the technology is robust and yield increases remain constant with improved environmental conditions. The probability that the *Azotobacter* treatment outperforms the untreated control at a randomly chosen farming environment in Merek was 73%.

The marginal costs for the inoculation treatment were low and equivalent to about 14 and 27 kg grain ha^{-1} for rain-fed and irrigated wheat or barley, respectively. These preliminary results suggest that inoculation of wheat and barley are low-cost and environmentally friendly options with low agronomic and economic risk for farmers to increase yields, water productivity and income.

Key words: *Azotobacter*, *Azospirillum*, wheat, barley, adaptability analysis, risk assessment

Introduction

The main sources of income in the rural areas of KRB rely on crop production and animal husbandry. Animal production is largely extensive, utilizing common pasture resources in the dry mountains. Crop production is dominated by the cereals wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.). In 2006, the irrigated land comprised only 8% and 24% of the total arable land in Merek, Kermanshah, and Honam, Lorestan, respectively. The total wheat area was 44% in Merek and 49% in Honam. Barley was grown on 9% of the arable land in Merek and on 22% in Honam. The only other crop of importance on both sites is chickpea with 44% in Merek and 18% in Honam. Crop yields are generally low. Mean grain yields of irrigated wheat, rain-fed wheat and rain-fed barley in Honam are 3,750, 1,350 and 1,500 kg ha^{-1}, respectively. In Merek, the situation is similar with average yields of 4,500, 1,500 and 1,200 kg ha^{-1} for irrigated wheat, rain-fed wheat and rain-fed barley, respectively. (Agricultural Research Center Kermanshah, 2007, personal communication; Agricultural Research Center Lorestan, 2007, personal communication). Therefore, any crop improvement will have a substantial impact on farmers' livelihood. At the same time, increased yields would also have a positive impact on a more efficient use of the scarce water resources.

At present, the government in Iran is heavily subsidizing mineral fertilizers for wheat and offers guarantee prices to achieve the national policy on self sufficiency for wheat. Besides environmental concerns of the use of high rates of chemical fertilizers, agricultural subsidies put a high burden on Iran's economy. There is now a shift in that policy towards more market-orientation and there are plans to reduce subsidies on fertilizers. Hence, any technology that could at least partly substitute fertilizer applications would be both helpful for farmers and Iran's economy.

Biofertilizers are inoculums of soil-borne beneficial organisms. The most widely known are *Rhizobium* bacteria, which can fix atmospheric nitrogen and therefore, can substitute nitrogen fertilizers. In Iran, every year some 85 thousand tons of nitrogen fertilizers are applied to legumes which could be substituted with *Rhizobium* biofertilizers to a great extend (Khavazi *et al.,* 2005).

Research on biofertilizers in Iran began in 1995 when the Soil Biology Research Division was added to the Soil and Water Research Institute (Khavazi *et al.,* 2005). Today, emphasis is put on plant growth regulating bacteria, microorganisms that are capable of increasing the rate of plant growth by direct or indirect mechanisms. Secretion of vitamins and amino acids, auxins, and fixing atmospheric nitrogen by *Azotobacter* and *Azospirillum* genus are among the direct mechanisms of increasing root development and plant growth (Radwan, 2002, Khavazi *et al.,* 2005, Akbari *et al.,* 2007). Secretion of siderophores and hydrogen cyanides and antibiotics that control some plant diseases are additional effects of improving the growth rate and yields of plants like wheat and barley (Khavazi *et al.,* 2005). Recent studies have even detected synergistic effects of plant growth promoting rhizobacteria (like *Azospirillum* and *Azotobacter*) and *Rhizobium* on nodulation and nitrogen fixation of legumes (Tilak *et al.,* 2006).

Increased yield and nutrient uptake by the use of biofertilizers in many crops has been documented. Higher nutrient uptake and seed yield in canola (*Brassica napus* L.) was reported by Yasari et al. (2007). Likewise, higher biological yields in wheat and barley after inoculation the seeds with *Azotobacter* and *Azospirillum* was found by Ali et al. (2005). In a subtropical environment in Sikkim, India, *Azotobacter* and *Azospirillum* increased maize yields by 1.15 folds over the control (Pandey *et al.,* 1998).

Yield improvements of more than 20% have been observed for wheat as a result of application of *Azotobacter* and *Azospirillum* inoculums in controlled field trials in Iran (Khavazi *et al.,* 2005). However, farmer-managed on-farm trials are still missing to explore its potential under farmers' conditions. Therefore, the current study aimed to close that knowledge gap by investigating the effect of *Azotobacter* and *Azospirillum* biofertilizer on crop yield and net return in farmer-managed trials at various locations in the upper catchments of KRB.

Materials and Methods

Sites

From 2005 to 2007 farmer-managed on-farm trials were conducted under rain-fed conditions in two pilot sites of the upper Karkheh River in southwest Iran: Merek plain in Kermanshah province is located south-east of Kermanshah city between the White Mountains in the North and the Nesar Mountain in the South (47º04'25" – 47º22'18" E longitude and34º0'38"-34º04'31" latitude) in Kermanshah province. The elevation stretches from 1,440 m to 2,800 m asl. The total area is 24,000 ha.

The main soil orders in Merek are Inceptisols, Entisols and Vertisols. The soil textures are usually very heavy (clay and silty clay) with cubic structures. The mountains and hilly areas contain 25–60% of gravel and rubble-stone. Soil pH is between 7.3 and 7.9 and soil salinity is between 0.4 and 0.8 dS m^{-1}. Organic carbon content ranges from 1–3% and soils contain 17–32% of lime.

The second pilot site, Honam is located in Lorestan province (33º51'50" – 33º44' 51" E longitude, 48º28'42" – 48º12'31" N latitude). The altitude ranges from 1,610 to 3,500 m asl. The total surface area of Honam is 14,200 ha. The main soil orders are Inceptisols besides large areas under rock outcrops (50%). The chosen sites covered a wide range of edaphic and climatic conditions with a single growing season of 8 months. Mean annual rainfall in Honam was 540 and 572 mm in 2005–‘06 and in 2006–‘07, respectively (Fig. 1). In Merek, the annual rainfall during 2006–‘07 was 616 mm.

Selection of farmers and experimental design

All data collection was carried out in the framework of the Livelihood Resilience Project of the CGIAR's Challenge Program for Water and Food. In the first year, the 2005–‘06 season, the farmers were chosen in close collaboration with the local Agricultural Service Centers and the Agricultural Research Institutes.

In 2006–07, the *Azotobacter* experiments were embedded within the new PTD (Participatory Technology Development) subcomponent of the Livelihood Resilience Project. Farmers were no longer pre-selected by the project; rather the farmers could voluntarily opt for one of the technical options offered by the project. After problem analysis, the formation of interest groups and identification of possible solutions, the farmers chose which technology to test according to their own priorities and needs. The data presented here refer only to those who tested *Azotobacter* and *Azospirillum* inoculants on barley or wheat.

Experimental design and treatments

The participatory nature of the research approach required a very simplified experimental design with only one test plot (*Azotobacter* treatment) and one control plot at each farmer's location.

Each farmer was asked to choose a wheat or barley field and to divide it into two parts similar in size, cropping history and

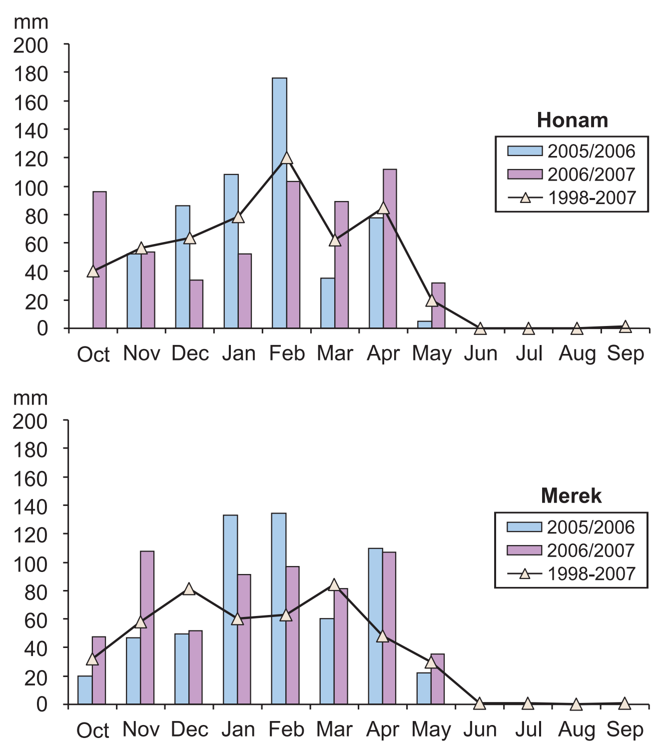

Figure 1. Rainfall distribution in the two sites Honam/Lorestan and Merek/Kermanshah.

average natural productivity. One part served as a control without *Azotobacter* inoculation, and the other part was planted with either wheat or barley seeds inoculated with *Azotobacter* and *Azospirillum*. The biofertilizer, comprising *Azotobacter* and *Azospirillum*, was developed by the Soil and Water Research Institute (SWRI), Tehran and is now manufactured under the brand name "*Nitroxin*" by a private company in Semnan, Iran.

Wheat and barley seeds were inoculated with *Azotobacter* by spraying "*Nitroxin*" over the seeds, which were spread on a plastic sheet just before planting. Seeds were thoroughly mixed by a shovel and after 10 minutes they were ready for sowing. The concentration of added "*Nitroxin*" was 1.5 liter per 100 kg of seeds. The seeds were kept in shade until planting time. Rain-fed crops were planted in November, while the irrigated crops were planted a month earlier.

In the 2005–06 season, six pre-selected farmers in Honam and Merek were cooperating to test the effect of the biofertilizer *Azotobacter* and *Azospirillum* inoculants on irrigated wheat under on-farm conditions. In the same season, four farmers from Honam applied similar treatments on rain-fed barley.

In 2006–07, trials were separately conducted in Merek and in Honam. In Merek, 13 interested farmers opted to test *Azotobacter* inoculants on rain-fed wheat, one farmer on irrigated wheat and one farmer on rain-fed barley. In Honam, 15 farmers tested the inoculants on irrigated wheat, three on rain-fed wheat and three on rain-fed barley.

Management of trial plots

Farmers were allowed to use the cultivar, sowing density, and management practices, such as mineral fertilizer applications and number and type of weeding operations, of their choice provided that both plots were treated the same.

Soils in irrigated wheat were first plowed followed by disk twice, before seeds are sown by machine. The chemical fertilizer application for irrigated wheat and barley were 200 kg ha^{-1} of Triple Super Phosphate (TSP) before plowing and 100 kg ha^{-1} urea applied as side dress in spring.

For rain-fed wheat, the fertilizer rates were 50 kg ha^{-1} TSP before plowing and 50 kg ha^{-1} urea in spring. Other cultural practices are the same as for irrigated wheat, but disking is done only once.

Cultural practices for rain-fed barley, which is usually grown on poor soils in hilly areas, started with broadcasting the seeds followed by shallow plowing (10–15 cm). Mineral fertilizers were not applied.

In both years, local collaborators recorded grain and straw yields at harvest in July for each farmer by taking 10 sub samples, 1.0 m2 in size from both plots. Sub samples were cut at soil surface, threshed separately with a mechanical thresher obtained from the Dryland Agricultural Research Institute (DARI), Kermanshah.

Statistical analysis

The data were analyzed for normal distribution with the Kolmogorov-Smirnov-test. Paired-samples t-tests were performed since both treatments were tested by the same farmer. The standard error of the mean difference (SED) was calculated. Comparison of experimental parameters and their interdependence were computed by regression analyses. The equation of the function is accompanied by the coefficient of determination with the number of asterisks indicating the significance level at $P \leq 0.05$ (*), $P \leq 0.01$ (**) and $P \leq 0.001$ (***).

Adaptability analysis

Where sufficient data were available, the paired data sets were also used to assess the adaptability of the *Azotobacter* treatment to the productivity level of each farmer's location. To this end, for each farm the yield mean (MEAN), defined as [0.5 (YAzo+Yctrl)], was computed as environmental index. The yields of each individual treatment were plotted against the environmental index and linear regressions were calculated. Interpretation of the results followed those described by Hildebrand and Russel (1996).

Risk assessment

Larger data sets were also used to assess the risk of either technology to fall below a critical yield level. Where normality of data was given, the probability that the yield this technology falls below a critical level ë in a randomly chosen environment *j* was calculated by

$$Pr(y_j < \lambda) = \Phi\left[\frac{\lambda - \mu}{\sigma}\right]$$ *(Eskridge, 1990),*

where Φ is the cumulative distribution function of the standard normal distribution, μ is the mean and σ is the standard deviation of the technology.

For a direct comparison of the *Azotobacter* technology with the farmers' practice, the probability of one system outperforming the other one was calculated by:

$$Pr(D_j > 0) = \Phi\left[\frac{\delta}{\sigma_D}\right]$$ *(Eskridge and Mumm, 1992),*

where D_j is the yield difference between the two technologies in a randomly chosen location, Φ is the cumulative distribution function of the standard normal distribution, $\delta = \mu 1 - \mu 2$, $\mu 1$ and $\mu 2$ are the mean yields of the two technologies and σ_D is the standard deviation of the difference D_j.

To estimate the economic risk, the marginal costs and benefits between the two technologies were considered in the analysis. For that reason, the probability to fall below a critical yield difference which needs to be surpassed before one technology becomes economically attractive compared to another was calculated:

$$Pr(y_j < \lambda) = \Phi\left[\frac{\lambda - \mu}{\sigma}\right]$$,

where D_j is the yield difference between the two technologies in a randomly chosen location, λ_D is the critical yield difference, Φ is the cumulative distribution function of the standard normal distribution, μ_D is the mean difference and σ_D is the standard deviation of the difference.

Economic analysis

Economic risk analysis was based on net returns per treatment. Since the main interest was in treatment differences, only the return and cost factors differing among treatments were taken into account. These were: grain yield (kg ha^{-1}); grain price = 2,200 Rials kg^{-1}; *Azotobacter* and *Azospirillum* inoculants (="Nitroxin") price = 18,000 Rials $liters^{-1}$; amount of inoculants = 1.5 liters per 100 kg seeds, seeds rate = 150–200 kg ha^{-1} in rain-fed wheat and barley and 250–400 kg ha^{-1} in irrigated wheat and barley. The additional time required for mixing the inoculants with wheat or barley seeds was negligible and therefore not considered in the analysis.

Results

In the 2005–06 season, *Azotobacter* and *Azospirillum* inoculums increased grain yields of irrigated wheat from 8,346 kg ha^{-1} to 9,265 kg ha^{-1} (Table 2), a difference of 11%. The average net return difference between the *Azotobacter* and the untreated control treatment was 1,940,164 Rials ha^{-1} (±717,782 Rials).

Table 1. Initial soil chemical and physical properties at 0–0.3 m depth taken at ten farmers' fields in Merek and Honam (± standard errors)

	Honam	Merek
Organic C (%)	1.1 ± 0.1	1.1 ± 0.1
N (%)	0.1 ± 0.01	0.1 ± 0.01
P (mg kg^{-1})	14.6 ± 1.1	9.1 ± 1.17
K (mg kg^{-1})	418.5 ± 28.2	324.7 ± 24.6
Calcium carbonate (%)	30.0 ± 1.3	33.0 ± 1.55
Saturation percentage (%)	47.3 ± 0.8	38.4 ± 1.4
pH	7.45 ± 0.05	7.51 ± 0.03
ECe (dS m^{-1})	0.66 ± 0.06	0.71 ± 0.08
Clay (%)	45.5 ± 0.6	35.8 ± 1.9
Silt (%)	43.7 ± 1.7	43.0 ± 2.0
Sand (%)	10.8 ± 2.0	21.3 ± 3.5
Texture	SiCl	SiCl

Table 2. Wheat and barley yield (kg ha^{-1}) as affected by Azotobacter treatment in 2005/2006 in Honam.

	Irrigated wheat (N = 6)			Rainfed barley (N = 4)		
	Grain	Straw	HI	Grain	Straw	HI
Azotobacter	9,265	13,715	0.41	3197	3460	0.47
Control	8,346	10,928	0.43	2356	2949	0.44
S.E.D.	326 **	1,400 ns	0.02 ns	172 *	309 ns	0.04 ns

S.E.D is the standard error of the mean difference; probability level of significance: (*) $p < 0.05$, (**) $p < 0.01$; (***) $p < 0.001$, (ns) not significant, $p \geq 0.05$; Grain and straw presented as kg ha^{-1}; HI = harvest index

In the same season, rain-fed barley yields increased by 36% from 2,356 to 3,197 kg ha^{-1} when seeds were inoculated with *Azotobacter*. The average net return difference between the two treatments was 1,803,867 Rials ha^{-1} (±378,470 Rials).

In 2006–07, the *Azotobacter* treatment increased grain yields of irrigated wheat from 3,656 to 4,536 kg ha^{-1} in Honam. (Table 3). The adaptability analysis revealed that yield differences varied among locations and significantly increased with improved productivity levels (environmental index) of the farm site (Fig. 2). Hence, there was an above-average yield response with higher environmental index. The risk analysis discovered that regardless the critical yield of choice, it was always more likely to achieve that yield level with the *Azotobacter* treatment than with the control (Fig. 3). For instance, there was a 71% risk for the control to fall below a yield level of 4,000 kg ha^{-1} while the corresponding risk for the *Azotobacter* treatment was only 30%. Comparing the two treatments with each other, there was only a 13% risk that the *Azotobacter* was outperformed by the control treatment, if grain yield was the parameter.

Table 3. Wheat and barley yield components as affected by Azotobacter treatment in 2006/2007 in Honam.

	Irrigated wheat (N = 15)			Rain-fed wheat (N = 3)			Rain-fed barley (N = 3)		
	Grain	Straw	HI	Grain	Straw	HI	Grain	Straw	HI
Azotobacter	4,536	5,173	0.32	2355	6225	0.27	2726	4090	0.40
Control	3,656	4,844	0.30	1927	5544	0.26	1359	1519	0.47
S.E.D.	196 ***	220 ns	0.01 *	213 ns	165 *	0.02 ns	460 ns	801 ns	0.02 ns

S.E.D is the standard error of the mean difference; probability level of significance: (*) $p < 0.05$, (**) $p < 0.01$; (***) $p < 0.001$, (ns) not significant, $p \geq 0.05$; Grain and straw presented as kg ha^{-1}; HI = harvest index

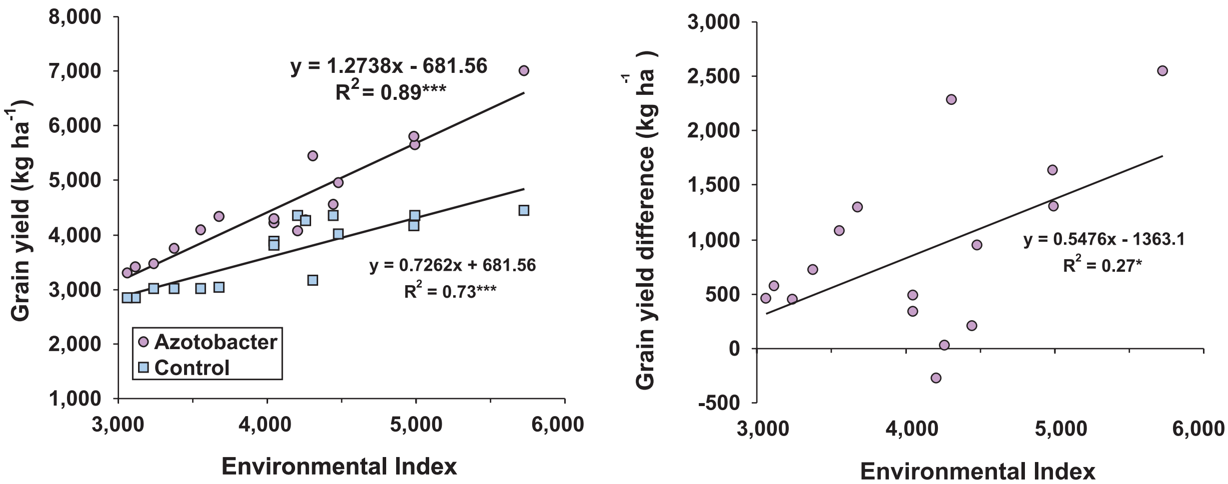

Figure 2. Adaptability of irrigated wheat inoculated with Azotobacter and Azospirillum and of untreated wheat to the environmental index in Honam 2006/2007.

The average net return increased by 1,847,838 Rials ha-1 (±430,224 Rials). The net return increase was also positively correlated with the environmental index (R2 = 0.27, P<0.05). The marginal costs for the *Azotobacter* application in irrigated wheat were equivalent to only 40 kg of grain per hectare. The economic risk of *Azotobacter* application to be outperformed by the control was only 14% and therefore similarly low as the agronomic risk.

The inoculants also increased grain yields of rain-fed wheat and barley in the same year (Table 3), but due to the high variability between sites and the low number of participating farmers the high differences were not significant. However, yield increases were detected at all farming locations and in rain-fed barley, yields even doubled as affected by *Azotobacter* inoculation. The marginal costs for the *Azotobacter* application in rain-fed wheat or barley were equivalent to only 21 kg of grain per hectare. The net return difference between *Azotobacter* treated rain-fed wheat and the untreated control and between rain-fed barley and its control was 892,883 Rials ha-1 (±469,216 Rials) and 2,959,417 Rials ha-1 (±1,012,893 Rials), respectively.

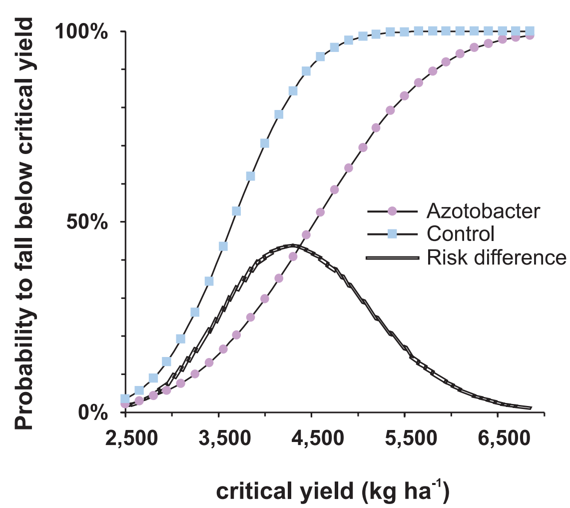

Figure 3. Probability of irrigated wheat inoculated with Azotobacter and Azospirillum to fall below the untreated control treatment in Honam 2006/2007.

Table 4. Rain-fed wheat yield components as affected by Azotobacter treatment in 2006/2007 in Merek (N = 13)

	Grain (kg ha^{-1})	Straw (kg ha^{-1})	HI
Azotobacter	1457	4260	0.25
Control	1314	4418	0.23
S.E.D.	65 *	139 ns	0.01 ns

S.E.D is the standard error of the mean difference; probability level of significance:
(*) $p < 0.05$, (**) $p < 0.01$; (***) $p < 0.001$, (ns) not significant, $p \geq 0.05$

In Merek, where the inoculants were tested for the first time during the 2006–07 season, *Azotobacter* treated rain-fed wheat yields increased on average moderately from 1,314 kg ha^{-1} to 1,457 kg ha^{-1}. Moreover, the adaptability analysis showed similar yield increases regardless the environmental index (Fig. 4). The probability to fall below a critical yield level was always higher for the control treatment than for the *Azotobacter* treatment but the risk difference between the two treatments was never higher than 15% (Fig. 5). Moreover, there was a 27 and 30% risk of the *Azotobacter* treatment to be outperformed by the control treatment, respectively when yield and net return was the criterion. The average net return difference between the *Azotobacter* and the control treatment was only 267,237 Rials ha^{-1} (±144,052 Rials)

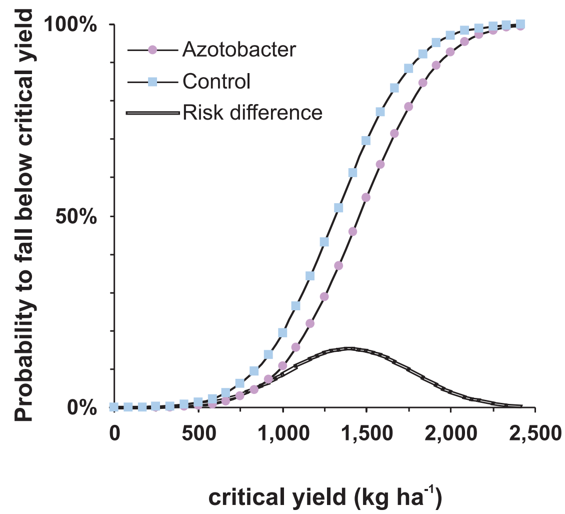

Figure 5. Probability of rain-fed wheat inoculated with Azotobacter and Azospirillum to fall below the untreated control treatment in Merek 2006/2007.

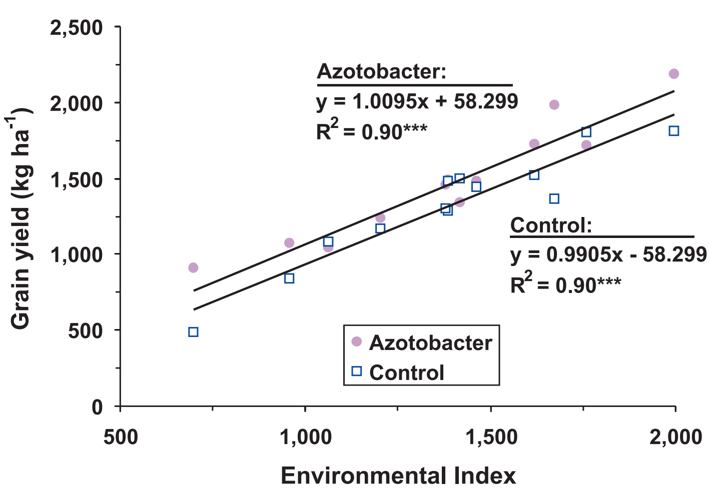

Figure 4. Adaptability of rain-fed wheat inoculated with Azotobacter and Azospirillum and of untreated wheat to the environmental index in Merek 2006/2007.

Discussion

The biofertilizers *Azotobacter* and *Azospirillum* significantly increased wheat and barley yields in both years and in irrigated land as well as in rain-fed crops. The adaptability of *Azotobacter* to harsh, dry environments is well documented. Hamdi et al. (1978) in Iraq, Mahmoud et al. (1978) in Egypt and Ahmed and Sahi (1979) in India have reported wide ecological distributions of *Azotobacter* spp. in arid and semiarid soils. Some species of *Azotobacter* are reported to withstand harsh habitats of salt, high pH levels and drought conditions (Fuller and Hanks, 1982), hence they are well adapted to the environmental conditions of dry mountains in Iran.

The Merek experiment in 2006–07 showed that the biofertilizers significantly increased rain-fed wheat yields and the increase was independent from the environmental index, hence regardless the productivity level at a given farmer location such an increase can be expected. The situation in Honam was different. Although the inoculation treatment increased irrigated wheat yields on average by 24% the obtained difference depended on the farmer's location. With increasing environmental index, the yield difference between the two treatments also increased, while in poorer environments the difference diminished. Environmental factors such as low winter temperatures prevailing in upper Karkheh may have had an influence. Seed inoculation did not result in improvement of plant performance at a temperate location in Sikkim, India, which was suggested to be due to the inability of the introduced bacteria to establish or survive at lower temperatures (Pandey *et al.,* 1998). The effect of low temperature on survival rates of *Azotobacter* and *Azospirillum* may have further consequences. While in warmer climates the level of inoculants might be maintained in the soil (Narula *et al.,* 2005), in cooler climates like upper Karkheh, an annual re-application of the inoculants is recommended. However, given the low costs for the biofertilizer this does not pose a serious obstacle to the viability of the technology.

The environmental conditions with respect to soils, elevations and slopes in the Merek watershed, which comprises a long and wide even valley, are more homogeneous which accounts for the lower variability of the yield difference between *Azotobacter* inoculated and untreated wheat (De Pauw *et al.,* 2007). In contrast, the Honam watershed is more diverse, which explains the significant farmers' fields effect.
Yield increases with the biofertilizer inoculation was within the expected range. In a greenhouse experiment, *Azotobacter chroococcum* increased wheat grain yields by 12.6 to 14.0% at N fertilizer rates of 60 to 120 kg ha^{-1} (Kumar *et al.,* 2001). In on-station field experiments in Iran, yield improvements of more than 20% have been obtained for wheat as a result of *Azotobacter* and *Azospirillum* inoculation. In this study, grain yields Narula et al. (2005) observed a net saving of 25–30 kg nitrogen by using *Azotobacter* inoculants for wheat.

The effect of the inoculants on wheat was less pronounced than the effect on barley. In 2005–06, the biofertilizer treatment increased irrigated grain yields by 11% in Honam, while the yields of rain-fed barley increased by 36%. In the following year, grain yields of irrigated wheat increased by 24%, while rain-fed barley yields doubled. These differences in response are suggested to be an effect of the fertility level of the soils and the fertilizer application. Wheat, and in particular irrigated wheat, is grown on the most fertile soils and receives the highest amounts of mineral fertilizers. On the contrary, rain-fed barley is grown on the most marginal soils with low inherent fertility, on gravel-rich hilly land, and receives little attention and no mineral fertilizers. This observation is supported by a pot experiment conducted by Rai and Gaur (1988) who detected a significant interaction between the inoculants and N-fertilizer rate on N uptake and yield of wheat. The effect of *Azotobacter* and *Azospirillum* on grain yield and N uptake was most pronounced without fertilizer application (+57% and +94%, respectively), but the effect gradually declined with increasing amounts of N application up to 120 kg N ha^{-1} where no differences could be observed. Highest biological yields for *Azotobacter* and *Azospirillum* inoculated wheat and barley were recorded at moderate fertilizer doses in greenhouse and field trials in Northern Sinai (Ali *et al.,* 2005). The stronger effect of the biofertilizer on barley compared to wheat is especially important for poorer households, who often have no access to the more fertile soils in the center of the valley and to irrigated land.

Inoculation of wheat and barley seeds with *Azotobacter* and *Azospirillum* was also a very suitable entry-point technology for the PTD approach of the project. The technology is relatively simple and easy to apply for farmers; it is cheap; and it does not require major changes of the farming system or the management practices. Over a wide range of farming environments, it proved to be superior compared to the common farmers' practice and it poses a low economic risk of failure. The increasing number of farmers asking for the technology proves the suitability for farming households in the upper catchments of Karkeh River Basin in Iran. After building up trust with the local communities and participating farmers, farmers may hesitate less to experiment with more complex options offered to them. In 2007, the Extension Department at the national level has launched a large program to disseminate the technology beyond the two pilot sites.

Conclusion

Azotobacter and *Azospirillium* inoculants are well adapted technologies to dry mountainous areas of KRB. The biofertilizers significantly increased wheat and barley yields and net returns. Moreover, there was a low economic risk for the *Azotobacter* treatment to be outperformed by the control treatment. The technology is also cheap, easy to handle, does not change major parts of the farming and cropping system and is easily available. Therefore, it can serve as one strategic component of farmers to cope with the harsh environments and to increase livelihood resilience in upper KRB.

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Study of Agronomic Characters and Adaptability of Kabuli Chickpea Lines at Farmers' Fields in Upper KRB

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Abstract

Rainfed crop in Iran, after wheat and barley. The average chickpea productivity in Iran is 400 kg/ha, which is less than half of the world average. One of the major reasons for low productivity in Iran is the use of local varieties, which have low yield potential and are susceptible to biotic and abiotic stresses and inappropriate sowing practices (broadcasting and spring sowing). Thus, there is a need for testing improved chickpea varieties with associated improved crop management practices in farmers' fields with farmers' participatory evaluation. The objective of this study was to compare 21 promising chickpea lines that are resistant to *Ascochyta* blight, resistant to cold, have early maturity (drought escape) and erect growth habit (suitable for mechanical harvest) and high yield. The experiments were conducted in Merek and Honam watersheds in the upper KRB in a randomized complete block design (RCBD) with four replications in each field during 2005–06 and 2006–07. The following data were recorded: days to 50% flowering and maturity, reaction to *Ascochyta* blight and *Fusarium* wilt diseases, number of pods per plant, height of the lowest pod, plant height, 100 seed weight, and seed yield. The results of a combined analysis of variance in Kermanshah for autumn and spring planting showed that there was a significant difference among the genotypes based on the mean of grain yield, stability parameters and seed size. Genotype X96TH3K4 for autumn planting and ILC1799 and ILC 3221 for spring planting were found the most desirable genotypes in Merek. Overall, based on the mean of grain yield, seed size and plant height, genotype FLIP 99–59 was found the most desirable genotype for both autumn and spring planting in Honam.

Key words: Chickpea, grain yield, autumn sowing, spring sowing

Introduction

Legumes are important for the sustainable production of food and feed in Iran. They are a valuable source of good quality protein in the diets of people and are valuable as animal feed. Legumes also increase and sustain the productivity of soil and in rotation with cereals reduce chances of build-up of diseases, insect-pests and obnoxious weeds for the following cereal crops (Sabaghpour, 2006). Chickpea is grown on 700,000 hectares in Iran, which ranks fourth in the world after India, Pakistan and Turkey in chickpea cultivation. The average chickpea productivity in Iran is 400 kg/ha. Most of the farmers grow chickpea on marginal area in spring (Sabaghpour, 2004). The majority of the chickpea area (95%) is under rainfed conditions. The yield of rainfed chickpea is about 34% less than that of irrigated chickpea. This indicates that improvement of moisture conservation in rainfed areas may improve the rainfed chickpea yield. Chickpeas frequently suffer from drought stress towards the end of growing season, i.e., during flowering, pod setting and seed formation. Drought is often accompanied by heat stress in rainfed conditions (Sabaghpour *et al*., 2006a). Singh and Hawtin (1979) reported that winter-sown chickpea gave higher seed yield than the traditional spring-sown chickpea. Saxena (1980) studied the effect of successive delay in date of sowing from autumn, through winter, spring; and reported a linear reduction in the yield as sowing was delayed. The results of previous experiments in research stations in Kermanshah and Lorestan showed that autumn planting had 72–79% higher yield than spring planting due to high water use efficiency (Sabaghpour, 2004).

Crop performance depends on the genotype, environment and the interaction between genotype and environment. Plant breeders aim to select genotypes with stable and high performing phenotypes across environments. However, the environment as well as the genotype × environment (G×E) interaction affect the phenotype of cultivars and breeding lines, especially if the target environments are not similar. This interaction also reduces the association between phenotypes and genotypes, thus, genotypes selected in one environment may exhibit a poor performance in another environment (Romagosa and Fox, 1993).

Identification of stable genotypes which show the least G×E interaction is an important consideration in sites where environmental fluctuations are noticeable. The G×E interaction is a major problem when comparing the performance of genotypes across environments. This interaction occurs when the performance of the genotypes is not consistent from one environment to another and complicates the selection and/or recommendation of genotypes. Stability of yield refers to the ability of a genotype to avoid substantial fluctuations in yield over a range of environments (Heinrich et al., 1983).

Various statistical methods such as Wrecker's ecovalence, Shokla's stability variance, and simultaneous selection for yield and stability have been developed for the analysis of G×E interaction (Kang, 1993). The objective of this study was to select varieties with high potential yield along with stable yield for autumn and spring planting in KRB under dryland conditions.

Materials and Methods

The experiments were conducted in two years, 2005–06 and 2006–07, using a randomized complete block design with four replications, at two sites in Merek (Kermanshah province) and Honam, (Lorestan province) in autumn and spring. The experimental material comprised 20 lines, tested at two locations in Merek, and 18 lines tested in one location in Honam, along with local checks. These genotypes were developed by various breeders at different research institutes and stations in Iran and at the International Center for Agricultural Research in the Dry Areas (ICARDA) in Syria. The genotypes were planted in four rows of 4 m length with a spacing of 30 cm between rows and 7 cm between plants within a row, in each plot. Appropriate pesticide was used to control pests. Fertilizers were applied prior to plowing at the recommended rates of 20 and 30 kg ha^{-1} for N and P_2O_5, respectively. Days to 50% flowering, days to maturity, plant height, *Ascochyta* blight disease, plant type, 100-seed weight and seed yield were recorded during the cropping season. Pooled analysis was done for two year in each site. Stability analysis was done by simultaneous selection for yield and stability.

Results and Discussion

The results of the combined analysis of variance in Kermanshah for autumn planting showed that there was no significant difference between years and locations. Also, year × location and genotypes × location interactions were not significant. The results showed that genotypes × year and year × location × genotypes were significant at 5% and 1% level of probability (Table 1). Significant differences were also found among the genotypes. The genotypes SEL95TH1716, X96TH3K4 and FLIP98–22, with 1138, 1077 and 1013 kg ha^{-1}, produced significantly higher yield than the local variety at 1% level of probability (Table 1 and 2). Results of the stability analysis on grain yield using simultaneous selection for yield and stability, showed that X96TH3K4, SEL93TH24460, FLIP99–58 and SEL95TH1716 were the most stable genotypes (Table 3). Overall, based on the mean of grain yield, stability parameters and seed size genotype X96TH3K4 was found the most desirable genotype.

The results of the combined analysis of variance in Kermanshah for spring planting showed no significant difference between years and locations. Also, interaction year

× location and genotypes × location were not significant. The results showed that genotypes × year and year × location × genotypes were significant at 1% level of probability (Table 4). Significant difference was found among the genotypes. The genotypes ILC1799, ILC3221 and ILC 1306 with 1032, 920 and 864 kg ha^{-1} produced higher yield than the local variety (Table 4 and 5). The local check (Bivanij) produced 804 kg ha^{-1}**.** Results of the stability analysis on grain yield using simultaneous selection for yield and stability, showed that X96TH3K4, ILC1799, and ILC 3221 were the most stable genotypes (Table 6). Overall, based on the mean of grain yield, stability parameters and seed size, genotype X96TH3K4 was found the most desirable genotypes. Overall, based on the mean of grain yield, stability parameters and seed size genotypes ILC1799, and ILC 3221 was found as a desirable genotypes. Ebadi *et al* (2007) tested 17 chickpea genotypes at six different research stations for two years in Iran. They reported that FLIP 94–123C was the most stable genotype.

Table 1. Combined analysis of variance of grain yield of chickpea lines under autumn planting during the 2005–07 cropping seasons in Merek.

Source of variation	Degrees of freedom	Mean square	F
Location	1	1598663	2.25 ns
Year	1	4434232	6.2 ns
Location × Year	1	710354	3.3 ns
Rep (Location × Year)	12	215957	
Genotype	20	353042	3.05**
Genotype × Year	20	100159	2.2*
Genotype × Location	20	85127	1.88 ns
Genotype × Year × Location	20	45369	4.98**
Error	240	9106	
Total	335		

ns, * and **: non significant and significant at 5% and 1% probability levels, respectively

Table 2. Agronomic characteristics of chickpea lines (means) under autumn planting during the 2005–07 cropping seasons in Merek.

No	Genotype	Origin	PT	PH	100 SW	AB	Yield (kg ha^{-1})	Check %	Class
1	FLIP 97-78	ICARDA	E	32	38	3	802	119	C
2	FLIP 97-102	ICARDA	E	36	36	3	903	135	C
3	FLIP 97-211	ICARDA	E	37	33	3	845	126	C
4	X95TH5K10	ICARDA	E	36	34	3	835	124	C
5	FLIP 99-59	ICARDA	E	34	32	3	820	122	C
6	FLIP 98-55	ICARDA	E	38	34	3	868	129	C
7	X94TH174K6	ICARDA	E	42	34	3	852	127	C
8	FLIP99-58	ICARDA	E	40	29	3	870	130	C
9	FLIP98-22	ICARDA	E	35	29	3	1013	151	A
10	FLIP 98-131	ICARDA	E	39	33	3	847	126	C
11	X96TH3K4	ICARDA	E	35	32	3	1077	160	A
12	FLIP 97-50	ICARDA	E	33	33	3	828	123	C
13	ILC1799	ICARDA	E	24	36	3	627	94	C
14	ILC1306	ICARDA	E	28	34	3	861	128	C
15	ILC 3221	ICARDA	E	23	34	3	788	117	C
16	SEL93TH24460	ICARDA	E	31	25	3	956	142	C
17	SEL95TH1716	ICARDA	E	33	24	3	1138	170	A
18	SEL93TH24469	ICARDA	E	30	25	3	881	131	C
19	Arman	Iran	E	36	28	3	750	112	C
20	Hashem	Iran	E	40	27	3	710	106	C
21	Bivanij	Iran	SE	25	44	3	672	100	C

PT: Plant type, PH: Plant height, 100 SW: hundred seed weight, AB: Ascochyta blight, Check: yield as % of local check (Bivanij), E: Erect, SE: Semi-erect; C , B and A: non significant and significant for higher yield than check at 5% and 1% probability levels, respectively; LSD0.05 = 261.9 (kg ha^{-1}); LSD0.01 = 346.8 (kg ha^{-1})

Table 3. Stability indices and Ysi for simultaneous selection for yield and stability of chickpea genotypes under autumn planting during the 2005–07 cropping seasons in Merek.

Gen. No.	Yield (kg ha^{-1})	Yield rank (Ý)	Adjustment to Ý	Adjusted (Ý)	Wi^2	Stability variance (σi^2)	Stability rating	Ysi
1	802	6	+1	7	9273	2404	0	7
2	903	17	+2	19	96516	33734	-8	11
3	845	10	+1	11	6510	1332	0	11
4	835	9	+1	10	70863	24499	-8	2
5	820	7	+1	8	26352	8475	-4	4
6	868	14	+1	15	28845	9372	-8	7
7	852	12	+1	13	108456	38032	-8	14
8	870	15	+1	16	8967	2216	0	16
9	1013	19	+2	21	103131	36115	-8	13
10	847	11	+1	12	90147	31441	-8	4
11	1077	20	+2	22	2088	260	0	22
12	828	8	+1	9	4635	657	0	9
13	627	1	-1	0	71727	24810	-8	-8
14	861	13	+1	14	18342	5591	-2	12
15	788	5	+1	6	27993	9065	-4	2
16	956	18	+2	20	15003	4389	0	20
17	1138	21	+2	23	71154	24603	-8	15
18	881	16	+1	17	54870	18741	-8	9
19	750	4	+1	5	172050	60926	-8	-3
20	710	3	+1	4	2520	105	0	4
21	672	2	0	4	163833	57968	-8	-4

Mean of check =672 (kg ha^{-1}); LSD0.05 =217.5 (kg ha^{-1}); LSD0.01 =291(kg ha^{-1}); Mean YSi value = +7.95

Table 4. Combined analysis of variance of grain yield of chickpea lines under spring planting during the 2005–07 cropping seasons in Merek.

Source of variation	Degrees of freedom	Mean square	F
Location	1	238324	7.76 ns
Year	1	236501	7.7 ns
Location × Year	1	30694	0.93 ns
Rep (location × Year)	12	32944	
Genotype	20	1559109	9.53**
Genotype × Year	20	46873	12**
Genotype × Location	20	128505	1.1 ns
Genotype × Year × Location	20	112467	5.65**
Error	240	19903	
Total	335		

ns, * and **: non significant and significant at 5% and 1% probability levels, respectively

Table 5. Agronomic characteristics of chickpea genotypes (mean) under spring planting during the 2005–07 cropping seasons in Merek.

No	Genotype	Origin	PT	DM	PH	100 sw	AB	Yield (kg ha^{-1})	Check %	Class
1	FLIP 97-78	ICARDA	E	93	26	35	3	205	25	C
2	FLIP 97-102	ICARDA	E	95	27	28	3	118	15	D
3	FLIP 97-211	ICARDA	E	93	29	32	3	214	27	C
4	X95TH5K10	ICARDA	E	94	32	31	3	182	23	C
5	FLIP 99-59	ICARDA	E	95	28	35	3	223	28	C
6	FLIP 98-55	ICARDA	E	93	33	39	3	325	40	C
7	X94TH174K6	ICARDA	E	98	33	33	3	195	24	C
8	FLIP99-58	ICARDA	E	100	31	30	3	87	11	D
9	FLIP98-22	ICARDA	E	91	29	30	3	698	86	C
10	FLIP 98-131	ICARDA	E	93	25	38	3	217	27	C
11	X96TH3K4	ICARDA	E	93	28	30	3	519	64	C
12	FLIP 97-50	ICARDA	E	94	28	31	3	174	22	C
13	ILC1799	ICARDA	E	90	26	33	3	1032	128	C
14	ILC1306	ICARDA	E	91	23	34	3	864	107	C
15	ILC 3221	ICARDA	E	91	26	34	3	920	114	C
16	SEL93TH24460	ICARDA	E	96	30	25	3	34	4	D
17	SEL95TH1716	ICARDA	E	93	26	24	3	369	46	C
18	SEL93TH24469	ICARDA	E	97	30	24	3	63	8	D
19	Arman	Iran	E	94	33	32	3	314	39	C
20	Hashem	Iran	E	95	35	30	3	66	8	D
21	Bivanij	Iran	SE	92	27	36	3	804	100	C

PT: Plant type, DM: days to maturity, PH: Plant height, 100 SW: hundred seed weight, AB: *Ascochyta* blight, Check: yield as % of local check (Bivanij), E: Erect, SE: Semi-erect; C and D : Non significant and significant for lower yield than check at 5% probability levels; LSD0.05 = 261.9 (kg ha^{-1}); LSD0.01 = 346.8 (kg ha^{-1})

Table 6. Stability indices and ysi for simultaneous selection for yield and stability of chickpea genotypes under spring planting during the 2005–07 cropping seasons in Merek.

Gen. No.	Yield (kg ha^{-1})	Yield rank (Ý)	Adjustment to Ý	Adjusted (Ý)	Wi^2	Stability variance (σi^2)	Stability rating	Ysi
1	205	9	-1	8	21207	6622	0	8
2	118	5	-2	3	45615	15653	-4	-1
3	215	10	-1	9	38124	12881	-2	7
4	182	7	-1	6	51258	17740	-4	2
5	223	12	-1	11	7548	1568	0	11
6	325	14	-1	13	6396	1142	0	13
7	195	8	-1	7	74352	26285	-8	-1
8	89	4	-2	2	41031	13956	-4	-2
9	697	17	-1	16	90006	32077	-8	8
10	217	11	-1	10	11106	2884	0	10
11	519	16	-1	15	88837	5745	0	15
12	174	6	-1	5	7539	1564	0	5
13	1032	21	+1	22	187311	68080	-8	14
14	864	19	+1	20	142527	51510	-8	12
15	920	20	+1	21	292590	107033	-8	13
16	33	1	-2	-1	9168	2167	0	-1
17	369	15	-1	13	47649	16405	-4	9
18	63	2	-2	0	2001	485	0	0
19	314	13	-1	11	44478	15232	-4	7
20	66	3	-2	1	21591	6764	0	1
21	804	18	0	18	236481	86273	-8	10

Mean of check (kg ha^{-1}); LSD0.05 = (kg ha^{-1}); LSD0.01 = (kg ha^{-1}); Mean YSi value = +7.95

In Lorestan, the result of the pooled analysis of variance for autumn planting showed that the difference between years was significant at 1% level of probability. The results also showed that interaction of genotypes × year was significant. The results of combined analysis showed no difference between yield of lines (Table 7). The comparison of mean productivity by Duncan's Multiple Rank Test showed that Genotype FLIP 99–59 produced the highest yield and significantly higher yield than FLIP 99–58 at 5% level of probability. Three lines, i.e., FLIP 99–59, SEL95TH1716 and FLIP97–78 with 1266, 1162 and 1154 kg ha^{-1} produced 152, 140 and 138% higher yield than the local variety, respectively. Local check (Greet) produced 833 kg ha^{-1}. Overall, based on the mean of grain yield, seed size and height, genotype FLIP 99–59 was found the most desirable genotype (Table 8).

Table 7. Combined analysis of variance of chickpea grain yield under autumn planting during the 2005–07 cropping seasons in Honam.

Source of variation	Degrees of freedom	Mean square	F
Year	1	1769786	169 **
Error1	4	10545	
Genotype	18	164390	0.89 ns
Genotype × Year	18	184559	3.67**
Error 2	72	50227	
Total	113		

ns, * and **: non significant and significant at 5% and 1% probability levels, respectively

Table 8. Agronomic characteristics of chickpea varieties (mean) under autumn planting during the 2005–07 cropping seasons in Honam.

No	Genotype	Origin	DF	PT	DM	PH	100 sw	AB	Yield (kg ha^{-1})	Check%	Class
1	FLIP 99-58	ICARDA	146	E	186	37	31	1	626	76	C
2	FLIP97-211	ICARDA	155	E	194	32	30	1	812	97	ABC
3	FLIP 98-55	ICARDA	149	E	190	34	35	1	1063	128	ABC
4	X95TH5K10	ICARDA	145	E	192	35	27	1	866	104	ABC
5	X96TH3K4	ICARDA	146	E	189	35	27	1	1038	125	ABC
6	FLIP 99-59	ICARDA	147	E	193	41	35	1	1266	152	A
7	FLIP97-50	ICARDA	142	E	191	34	27	1	1016	122	ABC
8	X94TH174K6	ICARDA	155	E	191	34	28	1	819	98	ABC
9	FLIP 98-22	ICARDA	154	E	188	29	26	1	953	114	ABC
10	SEL93TH24460	ICARDA	149	E	198	30	30	1	1072	129	ABC
11	FLIP97-102	ICARDA	149	E	194	36	28	1	1011	121	ABC
12	Bivanij	Iran	145	SE	186	30	31	3	790	95	ABC
13	Arman	Iran	150	E	196	34	28	1	1115	134	ABC
14	FLIP97-131	ICARDA	153	E	192	30	29	1	726	87	BC
15	FLIP97-78	ICARDA	144	E	196	34	27	1	1154	138	ABC
16	SEL95TH1716	ICARDA	149	E	186	29	26	1	1163	140	AB
17	Hashem	Iran	149	E	197	37	28	1	929	111	ABC
18	SEL93TH24469	ICARDA	146	E	201	37	25	1	1033	124	ABC
19	Greet	Iran	147	SE	182	28	33	3	823	100	ABC

PT: Plant type, DM: days to maturity, PH: Plant height, 100 SW: hundred seed weight, AB: Ascochyta blight, Check: yield as % of local check (Bivanij), Class: indicates significant differences at the 5% level, E: Erect, SE: Semi-erect.

The result of pooled analysis for spring planting in Lorestan showed that the difference between years was significant at 1% level of probability. The results showed that interaction of genotypes × year was significant. The results of combined analysis showed no difference between yield of lines (Table 9). The comparison of mean productivity by Duncan's Multiple Rank Test showed that Genotype FLIP 97–50 produced the highest yield and significantly higher yield than FLIP 99–58, at 5% level of probability. Three lines such as FLIP 97–50, FLIP97–78 and FLIP 99–59, with 826, 734 and 689 kg ha^{-1}, produced 151, 134 and 126% higher yield than the local variety, respectively. Local check (Greet) produced 547 kg ha^{-1}. FLIP 99–59, due to seed size and mean of grain yield, was the most desirable genotype (Table 10). Also, this line was a suitable genotype for autumn planting. The chickpea varieties Hashem (Sabaghpour *et al*., 2005) and Arman (Sabaghpour *et al*., 2006b) had high potential yield, were resistant to *Ascochyta* blight disease and had an erect growth habit suitable for mechanical harvesting. These varieties have been released for autumn planting in Iran in areas with moderate climate.

Table 9. Combined analysis of variance of chickpea grain yield under autumn planting during the 2005–07 cropping seasons in Honam.

Source of variance	Degrees of freedom	Mean square	F
Year	1	9245502	1048 **
Error1	4	8813	
Genotype	18	82035	1.5 ns
Genotype × Year	18	54628	4.62 **
Error 2	72	11815	
Total	113		

ns, * and **: non significant and significant at 5% and 1% probability levels, respectively

Table 10. Agronomic characteristics of chickpea genotypes (mean) under spring planting during the 2005–07 cropping seasons in Honam.

No	Genotype	Origin	DF	PT	DM	PH	100 sw	AB	Yield (kg ha^{-1})	Check%	Class
1	FLIP 99-58	ICARDA	88	E	120	34	34	1	342	63	C
2	FLIP97-211	ICARDA	88	E	118	33	34	1	497	91	ABC
3	FLIP 98-55	ICARDA	90	E	114	34	27	1	573	105	ABC
4	X95TH5K10	ICARDA	87	E	116	28	33	1	589	108	ABC
5	X96TH3K4	ICARDA	86	E	113	29	30	1	582	107	ABC
6	FLIP 99-59	ICARDA	89	E	117	40	28	1	689	126	AB
7	FLIP97-50	ICARDA	89	E	115	35	27	1	826	151	A
8	X94TH174K6	ICARDA	90	E	115	34	34	1	554	101	ABC
9	FLIP 98-22	ICARDA	91	E	112	37	29	1	689	126	AB
10	SEL93TH24460	ICARDA	91	E	118	34	29	1	470	86	BC
11	FLIP97-102	ICARDA	88	E	118	37	31	1	511	94	ABC
12	Bivanij	Iran	86	SE	114	32	32	3	595	109	ABC
13	Arman	Iran	85	E	115	29	30	1	671	123	ABC
14	FLIP97-131	ICARDA	88	E	116	39	28	1	488	89	BC
15	FLIP97-78	ICARDA	91	E	119	32	31	1	734	134	AB
16	SEL95TH1716	ICARDA	85	E	110	33	34	1	683	125	AB
17	Hashem	Iran	86	E	121	31	25	1	426	78	BC
18	SEL93TH24469	ICARDA	89	E	116	35	29	1	649	119	ABC
19	Greet	Iran	85	SE	115	31	31	3	547	100	ABC

PT: Plant type, DM: days to maturity, PH: Plant height, 100 SW: hundred seed weight, AB: Ascochyta blight, Check: yield as % of local check (Bivanij), Class: indicates significant differences at the 5% level, E: Erect, SE: Semi-erect.

Conclusion

The results of the present study showed that genotype X96TH3K4, based on the mean of grain yield, stability parameters and seed size, was the most suitable chickpea variety for autumn planting in Merek. Based on the same criteria, ILC1799 and ILC 3221 were found the most desirable genotypes for spring planting in Merek. In Honam, chickpea line FLIP 99–59 was found the most desirable genotype, both for autumn and spring planting.

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Evaluation of Agronomic Management for Enhancing Lentil Yield at Farmers' Fields under Dryland Conditions in KRB

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Abstract

Lentil is planted on 220,000 hectares in Iran, with 92% of this area under rainfed conditions. The average lentil productivity in Iran is 456 kg/ha, which is less than half of the world average. Low productivity is due to the use of local varieties, which have low yield potential, and poor agronomic practices applied by the farmers. The objective of this study was to evaluate agronomic management practices for enhancing lentil yield in KRB. The experiments were conducted under dryland conditions in 2005–06 and 2006–07 in a split plot design with two replications (regions), i.e., Merek watershed in Kermanshah Province and Honam watershed in Lorestan Province. Conventional methods and new methods were considered the main plot and the subplots were three improved varieties (Gachsaran, FLIP 92–12 and ILL6037) along with a local check. Data was recorded for the number of days to emergence, 50% flowering, and maturity, plant type, reaction to *Fusarium* wilt diseases, plant height, 100 seed weight, seed yield. The results of a combined analysis of variance showed that there was significant difference between research recommendations and conventional methods at the 10% level of probability. Significant difference was also found among the genotypes. Genotypes FLIP 92–12L, and ILL 6037 produced significantly higher yields than the local variety at 1% level of probability under autumn planting in Merek and Honam. For spring planting, genotype ILL 6037 produced significantly higher yield than the local check in Merek and Honam. The result of the economic analysis indicated that lentil grown using research recommendations had higher net benefits than lentil grown under conventional methods.

Key words: Agronomic managements, date of sowing, economic, rainfed, productivity, lentil

Introduction

Lentil (*Lens culinaris* Medikus ssp. *culinaris*) is an important crop in the highland cropping systems of West Asia and North Africa because of its contribution to human food, animal feed and soil health. It is also gaining popularity in the Central Asia and the Caucasus, and has been included as a component of crop diversification (Sarker, *et al.,* 2004). Lentil is grown on 220,000 hectares in Iran, which ranks fourth in the world after India, Turkey and Canada in lentil cultivation. The majority of the lentil area (92%) is under rainfed conditions and lentil is grown in rotation with cereals, mainly wheat and barely. Most of the farmers grow this crop on marginal areas in spring. The average lentil productivity in Iran is 456 kg/ha, which is less than half of average lentil productivity in the world. Low productivity is due to use of local varieties, which have low yield potential, and due to poor agronomic practices applied by the farmer such as broadcast sowing, use of furrow-turning plow (Moldboard plow) for covering the seed after sowing, low seed rate (about 85 seeds/m2) and late planting in spring (Sabaghpour *et al.,* 2004). Lentil frequently suffers from drought stress towards the end of the growing season: after flowering, during pod setting and seed formation. Drought is also often accompanied by heat stress in rainfed conditions (Sabaghpour, 2006). Production can be increased significantly by shifting from spring to winter planting (Sarker *et al*., 1988). This gives the crop the benefit of winter rainfall, and low evaporation. This environment allows optimum vegetative growth to attain higher yield potential through better water use efficiency. The taller canopy allows for mechanical harvest. The increased biomass from winter crop is also in high demand for feeding small ruminants (Sarker, *et al*., 2004). Sabaghpour (2006) reported that autumn planting had significantly higher yield as compared to spring planting, due to benefit of winter rainfall and higher water-use efficiency. One of the key means to increase lentil production in the rainfed areas of Iran is to shift lentil planting from spring to winter to exploit the benefits of winter rainfall and longer growth period. Efforts are underway to develop agro-ecologically suitable and high yielding winter-hardy lentil varieties, which is a major focus of lentil improvement programs at the Dryland Agricultural Research Institute in Iran.

Material and Methods

The experiments were conducted in a split plot design with two replications (regions) in Merek (Kermanshah province) and Honam (Lorestan Province) under dryland conditions in 2005–06 and 2006–07. Conventional sowing date (spring planting) and research recommendation (autumn planning) were the main plot. The research recommendation plots were sown on 10 December in Merek and on 13 December in Honam in 2005. In 2006, they were sown on 14 November in Merek and on 29 November in Honam. The conventional plots were planted on 11 March in Merek and 15 March in Honam in 2005; and on 16 March in Merek and on 19 March in Honam in 2006. The subplots were sown with three improved varieties (Gachsaran, FLIP 92–12 and ILL6037) along with a local check that was planted in 2500 m^2. Varieties were planted by planter with suitable seed rate (200 plant/ m^2) and the date of planting (autumn planting). For the conventional methods, agronomic practices were those used by farmers. Plots were fertilized with 30 kg P_2O_5 ha^{-1} and 20 kg N ha^{-1}. Weeds were controlled by hand weeding. The autumn-sown crop matured by late June and was harvested by a combine. The spring-sown crop matured by early July and was harvested by hand. No insecticide or fungicide was used to control insect pests and diseases. Data was recorded for number of days to emergence, 50% flowering, and maturity, plant type, reaction to *Fusarium* wilt diseases, number of pods per plant, plant height,100 seed weight, seed yield. Finally, the economic cost and benefits for both methods were compared.

Results and Discussion

The results of the combined analysis for two years in Merek and Honam showed that there was a significant difference between the research recommendation and the conventional method at the 10% level of probability (Table 1). Autumn planting (research recommendation) produced 31% higher yield than spring planting (conventional method). Sabaghpour (2006) reported that autumn planting had significantly higher yield as compared to spring planting, due to the benefit of winter rainfall, and low evaportranspiration, as temperatures are low when the crop approaches maturity. Autumn environment allows optimum vegetative growth, development of higher yield potential, and higher water-use efficiency. Furthermore, the canopy is taller which allows for mechanical harvest. The result of pooled analysis of this study showed that the difference between environments was significant at the 1% level of probability (Table 1). A significant difference was also found among the genotypes (Table 1). Genotypes FLIP 92–12L, and ILL 6037 with 793 and 743 kg ha^{-1} produced the highest yields, which were significantly higher than the local variety at 1% level of probability at autumn planting in Merek and Honam. Gachsaran variety did not produce significantly higher yield than the local check (Table 2). In spring planting, genotype ILL 6037 with 625 kg ha^{-1} produced significantly higher yield than the local check in Merek and Honam (Table 3). The results of the economic survey indicated that the research recommendation had a higher net income (benefit) than the conventional method (Table 4). ILL 6037 has large seed-size and is resistant to *Fusarium* wilt when compared to other lines and local check. Therefore, ILL 6037 is superior genotype for autumn and spring planting for both sites.

Table 1. Combined analysis of variance for lentil grain yield in Merek and Honam during the 2005–07 cropping season

Source of variation	Degrees of freedom	Mean square	P
Environment (Env.)	3	895875	<0. 001
Methods (Date of sowing)	1	426083	<0. 10
Env. × Date of sowing	3	69657	0.46
Error	8	72857	
Genotype	3	84899	<0.05
Genotype × Environment	9	21274	<0.01
Date of sowing × Genotype	3	30948	0.25
Date of sowing × Genotype × Env.	9	19062	<0.01
Error	24	2340	
Total	83		

Table 2. Mean of agronomic characters in autumn planting at Merak and Honam during 2005–07

No	Genotype	Origin	PT	DM	PH	100 sw	FU	Yield (kg ha^{-1})	Check %	Class
1	Gachsaran	Iran	E	173	25	4.45	3	607	99	C
2	FLIP 92-12L	ICARDA	E	176	28	4.65	3	793	129	A
3	ILL6037	ICARDA	E	177	26	5.3	3	743	121	B
4	Local check	Iran	SE	182	21	2.92	3	614	100	C

C, B and A : Non significant, and significant for higher yield than check at 5% and 1% probability levels, respectively

Table 3. Agronomic characteristics in spring planting in Merek and Honam during the 2005–07 cropping seasons

No	Genotype	Origin	PT	DM	PH	100 sw	FU	Yield (kg ha^{-1})	Check %	Class
1	Gachsaran	Iran	E	93	21	3.6		527	120	C
2	FLIP 92-12L	ICARDA	E	98	20	4.1		511	116	C
3	ILL6037	ICARDA	E	101	19	4.3		625	142	B
4	Local check	Iran	SE	104	17	2.5		441	100	C

Table 4. Economic comparison of research recommendation versus conventional methods for lentil practices)

Methods	Gross income $	Expenses $	Net benefit $ over Conventional
Conventional	591	311	
Research recommendation	849	346	223

Conclusion

The results of the combined analysis showed that there was significant difference between research recommendations and conventional method at 10% level of probability. A significant difference was also found among the genotypes. Genotypes FLIP 92–12L and ILL 6037 produced significantly higher yields than the local variety at the 1% level of probability for autumn planting in Merek and Honam.

Under spring planting, genotype ILL 6037 produced significantly higher yield than the local check in both Merek and Honam. Also, the result of economic survey showed that research recommendation provided a higher net income than the conventional method. ILL 6037 has large seed size and is resistant to *Fusarium* wilt as compared to other lines and the local check. Therefore, this study indicated that ILL 6037 is the superior genotype for autumn and spring planting in both Merek and Honam.

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A Glance at Biological Degradation in KRB

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Abstract

The mountainous rangelands and forests of KRB (KRB) represent vast natural ecosystems that have supported rural and pastoral communities for centuries. The upper part of KRB includes two major natural vegetation types: forest vegetation and rangeland vegetation. Human activities in the basin have degraded the vegetation and have affected its size, abundance (density and frequency), and diversity.
Fragmentation of the forest ecosystem of the basin is one of the major results of human activities. The disturbances resulted in open areas of various sizes in the forest. The main factors of biological degradation in the basin's rangelands include degradation due to overgrazing, conversion of rangelands in rain-fed croplands and inappropriate land management. Changes in traditional herding practices of rural and pastoral people, such as overstocking and non-seasonal grazing, have led to biological degradation in rangeland and forest ecosystems. As a result, biological productivity and conservation of biodiversity in ecosystems of the basin have been decreased by degradation of rangelands, forests, and even irrigated lands**.** A considerable number of desirable forage species or medicinal species of the rangelands have disappeared from many parts of the basin or have a very scarce presence on the rangelands. Biological degradation, as the major indication of land degradation, has triggered many environmental, social and economic problems for local people. Failure to implement rehabilitation and reclamation practices on rangelands and forests, such as re-vegetation and proper management, may result in permanent degradation of these ecosystems of the basin.

Key words: biological degradation, Rangelands, Forests, Vegetation, KRB

Introduction

Vegetation is the principal integrator and indicator of functional processes in ecosystem. Within vegetation cover of ecosystem, plant species and communities to which they belong are adapted to local environmental conditions. As long as the conditions remain unchanged, species and communities tend to survive and persist. We live in a time in which the world's biological diversity of plant species is being rapidly destroyed. As a result of human activities, the current rate of degradation of natural vegetation is greater now than at any time in the past. The loss of biological diversity is occurring at all levels; ecosystems and communities are being degraded and devastated, and species are being driven to extinction. Studies conducted by Willams and Nowak (1986) showed that the degradation is occurring in both terrestrial and aquatic ecosystems. Human activities alter and destroy natural vegetation to suit human needs. About two decades ago, Vitousek et al. (1986) declared that approximately 40% of the total net primary productivity of terrestrial environment was used or wasted in some way by people.

One of the major basins of Zagros Mountains region, in south-western part of Iran, is KRB (KRB). The mountainous rangelands and forests of KRB represent vast natural ecosystems, which have supported rural and pastoral communities for centuries. Human activities, in the basin, have resulted in a degradation of the vegetation and have affected the size, abundance (density and frequency), and diversity of vegetation. Biological degradation in KRB has been accelerating during the last six decades. Devastation of the vegetation in the basin is unprecedented. Never before in the history of the basin have so much destructions to its vegetation occurred in so short a time.

Materials and Methods

Various interviews with elderly persons in rural areas, and also with pastoral people, were conducted to provide information about the condition of vegetation and plant species in rangelands and forests of the basin. They were asked about the abundance of different plant species in the past decades. The ways people used to benefit from particular forest and range plant species were investigated. Also, using another approach, retired experts of forests and rangelands were interviewed about the long history, and also late history of vegetation in the basin. We traveled to different areas and localities of the basin to see individual tree species remained in forests and/or patches of range plants species from vegetation cover of rangelands. Finally, documents reserved in general provincial offices of natural resources were evaluated for recorded data and information, evidence, notes, and any written material about vegetation and plant species condition in the past decades.

Results and Discussion

Fragmentation of forest ecosystem of the basin is one of the major results of human activities. The disturbances resulted in open areas of various sizes in the forest. These open areas have been either cultivated as rain-fed farms or occupied by low-value annual herbaceous plants. In some parts of the forest, the density of trees is so low that annual herbaceous plants are able to occupy the surface of the soil under the forest canopy and form the under storey of vegetation.

For forest species such as Acer monspessulanum, Pistacia atlantica, Pistacia mutica. Crataegus pontica, Crataegus meyeri, Cerasus microcarpa, Cercis griffithii, Cotoneaster rasmiflora, Amygdalus orientalis, Pyrus glabra, Celtis caucasica, Lonicera hypoleuca, and Malus orientalis, the density (number of individual plants of the same species per unit area) has been reduced to a very small number, as compared to a few decades ago. Also, the density of different Quercus species has been reduced dramatically. Because of ecosystem degradation, there is almost no regeneration-by-seed for the species Quercus persica, which is the dominant tree of forests in the basin. Local people used to cut this tree either for its leaves to feed their livestock or for its wood to make charcoal. Instead of a standard form, now most of the individuals of this tree species are in coppice form (Tavakoli1998, Khodakarami and Taheri 2003). Among other forest species, whose abundances have been so reduced that they are almost near the stage of extinction, Crataegus aronia, Crataegus microphylla, Crataegus monogyna, Pistacia khinjuk, Crataegus psedoheterophylla, Cerasus brachypetala, Cerasus mahaleb, Cotoneaster luristanica, Amygdalus carduchorum, Amygdalus elaeagnifolia, Amygdalus haussknechtii, Amygdalus kotschyi, Pyrus syriaca, Olea europaea, and Ulmus carpinifolia could be mentioned.

The main factors of biological degradation in rangelands of the basin include degra-

Fig. 1. Open areas in forest due to degradation and cultivation.

dation due to overgrazing, conversion of rangelands in rain-fed croplands and inappropriate land management. Changes in traditional herding practices of rural and pastoral people, such as overstocking and non-season grazing, led to biological degradation in rangeland and forest ecosystems.

A considerable number of desirable forage species or medicinal species of the rangelands have disappeared from many parts of the basin or have a very scarce presence on the rangelands (Weiskarami 2000, Ahmadi 2004). Species such as *Prangos ferulacea, Ferula ovina, Dorema Aucheri, Festuca ovina, Dactylis glomerata Bromus tomentellus, Trigonella elliptica, Kochia prostrata, Sanguisorba minor, Thymus kotschyanus, Hypericum perforatum* are categorized in this group of species. Conversely, undesirable species (for foraging) such as *Euphorbia spp. Daphne mucronata*, *Astragalus adscendens*, low-value annual grasses and annual forbs have invaded the rangelands of the basin (Siahmansoor *et al.,* 2002). These undesirable species have very low palatability for livestock and are not grazed by domestic animals such as sheep and goat. Biological degradation, as the major indication of land degradation, has triggered many environmental, social and economic problems for local people. For example, migration from rural to urban areas and breakdown of traditional social values and practices.

As a result, biological productivity and conservation of biodiversity in ecosystems of the basin have been decreased by degradation of rangelands, forests, and even irrigated lands**.** In the past, so many forest species with reasonable densities formed the forest vegetation of the basin. There were hundreds of different shrubs and herbaceous species on rangelands too (Mehrnia, 1997).

Individuals of long-lived plant species that are living in severely disturbed and fragmented forests and rangelands of the basin may persist for many years, but they will eventually die out due to lack of reproduction. According to studies conducted in other parts of the world, species living in such conditions can be considered "the living dead" (Janzen 1986; Gentry 1986).

Three factors can be considered as the main primary causes of the degradation of vegetation in the basin. They are: 1) the demand of a rapidly increasing human population in the basin; 2) poverty in rural and pastoral parts of the basin, partly

Fig 2. Quercus in coppice form.

Fig. 3. Degraded rangelands in Honam.

because of the unequal distribution of the national wealth such as oil income; and 3) misuse of continued advances in technology, resulting in severe changes in land-use and land management without employing advanced methods of integrated management of natural resources.

The main secondary cause of the present condition is degradation stemming from human activities, such as overgrazing of rangelands and over-harvesting of forests, and using modern technology for converting rangelands and forests to rain-fed farms, to supply national and international markets. Combination of these activities resulted in severe destruction of original vegetation. Researches in other parts of the world show that the destructive factors combine additively or even multiplicatively to make species condition worse and accelerate degradation (Myers 1987).

Conclusions

Plant communities of the rangelands and forests in the basin are being gradually impoverished until there will be mass extinctions of plant species in the basin. Unless something is done to reverse the trend, the important species that form the essence of forests and rangelands will soon no longer be found in the basin. Failure to implement rehabilitation and reclamation practices on rangelands and forests, such as re-vegetation and proper management, may result in permanent degradation of these ecosystems of the basin.

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CHAPTER II

Water Productivity and Technologies in Lower KRB

Assessment of Wheat Water Productivity and Methods of Improvement in South KRB

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Abstract

In the Southern part of KRB, low water productivity is one of the main issues in irrigated agricultural areas. This study was conducted during the 2005–06 in a selected site (Sorkheh) to: (i) assess wheat water productivity WP: (ii) dentify the causes of low wheat WP: and (iii) suggest ways of improvement in irrigated areas. Twenty-two field units under wheat were selected for this study. The field units represented a range of soils, sources of water (wells, irrigation networks, river water, and a combination of well and network water), farmer managerial capabilities (progressive, average, poor), seeding rate and wheat varieties. The study also aimed at determining methods of improving WP and its potential level, where five field management systems were applied at on-farm level. According to the results, the mean wheat water productivity was 1.02 kg m^{-3}, which ranged between 0.51 to 1.80 kg m^{-3}, where water sources were wells and combinations of wells and networks respectively. The net wheat water requirement was 4610 m^3 ha^{-1}, of which about 2830 m^3 ha^{-1} was provided by rainfall. Fields with highest WP (>2 kg m^{-3}) received deficit irrigation during the irrigation season. On an average the amount of water applied into the fields after the fallow or leveling was about 20% higher and runoff 15% less compared to the fields after maize or beans. A seed rate of 165, 125, and 180 kg ha^{-1} is suggested for Chamran, Dez and Vierinak varieties respectively to be applied in Sorkheh site. The mean wheat WP improved to 2.32 kg m^{-3} when selected improved systems were applied to the fields.

Introduction

As the population is increasing, additional food is needed (Sekler *et al.,* 1998). Simultaneously, water is rapidly becoming scarce, particularly in arid and semiarid regions of CWANA (Central and West Asia, and North Africa). Moreover, water demand from non-agricultural sectors in industry and households, as well as for environmental purposes, will keep growing in both developed and developing countries. Irrigated agriculture has been an important contributor to the expansion of national and world food supplies and is expected to play a major role in feeding the growing world population (Cai and Rosegrant, 2003). With growing demand for irrigation water and increasing competition among water-using sectors, the world now faces the challenge to produce more food with less water. This goal will be realistic only if appropriate strategies set for water saving and for more efficient uses of water in agriculture.

Since in many parts of the world water, and not land or other factors, is the most limiting resource for agricultural production, improving agricultural water productivity (WP) could be a reasonable strategy to overcome water scarcity. Higher crop WP results in either the same production with less water, or a higher production with the same amount of water. Indeed, the greatest increases in the productivity of water in irrigation have not been achieved only through improved irrigation practices or management, but also through increased crop yields through the use of better varieties and mineral fertilizers.

Iran is situated in one of the arid regions of the world with an average annual precipitation of about 250 mm, which is less than one-third of the world average. Moreover, 179 mm of the precipitation evaporates, representing 71% of the total precipitation, while the annual potential evaporation in the country ranges mainly between 1000 and 3000 mm (Dehghanisanij *et al.,* 2006). The agricultural sector is the main water user in the country. The irrigated agricultural area in Iran comprises about 8.4 million ha (M ha) and presently is using 85.2 bm3 (92%) of total water use (92.5 bm3). Since the possibility to increase the water resources for the agricultural sector in arid and semiarid regions like Iran is limited, improvement of the agricultural water productivity might be a more realistic strategy. KRB (KRB) is an important agricultural zone, located in the southwestern parts of Iran. In KRB, two major agricultural production systems prevail: rainfed system in the upstream of the newly built Karkheh reservoir, and the fully irrigated system in the downstream. The river water quality is good, though it varies both seasonally and along the river. The area is suitable for a wide range of crops, i.e., wheat, maize, alfalfa, and off-season vegetable crops. The total area of KRB is 5.2 M ha, out of which only 1.07 M ha is irrigable and 0.9 M ha is suitable for dry farming agriculture. Out of total cultivated area, more than 70% is under cereals (wheat and barley). The agricultural water resources in KRB consists of both surface and groundwater. KRB (KRB) is a water shortage area and droughts are becoming a permanent feature of this region. Water productivity (WP) in these areas is also very low, not only compared to potential WP, but also to that in other river basins in Iran (Keshavarz and Ashrafi, 2004).

The objectives of this paper were to: (i) define the wheat WP in irrigated areas of lower KRB; (ii) assess the causes of low wheat WP; (iii) assess the impact of technical and agro-technical application on wheat WP improvement; and (iv) suggest ways of improvement.

Site Description

The study was conducted in Sorkheh Plain as a representative of irrigated area of KRB. Sorkheh is located in Khozestan Province and below the Karkheh Dam. The region has a semiarid climate (De Martonne classification). The average annual air temperature and humidity in this region range between 6.7–45.6°C and 27.4–74.5%, respectively. The rainy season usually starts in October and continues until the middle of May with an average annual rainfall of about 330 mm. The annual potential evaporation in this region is about 2400 mm, ranging between 50 mm month-1 during December and January and 400 mm month-1 during June and July. Sorkheh agricultural area is about 10000 ha of which about 4100 ha is under irrigation network, 5800 ha well water resources and 460 ha surface water (rivers). In total, there are 196 wells in this area and 29 pumps for pumping water from surface sources. Winter wheat and maize are the main crop-rotation system in this region. Wheat is grown from mid-November to mid-January. The rainfall does not meet the need of wheat for its normal growth, especially during the dry, windy spring season. Therefore, 3–4 irrigations are needed to maintain high yields.

Materials and Methods

The study was conducted in twenty-two field units under wheat during 2005–06. The field units represented a range of soils, sources of water i.e., well (6 units), irrigation network (10 units), river water (3 units), and 3 units using a combination of well and network water. In addition, the farmers' managerial capabilities (progressive, average and poor) and distance from the water source also varied in the selected farms.

The data collected from the selected field included the following: soil characteristics, soil fertility analysis, water quality, land leveling situation, irrigation amount and runoff, number of irrigation events, crop varieties, cropping calendar (time of planting, harvest, etc.), crop yields, tillage and cultivation practices, inputs timing and amounts, including fertilizers and pesticides, seedi rate and climate parameters to estimate crop water requirement.

To determine soil characteristics and fertility, soil samples were collected in three replications from each selected fields. Water quality (EC and pH) was determined based on water sampling and laboratory measurement. Irrigation water applied and the amount of runoff were measured for each irrigation event using different size of cut-flume, calibrated in local research station (Fig. 1). The number of the furrows selected to control inflow and outflow was different between the selected fields due to the difference in water discharge from the wells and water right from the river or irrigation network. The fields were also different in length of the furrows. Crop varieties and seed rate were collected based on the information recorded by local agricultural office. Crop development stages (time of planting, harvest, etc.) were recorded in all selected field during weekly visit from the site. Final harvest was performed in three sub-plots in each farm. The crop water requirement (ETc) was estimated based on Penman-Monteith model (Allen *et al.,* 1998).

In agricultural production systems, crop water productivity (WP) accounts for crop production per unit amount of water used (Molden, 1997). The numerator maybe expressed in terms of crop yield (kg ha^{-1}), which alternatively may be transformed into the monetary units (i.e., \$ ha^{-1}). Based on Molden (1997), a number of options are available to define the volume of water per unit of area (m^3 ha^{-1}) in the denominator, i.e., transpiration, evapotranspiration (ETc), irrigation water applied (I), water diverted, water beneficially consumed, and water beneficially and non-beneficially consumed. We used the fallowing definitions of crop WP (Dehghanisanij *et al.,* 2007);

$$\text{WP (kg m}^{-3}\text{)} = \frac{\text{Ya (kg)}}{\text{I(m}^3\text{)}} \quad (1)$$

where WP is crop water productivity based on the irrigation water applied into the field (I) and Ya is defined as the marketable part of the total above ground biomass production; for wheat the total grain yield is considered.

To determine the methods of improving WP and its potential level, research was conducted simultaneously both in Safi-Abad research station and at two farmers' fields. Three field management systems were compared with traditional one (control) from the Sorkheh site. The treatments included: (i) furrow irrigation with broadcasting, disking, and corrugating; (ii) full furrow irrigation, with raised-bed (bed width = 60 cm; 3 rows) system applied suing local furrower (Hamedani Barzegar type); (iii) border irrigation with row planting system;

Fig. 1 Installed cut-flume in selected fields of Sorkheh site.

and (iv) farmers system (control). Moreover, based on the field size and maize-wheat rotation in Sorkheh site, 3 more treatments were studied both in Safi-Abad research station and two on-farm fields as fallows. They were: (i) border irrigation with combinate for planting and chopper before planting; (ii) furrow irrigation with combinate for planting and chopper before planting, broadcasting and corrugating after planting; and (iii) farmers' system (control).

Results and Discussions

The selected fields varied in their extent from 1.5 to 17 ha (Table 1). A common rotation in the site was observed in the selected fields. Eight of the fields were fallow, in ten of them maize and in one bean was in rotation with wheat. In three of the fields leveling was already performed. The seed varieties, which have been sown in selected fields were Dez, Vierinak, Chamran and 118. The seeding rate was also different among the selected fields ranging between 154 to 300 kg ha^{-1}. The sowing dates were ranging from early December for the fields after fallow to mid-January due to the previous crop growth period in rotation.

The wheat yields measured ranged from 4030 to 5510 kg ha^{-1} in selected fields. The mean wheat yield was high where water resource was a combination of well and irrigation network and it was minimum under well water resources (Table 2). The same results were concluded for mean measured WP in selected fields (Table 2). The mean wheat WP was 1.02 kg m^{-3} which ranged from 0.51 to 1.80 kg m^{-3}, where water resource was from well and combination of well and network, respectively (Fig. 2).

Table 1: Specifications of the selected fields and their farming practices.

Fields	Area (ha)	Sources of water	Previous crop	Seed verities	Seeding rate (kg ha^{-1})	Sowing date	Soil texture	Irrigation event
1	12	Well-network	Fallow	Dez	154	2006/11/30	Silty-loam	4
2	8	Well-network	Fallow	Dez	185	2006/12/02	Loam	4
3	12	Well-network	Maize	Vierinak	250	2007/01/10	Loam	4
4	4	Network	Maize	Vierinak	300	2007/01/10	Loam	4
5	3.5	Network	Maize	Vierinak	300	2007/01/10	Loam	3
6	4	Network	Fallow	Chamran	250	2006/12/07	Silty-loam	3
7	3.5	Network	Leveling	Dez	280	2006/12/07	Loam	3
8	3.5	Network	Leveling	Dez	280	2006/12/07	Loam	3
9	2	Network	Fallow	Dez	280	2006/12/07	Loam	3
10	5	Network	Maize	Chamran	300	2007/01/10	Loam	4
11	3.5	Network	Maize	Vierinak				
	350	2006/12/07	Loam	4				
12	2	Network	Fallow	Chamran	250	2006/12/07	Silty-loam	4
13	1.5	Network	Fallow	Dez	300	2006/12/07	Loam	5
14	17	Well	Maize	Chamran	270	2006/12/07	Loam	3
15	4	Well	Maize	Chamran	270	2006/12/07	Loam	3
16	7	Well	Fallow	Chamran	180	2006/12/07	Silty-loam	3
17	4	Well	Leveling	Vierinak	250	2007/01/10	Silty-loam	7
18	4	Well	Maize	Vierinak	250	2007/01/10	Sandy-loam	7
19	3.5	Well	Fallow	Chamran	280	2006/12/04	Silty-loam	8
20	5	River	Maize	Vierinak	280	2007/01/10	Sandy-loam	4
21	7	River	Beans	Vierinak	280	2007/01/10	Sandy-loam	4
22	5	River	Maize	118	300	2007/01/10	Loam	3

Table 2: Average of wheat yield and water productivity in selected fields.

	Water resource			
	Network	Well	Well and network	River
Yield (kg ha^{-1})	4600 ± 300	4500 ± 470	5500 ± 10	4600 ± 200
Water productivity (kg m^{-3})	1.5 ± 0.25	1.6 ± 0.52	2.6 ± 0.37	1.4 ± 0.09

Based on the Penman-Monteith model, the wheat water requirement was about 4610 m^3 ha^{-1} during the 2005–06 in Sorkheh site of which 283 mm (2830 m^3 ha^{-1}) provided by effective rainfall. Accordingly, the total water needed to be provided through irrigation was about 1780. According to the total water applied into the fields, we could conclude that the fields with highest WP (>2 kg m^{-3}) have received deficit irrigation during the irrigation season. Moreover, considering the irrigation efficiency in this region (<30%), it is obvious that some of the selected fields were facing deficit irrigation (Fig. 2).

Due to the maize growth period, the sowing date of the wheat was 6 to 8 weeks later than that in fields after fallow, which may affect the total amount of water applying into the fields. On an average, the amount of water applied into the fields cultivated after the fallow or leveling was about 20% higher compared to the fields, which were under maize or beans, while there was not any significant difference between the average yields among them. Moreover, the results showed difference in amount of runoff between the fields which were cultivated before wheat cultivation season compared to the fallow fields. The runoff was about 15% less under the fields, which have been cultivated after the fallow. This could be attributed to the soil characteristic (infiltration rate) variation due to the cropping system.

The seed rate is an effecting factor on yield and water productivity. It ranged between 154 and 350 kg ha^{-1} in the selected fields. According to the results presented in Fig. 3, the yield decreased with the increased seed rate and on an average a seed rate of less than 200 kg ha^{-1}, showed highest yields in the selected

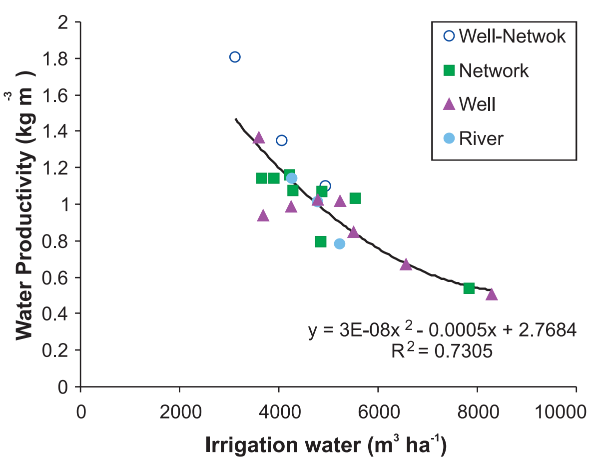

Fig. 2. Wheat water productivity variation with irrigation water applied in selected fields of Sorkheh site.

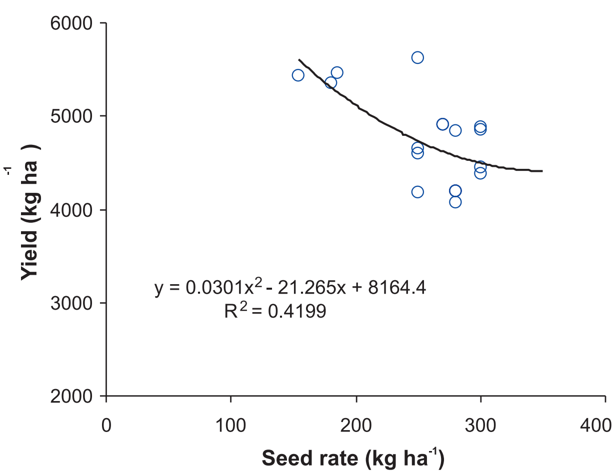

Fig. 3. Wheat yield variation with seed rate in irrigated fields of Sorkheh site.

fields. Based on the literature and current study, a seed rate of 165, 125 and 180 kg ha^{-1} is suggested for Chamran, Dez and Vierinak verities, respectively to be applied in Sorkheh site.

The mean wheat water productivity improved to 2.32 kg m^{-3} when different management systems as improvements treatments were applied to the selected fields (Table 3). There was not significant difference between the mean wheat yields in improvement fields after fallow or maize. However, the amount of applied irrigation water was less in the fields after maize compared to those after fallow, mainly due to the shorter wheat growth period after maize. Accordingly, the wheat WP was higher in the improvement fields after maize compared to those after fallow. In the improvement fields after maize, border irrigation with combinate for planting and chopper before planting showed higher impact on wheat WP (3.4 kg m^{-3}) compared to furrow irrigation with combinate for planting and chopper before planting, broadcasting and corrugating after planting (2.32 kg m^{-3}). In the improvement fields after fallow, the management of (i) furrow irrigation with broadcasting, disking, and corrugating and (ii) full furrow irrigation, with raised-bed system and sowing using local furrower (Hamedani Barzegar type) showed similar impact on wheat WP and both were higher compared to the full furrow irrigation, with raised-bed system and sowing using local furrower (Hamedani Barzegar type).

Table 3: Irrigation, yield, and water productivity in wheat fields under different treatments of field management.

Treatments	Irrigation (m^3 ha^{-1})	Yield (kg ha^{-1})	Water productivity (kg ha^{-1})
After fallow			
Furrow irrigation with broadcasting, disking, and corrugating	3220	6466	2.01
Full furrow irrigation, with raised-bed (bed width=60 cm; 3 rows) system applied suing local furrower (Hamedani Barzegar type)	3280	7134	2.17
Border irrigation with row planting system	3400	5836	1.71
After maize			
Border irrigation with combinate for planting and chopper before planting	1870	6369	3.41
Furrow irrigation with combinate for planting and chopper before planting, broad casting and corrugating after planting	2790	6480	2.32

Conclusion

In some arid and semi-arid regions, including KRB, low water productivity is one of the main issues in agricultural production. To assess the causes of low wheat WP and suggest ways of improvement wheat, the WP was measured in twenty-two field units representing a range of soils, sources of water, farmer managerial capabilities, seed rate and varieties. According to the results the mean wheat water productivity ranged between 1.08 to 2.97 kg m^{-3} in selected fields. The highest WP was measured in the fields under deficit irrigation. Field cropping system before wheat (maize or fallow) was recognized as an effective factor on the total irrigation water and amount of runoff. High seed rate decreased the yield and consequently WP.

The mean wheat water productivity improved 39% by field management system, especially by furrow irrigation with combinate for planting and chopper before planting, broadcasting and corrugating after planting.

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Assessment of the Causes of Low Water Productivity and Ways of Improvement in Irrigated Maize Areas of South KRB in Iran

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Abstract

In the Southern part of KRB, low water productivity is one of the main issues in irrigated agricultural areas. This study was conducted in 2006 in a selected site (Sorkheh) to: (i) define the maize water productivity WP: (ii) assess the causes of low maize WP: and (iii) suggest ways of improvement in irrigated areas. Twenty-two field units under maize were selected for this study. The field units represented a range of soils, sources of water (wells, irrigation networks, river water, and a combination of well and network water), farmer managerial capabilities (progressive, average, poor), seeding rate and seed verities. The study also aimed at determining methods of improving WP and its potential level, where five field management systems were applied at local research station (Safi Abad). The net maize water requirement was 6720 m^3 ha^{-1}. According to the results, the mean maize water productivity was 0.40 kg m^{-3}, which ranged between 0.18 to 0.68 kg m^{-3}, where water resources came from wells and networks, respectively. The mean maize WP improved to 0.52 kg m^{-3} when selected improved systems were applied to the on-farm fields. We suggest a mean crop density of about 75,000 plants per hectare to achieve the highest yield in the selected site.

Introduction

Irrigated agriculture produces about 40% of all food, and consumes 69% of all freshwater resources (FAO, 2000). Global population growth is expected to increase the demand for cereals, including rice and wheat, by 1.27% annually between 2000 and 2025 (Rosegrant and Cai, 2000). To meet the projected demand for food, irrigated agriculture will require an increase of 17% in freshwater resources (Seregeldin, 1999). In many arid and semi-arid countries where population growth is high, and freshwater is in short supply, there is pressure on the agricultural sector to reduce its water consumption and make it available for the urban and industrial sectors. This drives the demand to increase agricultural productions, using less irrigation water. This goal will be realistic only if appropriate strategies set for water saving and for more efficient uses of water in agriculture.

Since, in many parts of the world, water, and not land or other factors, is the most limiting resources for agricultural production, and improving agricultural water productivity (WP) could be a reasonable strategy to overcome water scarcity. Higher crop WP results in either the same production with less water, or a higher production with the same amount of water. Indeed, the greatest increases in the productivity of water in irrigation have not been achieved only through improved irrigation practices or management, but also through increased crop yields through the use of better varieties and mineral fertilizers.

Iran is situated in one of the arid regions of the world with an average annual precipitation of about 250 mm, which is less than one-third of the world average. Moreover, 179 mm of the precipitation evaporates, representing 71% of the total precipitation, while the annual potential evaporation in the country ranges mainly between 1000 and 3000 mm (Dehghanisanij *et al.,* 2006). The agricultural sector is the main water user in the country. The irrigated agricultural area in Iran comprises about 8.4 M ha and presently is using 85.2 bm3 (92%) of total water use (92.5 bm3). Since the possibility to increase the water resources for the agricultural sector in arid and semiarid regions like Iran is limited, improvement of the agricultural water productivity might be a more realistic strategy. KRB (KRB) is an important agricultural zone, located in the southwestern parts of Iran. In KRB, two major agricultural production systems prevail: rainfed system in the upstream of the newly built Karkheh reservoir, and the fully irrigated system in the downstream. The river water quality is good, though it varies both seasonally and along the river. The area is suitable for a wide range of crops, i.e., wheat, maize, alfalfa, and off-season vegetable crops. The total area of KRB is 5.2 M ha, out of which only 1.07 M ha is irrigable and 0.9 M ha is suitable for dry farming agriculture. Out of total cultivated area, more than 25% is under maize. The agricultural water resources in KRB consist of both surface and groundwater. KRB (KRB) is a water shortage area and droughts are becoming a permanent feature of this region. Water productivity (WP) in these areas is also very low, not only compared to potential WP, but also to that in other river basins in Iran (Keshavarz and Ashrafi, 2004).

The objectives of this paper were to: (i) define the maize WP in irrigated areas of lower KRB; (ii) assess the causes of low maize WP; (iii) assess the impact of technical and agro-technical application on maize WP improvement; and (iv)suggest ways of improvement.

Site Description

The study was conducted in Sorkheh Plain as a nominator of irrigated area of KRB. Sorkheh is located east of KRB, west of Khozestan Province and below the Karkheh Dam. The region has a semiarid climate (De Martonne classification). The temperature and humidity in this region range between 6.7–45.6°C and 27.4–74.5%, respectively. The rainy season usually starts in October and continues until the middle of May with an average annual rainfall of about 330 mm. The annual potential evaporation in this region is about 2400 mm, ranging between 50 mm month-1 during December and January and 400 mm month-1 during June and July. Sorkheh agricultural area is about 10000 ha of which about 4100 ha is under irrigation network, 5800 ha under well water resources and 460 ha under surface water (rivers). In total, there are 196 wells in this area and 29 pumps for pumping water from surface water. Winter wheat and maize are the main crop-rotation system in this region. Maize is grown from late July to mid-August, when the rainfall is almost zero.

Materials and methods

The study was conducted in twenty-two field units under maize during 2006. The field units represented a range of soils, sources of water i.e., well (6 units), irrigation network (10 units), river water (3 units), and 3 units using a combination of well and network water (Fig. 1). In addition, the farmers' managerial capabilities (progressive, average and poor) and distance from the water source also varied in the selected farms.

The data collection from the selected field included the following: soil characteristics, soil fertility analysis, water quality, land leveling situation, irrigation amount and runoff, number of irrigation events, crop varieties, cropping calendar (time of planting, harvest, etc.), crop yields, tillage and cultivation practices, inputs timing and amounts, including fertilizers and pesticides, seed rate and climate parameters to estimate crop water requirement.

To determine soil characteristics and fertilities, soil samples were collected in three replications from each selected fields. Water quality (EC and pH) was defined based on water sampling and laboratory analysis. Irrigation water applied and the amount of runoff were measured for each irrigation event using different size of cut-flume, calibrated in local research station. The number of the furrows selected to control inflow and outflow was different between the selected fields due to the difference in water discharge from the wells and water right from the river or irrigation network. The fields were also different in length of the furrows. Crop varieties and seed rate were collected based on the information recorded by local agricultural office. Crop development stages (time of planting, harvest, etc.) were recorded in all selected field during weekly visit from the site. Final harvest was performed in three sub-plots in each farm. The crop water requirement (ETc) was estimated based on Penman-Monteith model (Allen *et al.,* 1998).

In agricultural production systems, crop water productivity (WP) accounts for crop production per unit amount of water used (Molden, 1997). The numerator may be expressed in terms of crop yield (kg ha^{-1}), which alternatively may be transformed into the monetary units (i.e., \$ ha^{-1}). Based on Molden (1997), a number of options are available to define the volume of water per unit of area (m3 ha^{-1}) in the denominator, i.e., transpiration, evapotranspiration (ETc), irrigation water applied (I), water diverted, water beneficially consumed, and water beneficially and non-beneficially consumed. We used the fallowing definitions of crop WP (Dehghanisanij *et al.,* 2007);

$$WP\ (kg\ m^{-3}) = \frac{Ya\,(kg)}{I(m^3)} \qquad (1)$$

where WP is crop water productivity based on the irrigation water applied to the field (I) and Ya is defined as the marketable part of the total above ground biomass production; for maize the total grain yield is considered.

To determine the potential level and the ways for improvement of maize WP, an experimental research was conducted in Safi-Abad research station. Four field management systems were also compared with traditional one (control) from the Sorkheh site. The treatments were included 2 raised bed systems (75 cm bed width) of (i) alternate furrow irrigation and (ii) full furrow irrigation, and 2 furrow bed systems (75 cm furrow width) with (iii) single planting line and (iv) double planting line inside the furrow. The control treatment (v) was raised bed system (75 cm bed width) and single planting line under full irrigation. All the furrows were with 130 m length. According to the results, maize water productivity was higher under treatment (iii) where furrow bed system with 75 cm furrow width and single planting line inside the furrow was applied.

Fig.1. Different sources of water.

Results and Discussions

The selected fields varied in their extent from 1.5 to 17 ha (Table 1). The seed varieties, which have been sown in selected fields, were 704 and 666. The plant density was also different among the selected fields ranging between 45000 to 100,000 per ha^{-1}. The sowing dates were ranging from late to early December for the fields after fallow to mid-January due to the previous crop growth period in rotation.

Table 1: Specification of selected fields and progress of farming activities.

Fields	Area (ha)	Length of furrow (m)	Sources of water	Plant density (ha^{-1})	Seed varieties	Sowing date	Soil classification	Irrigation event
1	5	436	Network	72222	704	2006/08/02	Loam	10
2	7	252	Network	47037	704	2006/08/03	Loam	10
3	5	425	Network	58148	704	2006/08/12	Loam	9
4	3	262	Network	62963	704	2006/07/28	Loam-Sandy loam	10
5	4	221	Network	63704	704	2006/07/28	Loam	11
6	4	220	Network	57037	704	2006/07/27	Loam	11
7	4	238	Network	70000	704	2006/07/31	Loam	12
8	4	332	Network	91111	704	2006/07/20	Sandy loam	15
9	4	210	Network	55926	704	2006/07/30	Sandy loam	14
10	1.5	160	Network	58519	704	2006/08/14	Loam	11
11	8	268	Network-well	48519	704	2006/07/20	Loam	10
12	8	228	Network-well	50000	704	2006/08/02	Loam	8
13	12	384	Network-well	51852	704	2006/08/16	Silty Loam	6
14	17	327	Well	70370	704	2006/07/22	Loam	12
15	2	280	Well	45679	704	2006/08/10	Loam	10
16	4	274	Well	51852	704	2006/08/01	Loam	10
17	4	234	Well	99259	704	2006/07/19	Silty Loam	13
18	4	220	Well	55185	704	2006/07/24	Sandy loam	13
19	4	210	Well	70741	704	2006/08/04	Silty Loam	11
20	5	229	River	61481	704	2006/07/29	Loam	11
21	5	375	River	78148	666	2006/07/29	Sandy Loam	9
22	10	335	River	76296	666	2006/08/03	Loam	8

The maize yields measured ranged from 3383 to 6900 kg ha^{-1} in selected fields. The mean maize yield was high where water resource was river and that was 5490 kg m^{-3} and it was minimum under combination of well and network water resources, 4650 kg m^{-3}. The mean maize WP was 0.40 kg m^{-3} which ranged from 0.19 to 0.68 kg m^{-3}. The mean WP in selected fields with water from the network, well, river, and combination of well and network was 0.38, 0.46, 0.39, and 0.34 kg m^{-3}, respectively. The highest mean WP was measured in the fields under well water resources, where farmers could apply the water into the fields when it is needed. The highest WP variation ($\pm$0.29 kg m^{-3}) was observed in the fields under network, which could be attributed to the un-scheduled access of farmers to the sources of water (Fig. 2).

Based on the Penman-Monteith model, the maize water requirement was about 6720 m^3 ha^{-1} in 2006 in Sorkheh site. Total irrigation water applied to the fields in average was about 13500 m^3 ha^{-1}, which ranged between 7870 to 21920 m^3 ha^{-1} in the selected fields. To show the situation of irrigation management in selected site, we decided to focus our discussion on fields 17 and 22 under well and surface (river) water resources, respectively. The total applied water in field 17 was 7870 m^3 ha^{-1} and 21920 m^3 ha^{-1} in field 22. The total grain

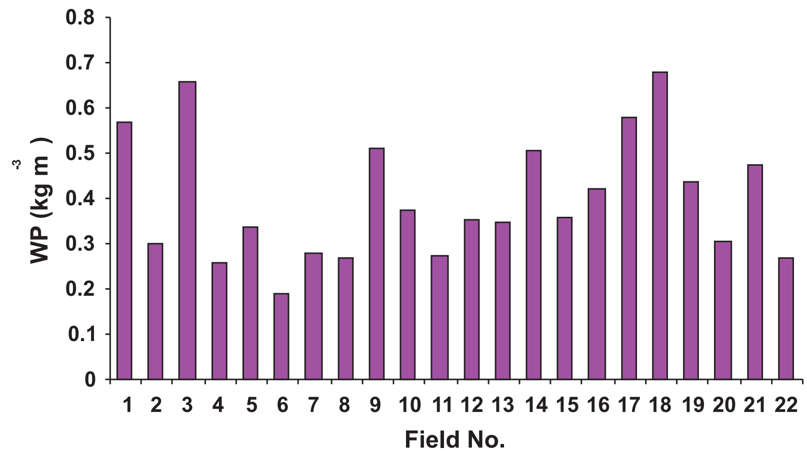

Fig. 2. Maize water productivity variation in selected fields.

yield measured in fields 17 and 22 was 4555 and 5909 kg ha^{-1} respectively, where maize WP was 0.58 and 0.27 kg m^{-3}. The total grain yield in field 22 is about 20% higher than that in 17 but maize WP is more than 50% less. The high variation in WP could be attributed to the field and irrigation management.

Access to the source of the water could be effective in irrigation management and consequently irrigation efficiency and water productivity. Number of irrigation events in filed 17 was 13 and that was 8 in field 22, while field 22 received 170% water higher compare to that in field 17. Accordingly, the farmer who has access to the source of water could confidently use the water more efficient and scheduled, if well educated. However, under irrigation network, the farmers have to use the water based on network management than field water requirement. In that case farmers do prefer to receive more water from the network when their turn is raised and consequently, more runoff and deep percolation is expected. The water flow from the network is another issue.

Field size is another effective factor in irrigation efficiency. Higher field length may results higher deep percolation. Herein, the length of field 17 was 234 m and 335 m in field 22. The total measured runoff in the entire crop growth stages was 2180 and 1740 m^3 ha^{-1} from field 17 and 22 respectively. Accordingly, field 17 faced deficit irrigation at some stage during the crop growth, while there was a deeper collation of about 13460 m^3 ha^{-1} field 22 (Fig. 3).

The plant density is an effecting factor on yield and water productivity. It ranged between 45000 to 100,000 per ha^{-1} in the selected fields. According to the results presented in Fig. 4, the yield decreased with the increased plant density and on an average a plant density of about 75000 plants ha^{-1} showed the highest grain yield in the selected fields

The mean maize water productivity improved to 0.52 kg m^{-3} when different selected management systems as improvements treatments were applied to the fields in research station (Table 3). The measured yield (5283 kg m^{-3}) under furrow bed system with 75 cm furrow width and single planting line inside the furrow was significantly less than that measured in other treatments. There was not significant difference between the mean maize yields in other improvement fields. However, the amount of applied irrigation water was higher (14360 m^3 ha^{-1}) in the field under furrow bed system with 75 cm furrow width and double planting line inside the furrow. According to the results, the maize WP was higher in the improvement fields compared to control. The highest WP (0.58 kg m^{-3}) was measured under raised bed system with 75 cm bed width and full furrow irrigation.

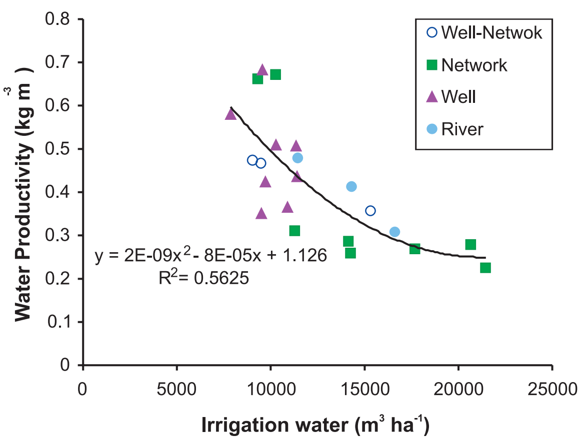

Fig. 3. Maize water productivity variation with irrigation water applied in selected fields of Sorkheh site.

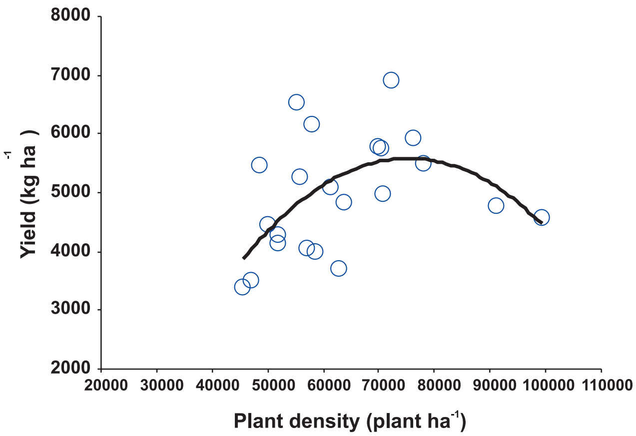

Fig. 4. Maize yield variation with plant density in irrigated fields of Sorkheh site.

Table 2: Irrigation, yield, and water productivity in maize fields under different treatments of field management.

Treatments	Irrigation (m^3 ha^{-1})	Grain Yield (kg ha^{-1})	Water productivity (kg ha^{-1})
Raised bed system with 75 cm bed width and alternate furrow irrigation	11620a	6361a	0.55
Raised bed system with 75 cm bed width and full furrow irrigation	10920a	6367a	0.58
Furrow bed system with 75 cm furrow width and single planting line inside the furrow	9760a	5283b	0.54
Furrow bed system with 75 cm furrow width and double planting line inside the furrow	14360b	6118a	0.49
Control; Raised bed system with 75 cm bed width and single planting line under full irrigation	11620a	6361a	0.43

Conclusions

In some arid and semi-arid regions, including KRB, low water productivity is one of the main issues in agricultural production. To assess the causes of low maize WP and suggest ways of improvement, the WP was measured in twenty-two field units representing a range of soils, sources of water, farmer managerial capabilities, seed rate and varieties. According to the results the mean maize water productivity ranged between 1.08 to 2.97 kg m^{-3} in selected fields. The highest WP was measured in the fields which faced deficit irrigation at least partially. Field size and water resources were recognized as an effective factor on the total irrigation water and amount of runoff. High plant density decreased the yield and consequently WP. The mean maize water productivity improved 20% by field management system, especially by Raised bed system with 75 cm bed width and full furrow irrigation.

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CHAPTER III

Water Productivity and Technologies in Saline Areas of Lower KRB

Comparisons of Yield of Several Wheat Genotypes in Saline Areas of KRB

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Abstract

Salinity is a major problem in irrigated areas of the lower part of KRB (KRB), due to high water tables. One of the ways to combat salinity in the short term is through selection of high yielding salt tolerant varieties. In this regard, five salt tolerant wheat genotypes, namely, Bam (DH4–209–1557F3-Vee"S"/Nac/1–66–22), 1–63–31/3/12300/Tob//Cno/Sx, Bank/Vee"S", Kavir and Roshan, and two local wheat cultivars (Chamran and Verinak) were compared in a two-year field experiment. The study was replicated at two locations in the second year. The experiment was arranged in a randomized complete block design with three replications. Results of the combined analysis of variance for two years at the same locations showed that Bam and Bank/Vee"S" had the highest grain yield. There were no significant differences among grain yields for Kavir, Roshan, Chamran and 1–63–31/3/12300/Tob//Cno/Sx genotypes. Results from the second location (during the second year) also showed that Bam and Kavir produced more grain yield than the others. There were no significant differences among 1000KW of genotypes at site 1 but Verinak and Kavir had the highest and lowest 1000KW at this site, respectively. Bank/Vee"S" had the highest 1000KW at site 2, while the differences among Roshan, Bam and 1–63–31 with Bank were not significant. Chamran, Verinak and Kavir also had the lowest 1000KW at site 2. Therefore, Bam, Bank/Vee"S" and Kavir could be considered as the new high yielding cultivars for the lower part of KRB.

Key words: Wheat genotypes, Salinity, Grain yield, KRB

Introduction

Salinity and waterlogging are the major problems inhibiting agricultural production in lower areas of the KRB. Efforts had been made to overcome these problems through installation of drainage system. However, this is a lengthy process as drainage installation is expensive and the waterlogged areas are expanding because of poor on-farm water management. The other alternative to combat salinity, in short terms, is through selection of high yielding salt tolerance crop varieties (Rhoades *et al.,* 1992).

Many crops are known to be salt tolerant (Mass and Hoffman, 1977). Some of these crops also show intra-specific variation in response to salinity (Epstien, 1985; Noryline & Epstien, 1984; Hollington, 1998; Parida & Das, 2004). There are evidences to show that considerable intra-specific diversity exists among wheat genotypes with regard to salt tolerance (Kingsbury & Epstien, 1984; 1986). Tanveer –Ul-Haq *et al.,* (2003) noted that some varieties of wheat are more salt tolerant than the others and could be used as genetic materials for further selection for saline as well as waterlogged areas. Pervaiz *et al.,* (2003) also observed the same result among wheat genotypes. These differences were also found among Iranian wheat cultivars (Kafi & Stewart, 1998). They noted that Besostaya, Cross Roshan and Navid could be considered as salt tolerant while Qods and Falat are relatively salt sensitive cultivars. Recent studies at the National Salinity Research Center (NSRC) of Iran also indicated that there are differences among wheat cultivars in response to salinity. However, these differences were not always significant, although salt tolerant varieties produced highest grain yield.

Many efforts have been made to release salt tolerant wheat varieties in the country. In this process varieties such as Roshan, Kavir, Bam (a double haploid line) and Bank /Vee "S" and 1–63–31/3/12300/Tob//Cno/Sx are released for saline conditions. The objective of this study was to compare yield of these salt tolerant varieties and the local wheat cultivars in the saline areas of lower part of KRB,

Materials and Methods

This study was conducted at Azadegan plain in Khuzestan province during 2005–2007. Azadegan plain is located in the lower part of KRB and lies between 31o 04’ 35” to 31o 51’ 39” north latitude and 47o 46’ 34” to 48o 35’ 12” east longitude. The study was carried out at the upper part of the valley where ground water was low in the first year.
The crops were grown in 4.0 by 7.0 m plots with each plot containing 18 rows of each genotype. The rows were spaced 0.2 m apart. Prior to planting triple super phosphate was mixed into the top 0.25 m of soil at a rate of 115 kg P ha^{-1}. To assure adequate N fertility throughout the experiment urea was added at a rate of 150 kg N ha^{-1} at planting, tillering and stem elongation. Herbicides were applied to control weeds whenever necessary.

Five salt tolerant wheat and two local cultivars were planted in level plots on 18 November, 2004 and 23 November, 2005. The salt tolerant genotypes were Bam (DH4–209–1557F3-Vee”S”/Nac/1–66–22), 1–63–31/3/12300/Tob//Cno/Sx, Bank/ Vee”S”, Kavir and Roshan. The local wheat cultivars were Chamran and Verinak. The experimental design consisted of seven wheat genotypes replicated three times in a random completely block design. The initial average ECe to a depth of 0.9 m for the whole experiment in 2004 was 9.86 dS/m while in 2005 was 6.98 dS/m at location 1 and 7.71dS/m at location 2. Salinity of irrigation water was less than 1 dS/m. During the growing season, all plots were irrigated at the same time with the same amount of irrigation water. Soil samples were collected from each two adjacent plots approximately five times during the growing season. Plant growth and developments were monitored and were rated with the Zadoks- Chang- Konzak (1974).
To determine grain and straw yield of each genotype, a 3.0 m2 area was harvested from the center of each plot. 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

Mineral composition of soils at sites1 (upper part) and 2 (lower part) in Azadegan plain is presented in Tables 1 and 2. Soil samples from all depths are medium to heavy textured saline sodic soils. One can conclude that this high sodium adsorption ratio in addition to the fine size of soil particles will lead to problems of infiltration rate and waterlogging. Poor organic matter, and as a result low nitrogen content, are the most obvious fertility aspects of soils. The soils are poor in available phosphorus content except of the topsoil in the site 2.Generally, the available potassium in site 2 is somewhat fair and a bit potassium deficiency in site 1 is felt.

Root zone salinity

Crops were irrigated five times during the growing season with irrigation water diverted from Karkheh river. Salinity of river water was around 1 dS/m. The relatively good quality of 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. As shown in Fig. 1, the average soil salinity during growing season was 5.13 and 10.45 dS/m at site 1 and 2, respectively. Site 2 was located in the lower part of the valley where water table was much higher than site 1 located in the upper part of valley. Therefore, crops were affected by salinity during the growing season in addition to other environmental stresses (i.e., waterlogging and end of the season hot stress).

Grain yield:

Statistical analysis of combined grain yield for 2 years at site 1 showed that yield performance of the genotypes varied significantly. Among the genotypes, Bam and Bank/Vee"S" showed highest yields, while Verinak and 1–63–31 produced the least regardless of the year (Fig. 2). The mean grain yields of these genotypes were 432.8, 409.8, 280.1 and 318.5 g.m-2, respectively. Interaction between year and genotypes did not induce significant effect on grain yield, However, mean yield comparison of genotypes in each year using DMRT test showed that Bam variety was most productive in both the years (Table 3). Again, Verinak showed the lowest grain yield compared to the other varieties (Table 3). The range of grain yields of genotypes were 266.67–446.67 and 293.51–430.10 g.m-2 at site 1 and 2, respectively (Table 3). These data showed that the higher salinity at site 2 reduced grain yield more than 50% regardless of genotypes.
Comparison of mean yield at site 2 in the second year showed that Bam and Kavir produced more grain yields than the others; however, this was not significant different (Fig. 3).

Biological yield

The differences in biological yields of genotypes were significant. The highest biological yield was found for Bam (1386.7 g.m-2) cultivar. Verinak (775.6 g.m-2) and 1–63–31 (870.0 g.m-2) produced the lowest biological yields (Fig. 4). The biological yields of Kavir, Roshan and Bank/Vee "S" were not significantly different when compared with Bam cultivar (Fig. 4). The differences among straw yields of genotypes were the same as of biological yields for all genotypes (Fig. 5).

1000 kernel weight:
The mean of 1000 kernel weight (1000 KW) at site 2 (35.96g) was significantly higher than at site 1 (32.93g), regardless of genotypes. The main causes of this reduction in 1000 KW at site 1 were lodging and greater number of kernels in each spike. There was not a significant difference among genotypes in terms of 1000 KW at site 1, but Verinak and Kavir had the highest and lowest 1000 KW at site 1, respectively (Table 4). Bank/Vee"S" had the highest 1000 KW at site 2, however, the differences among Roshan, Bam and 1–63–31 and Bank were not significant. Chamran, Verinak and Kavir also had the lowest 1000 KW at site 2 (Table 4). Thousand KW is a genetic trait and is not generally affected by environmental stresses (Hay & Walker, 1989). However, severe stresses like salinity (Shannon, 1997) and lodging (Hay & Walker, 1989) can markedly reduce 1000 KW.

Morphological traits
From the present study it appears that all genotypes had the same main stem leaf number, and equal times for initiation of emergence, tillering and stem elongation stages. In spite of this, Bam and Bank/Vee "S" showed higher yield than the others. There are many genetic factors which affect grain yield under saline conditions, such as number of tillers and leaf area duration index (Hay & Walker, 1998). As shown in table 5, salt tolerant genotypes produced more tillers than the local varieties. Roshan produced more tillers during the growing season (Table 5), but it lodged at the end of the season and its grain yield was markedly reduced.

The other very important factor affecting grain yield under stressed condition, is the leaf area duration index or grain filling period. It is interesting to note that Bam had the highest ground cover and grain filling period (field observation). This allows for more mobilization of soluble carbohydrates from other parts of plant to developing grains. Short grain filling period could be a factor causing low yield in some varieties like Verinak

Therefore, variation in genetic aspects of salt tolerant varieties (Shannon, 1997) can be exploited for selecting the crops which could produce satisfactory yield under saline condition.

Conclusions

Based on the results of this study varieties like Bam, Bank/Vee"S" and even Kavir could be considered to be more tolerant than the other varieties under saline (also waterlogging) conditions of lower KRB.

Table 1: Physico-chemical properties of soil at site 1 (upper part of Plain).

Depth (cm)	Texture	ECe	SAR (dS/m)	K^+	Na^+	Mg^{2+}	Ca^{2+}	$So4^{2+}$	Cl^-	Hco_3	K(av.) (ppm)	P(av.) (ppm)	Total N (%)	O.C. (%)
				Meq./lit.										
0-30	L	13.09	16.63	0.89	91.06	28.56	31.44	61.53	81	2.5	102	10.16	0.019	0.22
30-60	SL	9.81	14.46	0.46	70.28	17.72	29.52	65.08	40	2.5	78	-	0.011	0.13
60-90	L	9.57	16.00	0.44	71.9	14.4	26	70.12	30	2.55	84	10.42	-	-

Table 2: Physico-chemical properties of soil at site 2 (lower part of Plain).

Depth (cm)	Texture	ECe	SAR (dS/m)	K^+	Na^+	Mg^{2+}	Ca^{2+}	$So4^{2+}$	Cl^-	Hco_3	K(av.) (ppm)	P(av.) (ppm)	Total N (%)	O.C. (%)
				Meq./lit.										
0-30	L	14.46	15.22	1.03	88.99	26.96	41.44	47.05	107	2.5	150	14.81	0.029	0.34
30-60	L	9.88	16.05	0.53	73.53	15.24	26.76	64.81	39	2.5	96	5.93	-	-
60-90	Si. L	10.88	21.60	0.42	90.92	9.6	25.84	79.10	36.5	2.5	115	7.3	-	-

Table 3: Comparison of mean grain yield ($g.m^{-2}$)of genotypes during 2005–06 and 2006–07.

Year	Kavir	Roshan	Bam	1-63-31	Bank/Vee	Chamran	Verinak
2004-05	405.55 ab	382.78 abc	446.67 a	320.00 bc	389.44 ab	378.63 abc	266.67 c
2005-06	390.75 ab	372.87 ab	418.87 a	317.05 ab	430.10 a	400.8 ab	293.51 b

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

Table 4: Comparison of mean of 1000KW (g) of genotypes at different sites during 2005–06.

Location	Kavir	Roshan	Bam	1-63-31	Bank/Vee	Chamran	Verinak
Site 1	29.87 b	35.63 a	32.27 ab	29.07 b	32.30 ab	35.27 a	36.10 a
Site 2	31.17 d	37.00 ab	38.18 ab	38.23 ab	40.10 a	31.83 cd	35.23 bc

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

Table 5: Phenological and morphological characteristics of wheat genotypes.

Genotypes	Main stem leaf no.	Days till emergence	Days till tillering	Days till stem elongation	Average tiller no.	Average fertile tiller	Logging (%)
Kavir	4.10	9	28	56	2.88	2.00	-
Roshan	3.33	8	26	67	4.10	2.20	25
Bam	4.01	6	23	61	3.53	2.00	-
1-63.3…	3.30	6	23	66	3.70	2.20	-
Bank/Vee	4.00	9	27	66	4.03	2.20	-
Chamran	4.30	8	25	54	2.18	1.10	-
Verinak	3.80	5	21	46	2.00	1.00	-

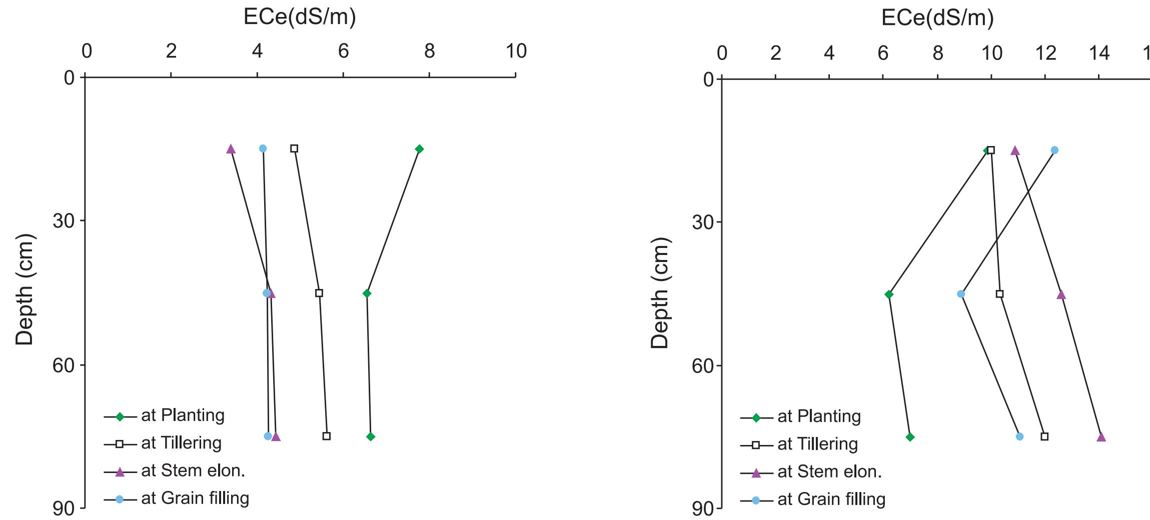

Fig. 1. Average soil salinity at different growth stages at site 1 (left) and site 2 (right).

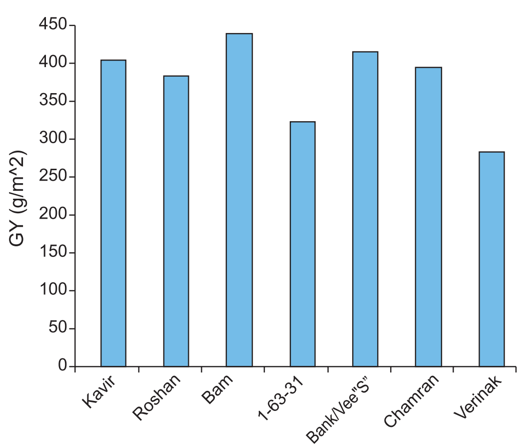

Fig. 2. Yield comparison of wheat genotypes regardless of the year at site 1.

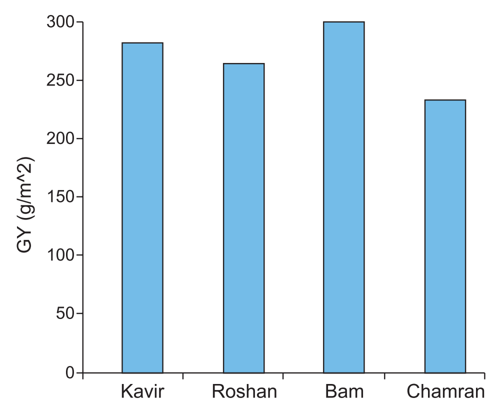

Fig. 3. Yield comparison of wheat genotypes at site 2 in the second year.

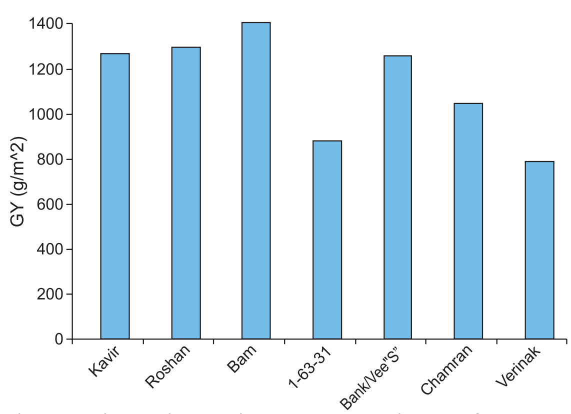

Fig. 4. Biological yield comparison of wheat genotypes.

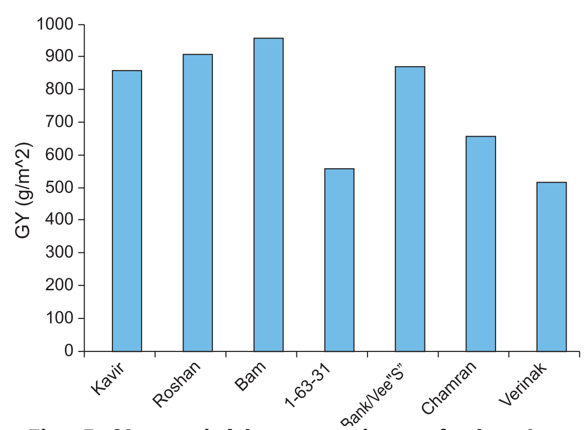

Fig. 5. Straw yield comparison of wheat genotypes.

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Comparisons of Yield of Several Sorghum Cultivars in Saline Areas of KRB

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Abstract

To compare the performance of forage sorghum varieties under saline conditions, a field experiment was conducted in a randomized complete block design (RCBD) with 3 replications. The treatments were 4 hybrid varieties namely, Speed feed, Sugar graze, Jumbo and Nectar and 4 purelines namely, KFS1, KFS2, KFS3 and KFS4. The result showed that fresh and dry matter production of sorghum varieties and lines was significantly different. KFS4 had the highest fodder yield of 100.67 t ha^{-1} among purelines followed by KFS2 and KFS1 lines with 92.67 and 86.33 t ha^{-1}, respectively. KFS3 line with 66.83 t ha^{-1} produced the lowest total fresh matter. Dry matter yield of purelines had the same rating. For hybrid varieties, Speed feed had the highest fodder yield (117.0 t ha^{-1}). The yield was significantly higher, at the 1% level of probability, than the yields of the other hybrid varieties. Sugar graze, Nectar and Jumbo produced 86.33, 81.93 and 70.17 t ha^{-1} respectively, and were statistically placed in the same Duncan's group.

Keywords: forage sorghum, fodder yield, variety/line and salinity.

Introduction

Sorghum is often grown in high temperate climates, relatively low rainfall condition and saline soil areas (Netondo, *et al.,* 2004a; Zulfaqar and Asim, 2002). Sorghum plant seems to withstand extreme heat better than other crops. This characteristics accounts, in large part, for the success of sorghum in a dry season and that is why it is called a crop camel.

Sorghum can be grown successfully as a second crop after wheat, barley, chickpea, and lentil and it can be grown as a delayed crop because of shorter growth season instead of cotton.

Sorghum is used as a grain crop by humans and also as a forage crop for poultry and livestock consumption in many developing countries. In Asia and Africa, sorghum is consumed as basic food, but in Europe and North America it is mainly consumed as poultry and livestock feed.

Sorghum is moderately tolerant to salinity (Maas *et al.,* 1986; Francois, *et al.,* 1984) and is grown in some areas of Iran such as Khuzistan, Sistan and Balochistan, Khorasa and Fars provinces. Salinity is the most important environmental stress in some part of these areas.

The effect of salinity on plant growth is a complex syndrome that involves ion toxicity, osmotic stress, mineral deficiencies, physiological and biochemical perturbations and combination of these stresses (Shannon, *et al.,* 1994; Munns, 1993; 2002; 2006; Katerji, *et al.,* 1996; 1997; 1998; Greenway and Munns, 1980; Tester and Davenport, 2003). These effects are still not well understood. According to Munns (1993; 2002; 2006) osmotic stress is effective in the beginning of exposure to salt, and ion toxicity becomes important in affecting plant growth after prolonged exposure. However, this hypothesis is still a matter of debate. Ion toxicity damage is also associated with the accumulation of Na^+ in leaf tissues and results in necrosis of older leaves starting at the tips and margins and working back through the leaf. Growth and yield reductions accure as a result of the shortening of the lifetime of individual leaves, thus reducing net productivity and crop yield (Tester ad Davenport, 2003; Munns, 1993; 2002).

Generally, substantial genotypic differences exist among sorghum cultivars in response to salinity stress (Sunseri, *et al.,* 2002; Netondo, *et al.,* 2004a, b). Yang, et al. (2003) argued that Glycinbetaine enzyme is thought to play an important role, physiologically in sorghum's adaptation to saline and environmental stresses. Improving salt tolerance of crop and pasture species requires access to new genetic diversity (either natural or transgenic), and efficient techniques for identifying salt-tolerance (Munns and James, 2003). Generally, it is very important to determine most suitable variety in any region for increase in yields.

The exiting forage production and natural fodder resources in Iran is not enough to the existing livestock population. The strategy for the enhancement of livestock production in the county should, therefore, be primarily focused on increasing forage and fodder productivity both quantitatively and qualitatively through introduction of high yielding variety/lines in sorghum cultivated areas. Variety selection on the better production basis could be one of the shortest ways to overcome the existing dry matter deficiency and improve livestock performance in the sector. The aim of the present study was to compare the performance of forage sorghum varieties under saline conditions of Dasht-e-Azadegan, Khuzestan province.

Materials and Methods

The experiment was conducted at Dasht-e-Azadegan, Khuzestan province, during spring and summer of 2006. The experiment was laid out in randomized complete blocks design with 3 replications. The treatments were 4 hybrid varieties namely Speed feed, Sugar graze, Jumbo and Nectar and 4 purelines namely KFS1, KFS2, KFS3 and KFS4.

Each plot was 6.0 m long and 1.8 m wide and contained 6 rows, which were spaced 0.3 m apart. Fertilizer was applied before sowing at a rate of 100 kg of N ha^{-1}, 144 kg of P_2O_5 ha^{-1} and 75 kg of K_2O ha^{-1}. Also 100 kg ha^{-1} of N ha^{-1} were added after each cut.

Leaf and stem weight were obtained through destructive sampling on 3 representative plants at harvest time. Plant samples were then dried in the oven at 68°C for 48 hours to estimate dry masses. The same data reported for leaf and stem masses of plant was also used to calculate leaf to stem ratio. Plant height was also reported on the same plant sample in each variety at each cut.

For obtaining fresh and dry matter yield, a 1 square meter plot was harvested from central rows. A sample of 2 kg fresh matter was dried in the oven to estimate the dry matter yield.

All data were analyzed using SAS statistical package. Means found significant were tested using Duncan's test at 5% level of probability.

Results and Discussions

Fodder yield

Fresh matter product of sorghum varieties/lines was found to be significantly different (Table 1). KFS4 gave maximum fresh matter of 69 t ha^{-1} in the first cut, followed by KFS2 and KFS1, with 58.17 and 57.00 t ha^{-1} respectively, which were not significantly different. A minimum of 49.00 t ha^{-1} fresh matter was observed for KFS3 in the 1'st cut (Table 2). The highest fresh matter obtained for KFS4 could be due to its maximum height in the 1'st cut and also to its high number of tillers (Table 2). Purushotham and Sidaraju (1998) argued that tallest plants yield maximum production.

In the next cut, the maximum fresh matter was measured for KFS2, with 34.50 t ha^{-1} followed by KFS4 and KFS1 with 31.67 and 29.33 t ha^{-1}, respectively, which were not significantly different. Also, a minimum of 17.83 t ha^{-1} fresh matter yield was observed for KFS3 again, which was significantly different from other lines at 5% level of probability (Table 2).

For total fresh matter yield, KFS4 line showed the highest yield of 100.67 t ha^{-1} followed by KFS2 and KFS1 lines with 92.67 and 86.33 t ha^{-1}, respectively, but with no significant difference. KFS3 line with 66.83 t ha^{-1} produced the lowest yield and it was significantly different from other lines at 1% level of probability (Table 2).

For hybrid varieties, Speed feed produced the maximum fresh matter yield (67.33 t ha^{-1}) in the 1'st cut followed by Sugar graze and Nectar, with 56.00 and 53.22 t ha^{-1}, respectively, which were not significantly different. There was significant correlation between height of plant and fodder yield (Table 4). Jumbo had the lowest productivity in all cuts (Table 3).

Speed feed also produced the maximum yield of 49.67 t ha^{-1} in the next cut. Therefore, overall it had the maximum total fresh matter yield of 117.00 t ha^{-1}, which was significantly different at 1% level of probability compared to other hybrids. Sugar graze, Jumbo and Nectar showed a low yield of 33.33, 30.88 and 28.67 t ha^{-1} in the next cut, respectively. Overall, these hybrids produced 89.33, 81.93 and 70.17 t ha^{-1}, respectively with no significant difference among them (Table 3).

Based on the above, KFS4 and Speed feed showed highest fodder yield among purelines and hybrid cultivars, respectively.

Dry matter

Dry matter production of the sorghum purelines was not found significantly different in the 1'st cut, but it was found to be significantly different in the next cut at 1% level of probability and was found significantly different in total dry matter production at 5% level of probability(Table1).

The highest dry matter yield of 23.55 t ha^{-1} was measured for KFS4, followed by KFS2 and KFS1, with 22.80 and 20.56 t ha^{-1}, respectively, which were not significantly different. KFS3 produced minimum total dry matter of 17.03 t ha^{-1} among lines (Table 2).

The total dry matter production of hybrid varieties differed significantly from one to another (Table 3). The highest total dry matter yield of 28.31 t ha^{-1} was measured for Speed feed variety. Sugar graze and Nectar produced the next highest dry matter of 22.27 and 18.69 t ha^{-1}, respectively. Both varieties' total dry matter was not significantly different.

The minimum total dry matter of 17.07 t ha^{-1} was measured for Jumbo variety among hybrid varieties. This minimum fresh and dry matter could be due to less tillers per plant (Table 3). There was significant correlation between number of tiller and height with yield (Table 4). This finding is in agreement with the observation made by Zulfaqar and Asim (2002).

Conclusions

Selection of a variety/line should be based on highest production, both in fresh matter and dry matter yield. Based on the above results, KFS4 and KFS2 produced highest fresh and dry matter yield among the lines. Generally, there was significant correlation among height of plant and number of tillers with fresh and dry matter yields. For hybrid varieties, Speed feed showed the highest fresh and dry matter yield in comparison to other hybrids. These varieties are common among farmers in Dasht-e-Azadegan.

Table 1: Analysis of variances

Hybrid /line	SOV	Tiller	height		Leaf/stem		Fresh matter yield			Dry matter yield		
			Cut 1	Cut 2	Cut 1	Cut 2	Cut 1	Cut 2	Total	Cut 1	Cut 2	Total
Hybrid	Replication	1.18^{ns}	31.75^{ns}	57.65^{ns}	0.03^{ns}	0.002^{ns}	9.41^{ns}	20.69^{ns}	47.51^{ns}	0.12^{ns}	0.17^{ns}	0.36^{ns}
	Variety	1.20^{ns}	259.19*	754.08^{ns}	0.02^{ns}	0.02^{ns}	397.42*	273.80*	1187.26 **	16.22 *	22.86 **	74.39**
	Error	0.84	84.19	466.87	0.014	0.03	132.90	43 .80	119.25	2.94	1.97	3.48
	%C.V	13.91	5.50	18.98	12.38	14.80	21.35	18.58	12.19	13.04	16.67	8.64
Line	Replication	1.47^{ns}	533.91^{ns}	640.23*	0.05*	0.04^{ns}	1048.77*	31.77^{ns}	926.69 *	47.73 *	2.58^{ns}	43.10 *
	Variety	2.15^{ns}	669.67*	26.71^{ns}	0.01^{ns}	0.008^{ns}	202.69*	160.39*	625.46 **	4.20 ns	9.61 **	25.68 *
	Error	1.50	206.47	36.44	0.006	0.009	59.27	19.08	59.71	4.11	0.52	3.75
	%C.V	24.28	12.79	8.11	9.00	9.62	13.21	15.41	8.92	14.64	10.12	9.23

Table 2: Means of pure-lines by Duncan's multiple test (P≤0.05).

Characteristics line	Tiller	Height (cm)		Leaf/stem		Fresh matter yield (t ha^{-1})			Dry matter yield (t ha^{-1})		
		Cut 1	Cut 2	Cut 1	Cut 2	Cut 1	Cut 2	Total	Cut 1	Cut 2	Total
Hybrid	Replica										
KFS$_1$	4.73 b	101.82 b	75.60 a	0.84 a	1.06 a	57.00 ab	29.33 a	86.33 a	13.59 a	6.97 b	20.56 ab
KFS$_2$	5.97 a	100.93 b	72.13 a	0.88 a	0. 98 a	58.17 ab	34.50 a	92.67 a	14.29 a	8.50 a	22.80 a
KFS$_3$	4.03 a	113.80 ab	71.77 a	0.94 a	0.93 a	49.00 b	17.83 b	66.83 b	12.39 a	4.64 c	17.03 b
KFS$_4$	5.47 a	133.00 a	78.03 a	0.80 a	1.00 a	69.00 a	31.67 a	100.67 a	15.19 a	8.36 ab	23.55 a

Table 3: Means of hybrid varieties by Duncan's multiple test (P≤0.05)

Characteristics line	Tiller	Height (cm)		Leaf/stem		Fresh matter yield (t ha^{-1})			Dry matter yield (t ha^{-1})		
		Cut 1	Cut 2	Cut 1	Cut 2	Cut 1	Cut 2	Total	Cut 1	Cut 2	Total
Speed feed	7.43 a	178.33 a	136.67 a	0.88 a	1.13 a	67.33 a	49.67 a	117.00 a	15.96 a	12.35 a	28.31 a
Sugar graze	6.47 a	169.33 ab	108.53 a	0.93 a	1.25 a	56.00 ab	33.33 b	89.33 b	13.86 ab	8.41 b	22.27 b
Nectar	6.60 a	156.67 b	100.03 a	1.06 a	1.20 a	53.27 ab	30.83 b	81.93 b	12.29 b	6.58 b	18.69 bc
Jumbo	5.90 a	162.67 ab	110.07 a	0.97 a	1.05 a	39.33 b	28.67 b	70.17 b	10.49 b	6.41 b	17.07c

Table 4: Correlation coefficient among characteristics.

	FMY1	DMY1	FMY2	DMY2	TFM	TDM	TILLER	HIEGHT1	$HIEGHT_2$
FMY_1	1.00	0.91**	0.39*	0.35^{ns}	0.87**	0.81**	0.49*	0.61*	0.12^{ns}
DMY_1		1.00	0.13^{ns}	0.32^{ns}	0.77**	0.86**	0.57*	0.41*	0.09^{ns}
FMY_2			1.00	0.93**	0.64**	0.60**	0.50*	0.49*	0.65**
DMY_2				1.00	0.73**	0.76**	0.51*	0.45*	0.59*
TFM					1.00	0.93**	0.48**	0.85**	0.42*
TDM						1.00	0.46*	0.25*	0.38*
TILLER							1.00	0.57*	0.21^{ns}
$HIEGHT_1$								1.00	0.83*
$HIEGHT_2$									1.00

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Comparisons of Yield of Several Barley Genotypes in Saline Areas of KRB

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Abstract

To introduce compatible barley genotypes for saline areas of lower KRB, a 2-year field study comparing yield of six barley genotypes was conducted in Dasht-e Azadegan plain, Khuzestan province, during 2005–2007. The varieties were two barley cultivars (Afzal & Reyhan) and four barley lines (Karon× Kavir, M-80–9, M-80–19 and On-4). The experiment was carried out in a random complete block design with three replications. The experiment was replicated at two locations in the second year. Results from the first year showed that On-4 and Reyhan had the highest and lowest grain yields, respectively. There was not any significant difference among other lines. Results from the second year showed no significant differences between the two locations. On-4 and M-81–19 produced higher grain yield compared to the others in this year. Afzal also had the lowest grain yield regardless of the location. Based on these results, On-4 and M-81–19 lines could be considered as new barley sources for lower parts of the KRB.

Key words: Barley, Salinity, Grain yield, KRB

Introduction

The lower part of KRB is now facing the dual problems of salinity and waterlogging. These problems are intensified in irrigated areas where over irrigation and improper land use raises the water-table and facilitates soil salinization process.

A wide range of options are available for tackling salinity and waterlogging, but technical, economical, social and even political considerations are some of the factors which influence their applications on a large-scale. The prime approach for successful crop production in saline/waterlogged soils is by providing natural or artificial drainage systems (Rhoades, *et al.,* 1992). For sustainable crop production in saline soils after providing the necessary drainage systems, adaptation of specific system of management is advocated based upon the soil-crop and climatic factors at the site (Minhas & Sharma, 2004). An applicable approach for use of saline soil is through selection of appropriate crop cultivars (Rhoades, *et al.,* 1992, Minhas & Sharma, 2004). Varieties of crops differ considerably in their ability to tolerate salinity and these differences can be exploited for selecting the varieties, which produce significant yield under saline conditions.

Barley is one of the most-salt tolerant crop species, but there are wide variations among its genotypes under saline conditions. Wild genotypes, generally, can grow under a range of soil conditions varying from non-saline to highly saline conditions (Sahayda, *et al.,* 1992). Experiments on determining the relative yield responses of commercial barley cultivars under NaCl salinity showed that some varieties were more salt tolerant than the others (Suhayda, *et al.,* 1992). Other investigations have shown that some barley varieties developed primarily for high yield in saline region of Pakistan, India, Egypt and the United States have better salt-tolerance than varieties developed in non-saline areas (Minhas & Sharma, 2004; Kingsbury & Epstein, 1986). These differences provoked extensive screening for salt-tolerance among thousands of barley accessions of the world collection (Kingsbury & Epstein, 1984). The objective of this study was to compare grain yield of some barley genotypes under saline condition to introduce the most productive and salt tolerant varieties for the lower areas of KRB.

Materials and Methods

A field experiment was conducted in Azadegan plain, Khuzestan province, during 2005–2007. The experiment was replicated at two sites in the second year. The field at site 1 was underlain by a low water-table (1.8 m deep) with a good drainage system. The location of site 2 was in the center of the plain having saline soils and high saline water-table (0.8 m deep).

The treatments included two barley cultivars (Afzal & 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 planted on November 18, 2005 and November 23, 2006. Barley rows were spaced 0.2 m apart with sowing density of 350 seeds per m^{-2}. Each plot was 4.0 by 6.5 m, so that eighteen rows of each genotype were sown in every plot.

All plots were fertilized with 25 kg N ha^{-1} of urea and 85 kg P ha^{-1} of triple super phosphate before planting. At tillering and stem elongation, 50 kg N ha^{-1} of urea was used as top dressing to each plot. Herbicides were applied to control weeds whenever necessary.

All plants received adequate amount of water during the growing season. Irrigation water for the experiments was taken directly from the Karkheh River. The electrical conductivity of river water was always below 1 $dS.m^{-1}$ during the experiment. At harvest, a 3.0 m^2 area was harvested from the center of each plot. Data were analyzed using analysis of variance techniques. DMRT test was used to differentiate between measured yields across the genotypes.

Results and Discussion

Soil characteristics at the two sites are presented in tables 1 and 2. Soil samples from all depths in site 2 are saline sodic soils. It seems that this high sodium adsorption ratio, in addition to the fine size of soil particles, lead to problems of infiltration rate and waterlogging. Poor organic matter content and as a result low nitrogen content are the most obvious fertility aspects of soils of two sites.

All the genotypes produced the same grain yield in the first year except for Reyhan. The maximum grain yield was obtained from On-4 line (372.60 $g.m^{-2}$) (Fig. 1). Afzal was lodged completely in the first year and was omitted from the analysis.

Combined analysis of variance in the second year showed that the location did not have any significant effect on the grain yield of genotypes (Table 3). In fact, the yield performance of each genotypes was the same at two locations, so the interaction between location and genotype did not significantly affect grain yield of genotypes (Table 3).

The effect of genotype on grain yield was significantly different (Table 3). On-4 and Afzal produced the highest and lowest grain yield, regardless of the location (Fig. 2). The mean grain yield of On -4 and Afzal were 344.88 and 162.11 $g.m^{-2}$, respectively. Grain yield of other genotypes were not significantly different when compared to On-4.

The mean ECe at site 2 was markedly higher than site 1 (Fig. 3), but the yield performance of each genotype was approximately the same at two locations (Table 4). It seems that lodging and salinity were the most limiting factors at site 1 and 2, respectively. High yielding barley crops are always tall plants (Hay & Walker, 1989). Thus, under normal conditions (site 1), the grain yield could be decreased significantly by lodging.

As shown in table 5, all genotypes were lodged at site 1 during 2005–06 and 2006–07. However, the percentages of lodging among genotypes were different and it was the main factor that reduced grain yield of varieties at this site.

At site 2, all genotypes had erect stem throughout the growing season (lodging was not observed, Table 5). Thus, the main factor that could be related to the reduction of grain yield was salinity stress. Many studies show that salinity reduces grain yield of barley, but generally, genotypes with the highest yield in non-saline condition are also the most productive at medium and high salinities. In other words, when the other conditions are the same (climate, soil texture, irrigation depth, etc.) productive genotypes in non-saline conditions produced significant yield in saline conditions. Therefore, the locations of the experiments did not have any effect on the performance of barley genotypes.

Thousand KW(1000 KW) of genotypes were significantly different (Table 3). On-4 and Afzal had the highest and lowest 1000 KW when compared to others (Fig. 4). However, 1000 KW of Karon × Kavir and Reyhan were not significantly different compared to On-4. The relationship between location and genotype of this trait was significantly different (Table 3). In addition, 1000 KW of genotypes at site 2 was higher than at site 1(Table 6). Since salinity reduces the number of tillers and kernel per spike, therefore, the mean kernel weight was increased (Francois, *et al.,* 1986).

Conclusion

Based on the results of this study, On-4 and M-81–19 lines could be considered as new barley sources for the lower parts of the KRB.

Table 1: Physico-chemical compositions of soil at site 1(upper part of Plain)

Depth	Texture	ECe	SAR	K^+	Na^+	Mg^{2+}	Ca^{2+}	$So4^{2+}$	Cl^-	Hco_3^-	K(av.)	P(av.)	Total N	O.C.
(cm)		(dS/m)		Meq./lit.							(ppm)	(ppm)	(%)	(%)
0-30	Si.C	1.85	2.83	0.26	7.34	4.6	8.8	4.91	7	5	129	8.57	0.023	0.27
30-60	S.L	2.52	2.42	0.32	9.36	7.92	22	25.35	7.5	2.5	84	6.72	-	-
60-90	S.L	2.59	1.95	0.32	8.37	10.92	26.08	34.96	4.5	2.5	78	6.46	-	-

Table 2: Physico-chemical compositions of soil at site 2(Lower part of Plain)

Depth	Texture	ECe	SAR	K^+	Na^+	Mg^{2+}	Ca^{2+}	$So4^{2+}$	Cl^-	Hco_3^-	K(av.)	P(av.)	Total N	O.C.
(cm)		(dS/m)		Meq./lit.							(ppm)	(ppm)	(%)	(%)
0-30	L	23.6	25.05	1.22	178.55	38.16	63.44	45.4	230	2.85	109	11.85	0.020	0.23
30-60	L	11.76	12.56	0.7	69.13	21.12	39.48	38.64	85	2	115	9.89	-	-
60-90	Si.C.L	7.11	12.61	0.43	50.88	7.16	25.4	55.54	18.65	2.25	135	7.88	-	-

Table 3: Mean squares of grain yield and 1000KW of barley genotypes.

Source	df	Grain yield	1000 kw
Site	1	4430.01^{ns}	17.78^{ns}
Error 1	4	7187.6	7.32
Genotype	5	28670.18**	46.79**
Site ×Genotype	5	5115.47^{ns}	31.40**
Error 2	20	6535.30	6.93

**: significant at the 1% levels of probability. Ns: not significant.

Table 4: Comparison of mean grain yield ($g.m^{-2}$) of barley genotypes at two sites

Site	Karon x Kavir	Afzal	Reyhan	M81-19	M80-9	On-4
1	315.75 a	101.03 b	306.93 a	340.37 a	257.78 a	362.80 a
2	290.67 ab	223.18 b	355.88 a	335.83 a	285.25 ab	326.97 ab

† means followed by the same letter as each row were not significantly different (Duncan 5%)

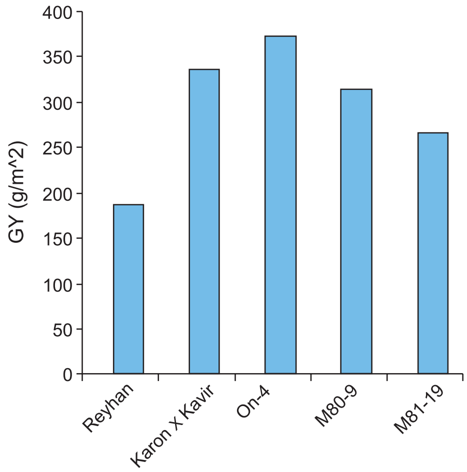

Fig. 1. Yield comparison of barley genotypes during 2005-06.

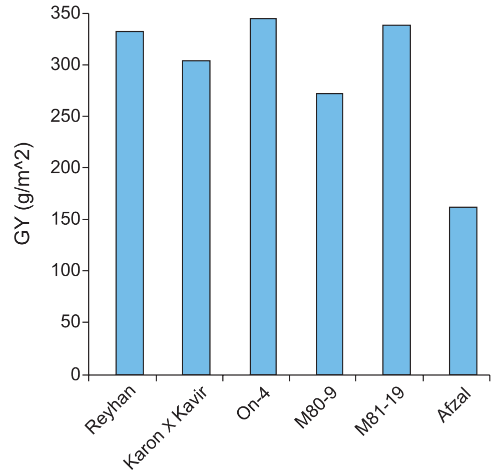

Fig. 2. Yield comparison of barley genotypes regardless of the locations during 2006-07.

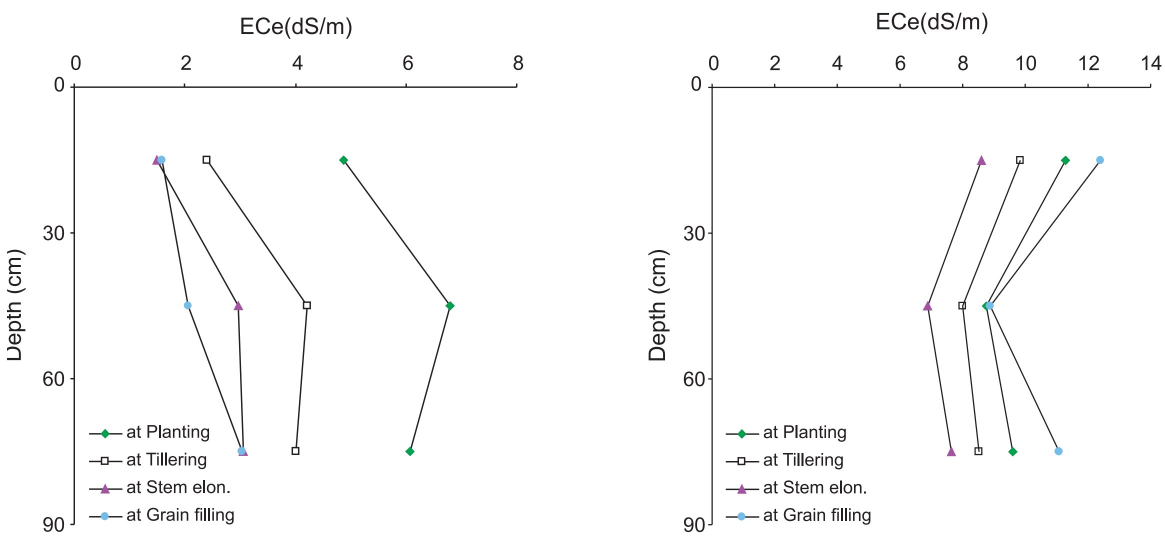

Fig. 3. Average soil salinity at different growth stages at site 1 (Left) and site 2 (right).

Table 5: Lodging percentage of barley genotypes during 2005–06 and 2006–07.

Genotypes	Lodging (%)		
	2005-06	2006-07	
		Site 1	Site 2
Karon × Kavir	10	15	-
Afzal	100	60	-
Reyhan	40	10	-
M81-19	5	10	-
M80-9	5	5	-
On-4	5	5	-

Table 6: Comparison of mean of 1000KW of genotypes at different sites during 2006–07.

Site	Karon × Kavir	Afzal	Reyhan	M81-19	M80-9	On-4
1	38.50 b	28.03 d	37.89 b	34.33 c	36.90 bc	41.73 a
2	38.20 ab	37.97 ab	40.43 a	39.40 c	36.37 bc	38.43 ab

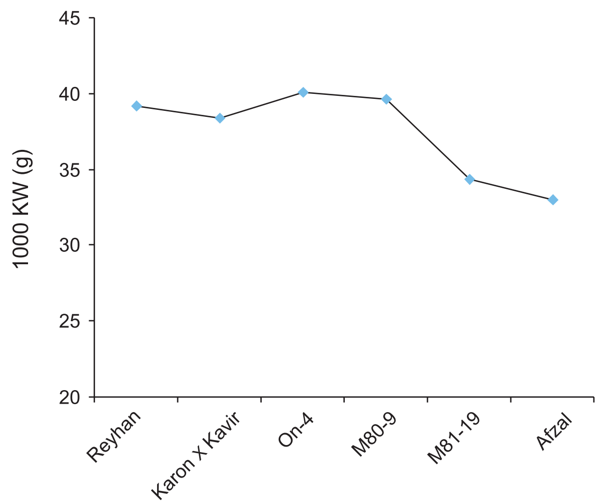

Fig. 4. Comparison of mean of 1000KW g of barley genotypes during 2005-06 regardless of sites.

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Determination and Evaluation of Water Productivity in the Salt-Prone Areas of Lower KRB, Iran

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Abstract

KRB (KRB) is one of the most important basins in Iran regarding water resources, where both rainfed and irrigated agricultural production systems prevail. Waterlogging and soil salinity are the major threats to water productivity and sustainable agricultural production in the southern parts of lower KRB. In the southern parts of L-KRB, mainly in Dasht-e Azadegan plain (DA), available data and surveys show that the problem of soil salinity is magnified due to lack of farmers' knowledge and skills, inadequate drainage networks, and the absence of new and improved farming practices. In general, the main cause of soil salinity in the L-KRB is the high watertable, usually varying between 1.2–3.0 m below the soil surface. More than 78% of agricultural production in Dasht-e Azadegan region is dominated by grains, mainly wheat and barley. The main objective of this research was to determine and evaluate the water productivity (WP) of irrigated wheat as a major cultivated crop in DA, and to recommend simple and applicable management guidelines for better management of irrigation and amelioration of salinity-waterlogging hazards on crop yield and WP. The research was conducted in seven farmers' fields, typical of the farms in the region, during the cropping season of 2006–07. Based on the total applied water, calculated ET, and crop yield, wheat water productivity values were calculated and determined. Analysis of measured WPs indicated that the range of variation in WP values is relatively high and varies between 0.2–2.0 kg m^{-3}. Evaluation of results indicate that sources of inefficiencies and the limiting factors affecting WP in southern part of L-KRB have combined effects and can be classified into four main categories: Socio-cultural problems governing the region leading to low motivation for investment in irrigation management and on-farm improvement activities by the farmers; limitations that are out of farmer's management control and authority (e.g., irrigation intervals and rationing, and shortage of agricultural inputs like 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 should be supported by the government; managerial problems and limitations that have simple solutions, do not need much investment, and can be accomplished easily.

Keywords: Water productivity, Salinity, Karkheh, Evaluation

Introduction

Agriculture plays an important role in the economy of Iran. It accounts for 18% of the Gross Domestic Product (GDP), 25% of employment, supply of more than 85% of food requirements, 25% of non-oil exports, and 90% of raw materials used in the Industries (Keshavarz *et al.,* 2003). The climate of Iran is one of great extremes due to its geographic location and varied topography. Approximately, 90 percent of the country is arid and semi-arid. The summer is extremely hot with temperatures in the interior reaching as high as 55°C. Water resources management in such extreme environments is a great challenge.

Despite large reliance of the country on agriculture, especially irrigated agriculture, water resources required for the agricultural production is limited. Therefore, availability of fresh water resources is the most limiting factor and vital input for agricultural production in Iran.

Currently, more than 93% of water consumption (84 BCM) is used for irrigation of 8.1 million hectare of irrigated agriculture. As agriculture, in general and irrigated agriculture in particular, is the greatest consumer of water in the country's economical sectors, the major losses of water occur in this sector.

Considering the growing demand for water for industry and municipalities, combined with environmental concerns, there will be less water for agriculture in the country in future. Therefore, agricultural water use efficiency has to be increased.

Based on the latest agricultural statistics, the country produced 67 million tons agricultural products from 84 BCM of water consumed. Therefore, currently the country's average WUE is almost 0.8 kg m^{-3} which seems quite low in comparison to the world's value. Based on farmer's field studies that were conducted in five regions in the country namely Kerman, Hamedan, Moghan, Golestan, and Khuzestan, the crop Water Use Efficiency (WUE) for the irrigated wheat, sugar beet, sugarcane, potato, silage corn, cotton, alfalfa, barley, and chickpea was in the range of 0.56–1.46, 0.59–1.28, 0.31, 1.45–3.0, 6.46, 0.73, 1.48, 0.56, and 0.18 kg m^{-3} respectively (Heydari *et al.,* 2006).

However, there are not any literature on the measurement and assessment of WUE in the LKRB. Based on rough estimates concluded from farmers field visits and questionnaire on crop yield and applied water, WUE of irrigated wheat for instance in this area is quite low and is about 0.6 kg m^{-3}. KRB (KRB) is one of the important basins in Iran regarding water resources and both dry-land and irrigated agricultural production systems. Water in KRB is limited and becoming scarcer as population and demand are increasing. The productivity of rain-fed agriculture is very low, conventional irrigation management is poor, cropping systems are sub-optimal, and policies and institutions are weak (Anonymous, 2007). Despite these constraints, Iran's agricultural strategy identifies water productivity improvement as a top priority.

The challenges for the rural households in the upper catchments of the KRB are similar to the ones in other dry areas. As agricultural options are limited, wheat and extensive sheep rearing dominate the landscape. Agricultural output is usually low and unstable, due mainly to resource degradation and unpredictable droughts (Anonymous, 2007). Irregular rainfall on poorly vegetated hill slopes results in severe soil erosion, downstream flooding and sedimentation. Consequently, the lifetime of the Karkheh Dam reservoir is dwindling rapidly. These environmental constraints combined with their economic problems make this southwest corner of Iran one of the poorest of the country with a very high out migration rate (Anonymous, 2007).

KRB (KRB) is one of the important basins in Iran regarding water resources. Water in KRB is limited and becoming scarcer as population and demand are increasing. Two major agricultural production systems i.e., dry-land and irrigated systems, prevail in the KRB. The dry-land system prevails in the upstream basin and the fully irrigated areas are located in some part of upstream and of the entire downstream of the KRB. The dry-land areas are well established and cover most of the basin's agricultural lands, occupying 894125 ha. It is estimated that about one million ha are irrigable in KRB, of which about 380,000 ha are currently under irrigation. About 340,000 ha of additional available arable lands will be brought under irrigation following the construction and completion of the irrigation networks under Karkheh reservoir Dam.

Presently, the productivity of rain-fed agriculture is very low, conventional irrigation management is poor, cropping systems are sub-optimal, and policies and institutions are weak (Anonymous, 2007).

Salinity stress posses one of the most serious threats to food production and sustainability of natural resources in Iran. Salt-affected soils are present in many parts of the country, particularly in the Central Plateau.

Average yields of the common crops vary according to locations and climatic condition. However, they are generally lower than the potential yields. There are a number of natural, technological, and man-made reasons for the relatively low yields obtained under farmers' condition. Waterlogging and soil salinity are the major threats to water productivity and sustainable agricultural production in the southern parts of lower KRB (Hajrasuliha, 1970).

Heavy soil texture and recharge from upstream areas cause natural condition for waterlogging and secondary salinization. It is more induced by huge water losses caused by low irrigation efficiency of irrigated agriculture in the region. If left alone, the problem is likely to worsen with the current plans for expansion of irrigation networks in the region.

In the L-KRB, because of the differences in factors affecting agricultural water productivity, two distinct regions i.e., northern and southern parts, can be identified. In the northern part, there are not much limiting factors regarding soil and water quality. In this area, it seems that enhancing farmers' skills and application of appropriate farming systems can improve water productivity greatly. Limitations in water supply and irrigation water losses cause lower water productivity of crops. In the southern parts of L-KRB, mainly in Dasht-e Azadegan plain (DA), available data and surveys show that the problem of soil salinity is magnified due to lack of farmers' knowledge and skills, inadequate drainage networks, and absence of new and improved farming practices. In general, the main cause of soil salinity in the LKRB is high water table, usually varying between 1.2–3.0 m below the soil surface.

DA plain is located at the farthest southern part of the delta of Karkheh River, 20 km west of Ahwaz. This plain is located between 47' 55" to 48' 30" E longitude and 31' 15" to 31'45" N latitude and is 3 to 12 m above the mean sea level.

DA consists of fine sediments carried by Karkheh River and with an almost even surface and mild slope expands towards West and East flanks. The general slope of the plain is also towards southwest.

DA comprises of three subdivisions (or towns) namely Sosangerd (center), Hoveyzeh, and Bostan. A fourth community is identified by the Rufai town, located in the southern parts of L-KRB and near the Hawr-Al Azim Wetland that is the outlet of KRB main basin. The total population of the DA is almost 160,000, 65% of which is living in the towns. The total number of villages at present is 180 villages, a number that was nearly twice (300) before the aggressive war against Iran.

Based on the existing sociological statistics of the area the total number of the villages in DA and Hamidieh is 219 of which 96 villages have been abandoned for now. These villages are located in seven districts, namely, Nahr-e Hashem, Bostan, Bani-Saleh, Homeh, Shorfeheh, Hamd and Howeyzeh. The main cities of the region include Hamidieh, Sosangerd, Howeyzeh and Bostan.

The weather is hot in summer with mild and short winter. Annual mean temperature of the region is 23.1°C with an average precipitation of 175 mm. Annual mean evaporation in this area is 2005 mm (Mahab-e Ghods, 1993).

Current crops in Dashte-Azadegan are diversified and include cereals such as wheat, barely, and rice; vegetables such as watermelon, tomato, and cucumber, and fodder crops such as alfalfa, barely, corn, and Sudan grass. More than 78% of agricultural production in Dasht-e Azadegan region is dominated by grains, mainly wheat and barely. This is because of the poor quality of a vast area of this region due to saline-sodic soil with high toxicity, which makes cultivation of other crops almost impossible. Water supply limitation, guaranteed purchase of wheat by the Government, and the facts that wheat needs less labor, less irrigation, and less time of the farmer and his family are the main reasons for farmers' interest in wheat cultivation.

The main source of irrigation water is the Karkheh river. There are also limited irrigation networks in the region (mainly pumping from river to the canal). In the Hamidieh area (the faraway area to the border and the beginning of the plain, near to Ahvaz City), there is also a diversion dam. The main canals and drains are mainly constructed or under completion.

The salinity (EC) of groundwater and irrigation water in this area is 6–9 dS.m^{-1} and 3 dS m^{-1}, respectively. Operations of main drains started in 2003. The outlet is Hawr-al Azim wetland.

Considering the recognition of improving agricultural water productivity (WP) and its sources of inefficiencies, as one of the top priorities in Iran and especially in KRB, this research was conducted in the downstream areas of L-KRB located in the DA plain in the Khuzestan province. The main objective of this research was to determine and evaluate water productivity of irrigated wheat, as a major cultivated crop in DA and recommendation of simple and applicable management guidelines for better management of irrigation and amelioration of salinity-waterlogging hazards on crop yield and WP[1].

Materials and Methods

The research was conducted in seven farmers' fields, typical of the farms in the region, during cropping season of 2006–07. In Fig. 1 location of the selected fields are shown.

The measured parameters were water inflow and outflow; soil texture; soil and water salinity; pH; soil organic matter; the P, K, Fe, Mn, Zn, Cu of the soil; depth and quality (EC) of groundwater during growing season; and crop yield.

Crop yield and yield components were measured through 20 field samples before harvest. The amount of applied irrigation water was measured by WSC flumes. The irrigation intervals were the same as practiced by the farmers. Table 1 shows some soil and water characteristics of the studied farms, measured before planting.

Table 1: Some soil and water characteristics of the different farms

Field	Area (ha)	Soil texture	EC (soil depth 0-30 cm) (dS.m^{-1})	Depth of water table (cm)	EC of ground water (dS.m^{-1})
F1	1.05	SiL	26.4	105	8.8
F2	1.47	SiCL	10	205	39
F3	4.49	CL	52.6	180	71.5
F4	3.44	C	17	195	31
F5	1.73	C	21.5	182	48
F6	0.46	SiC	21.3	173	46
F7	5.24	C	10.5	213	8.7

[1].KRB has been selected as one of the nine bench mark basins of the CGIAR Challenge Program on Water and Food (CPWF). One of the CPWF ongoing projects addresses interventions for the improvement of on-farm agricultural water productivity in KRB. This project is carried out jointly by the International Center for Agricultural Research in the Dry Areas (ICARDA) and Agricultural Research and Education Organization (AREO). The objectives of the project are to develop biophysical interventions to improve the farm and basin water productivity and sustainable management of the natural resource base, and to develop appropriate policies and institutions supporting the project interventions to help the poor communities for the improvement of their income and livelihoods. Moreover, the project aims at strengthening and enhancing the capacity of National Agricultural Research and Extension Services (NARES) of Iran.

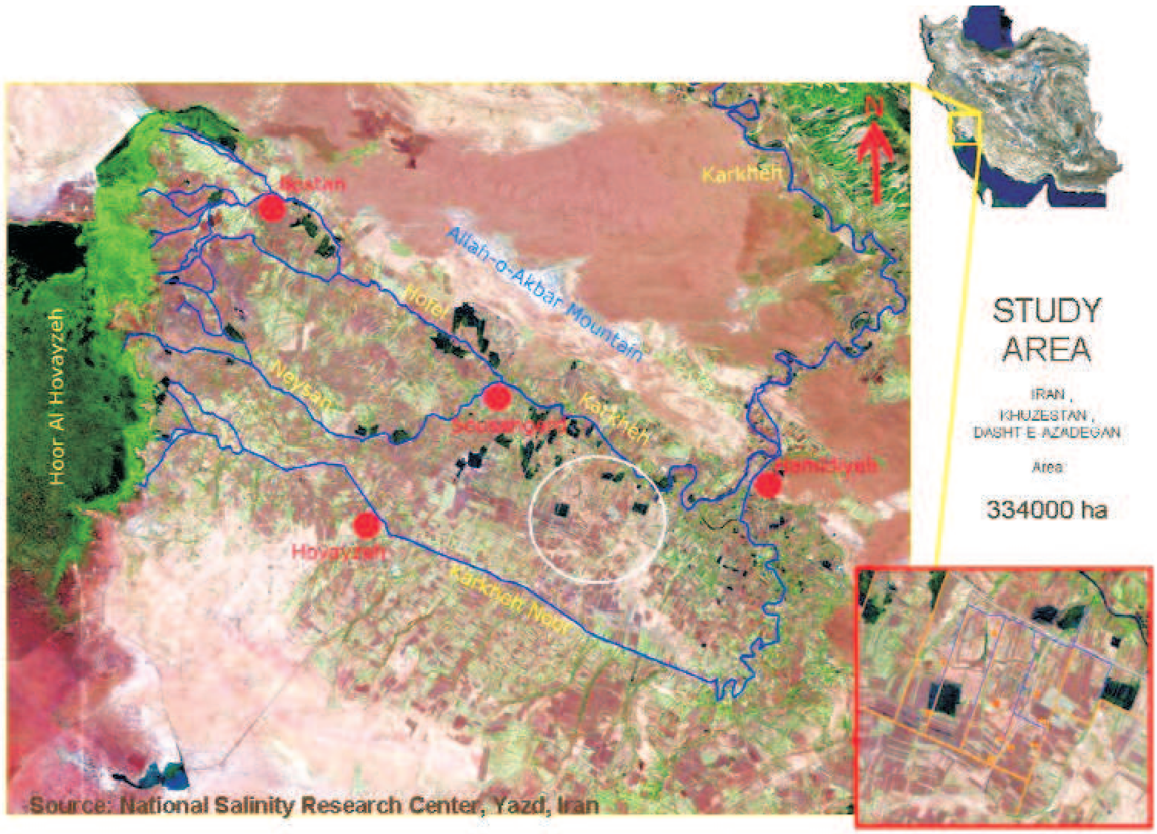

Fig. 1. Study Area.

Results

In Table 2, the results of measurement of water for different irrigation events and total applied water are provided. Based on the total applied water, calculated ET, and crop yield, wheat water productivity values were calculated and determined. The results are shown in Table 3.

Previous results of field studies conducted in three provinces, namely, Kerman, Golestan, and Khuzestan, indicated that the WP for the farmer managed irrigated wheat is in the range of 0.56–1.46 kg m^{-3} (Heydari *et al.*, 2006). Zwart and Bastiaanssen (2004) based on review of 84 references on WP during the past 25 years found out that the average WP of wheat is 1.09 kg m^{-3}. The range of WP is generally wide and, for wheat, is between 0.6–1.7 kg m^{-3}. Analysis of measured WPs in this research also indicates that the range of variation in WP values is relatively high and varies between 0.2–2.0 kg m^{-3} (Table 3).

Based on these results with increase in farm size, the amount of water consumed per unit of areas, in general, has increased. This is an indicator of the problems associated with irrigation management in larger field sizes. Lack of suitable equipment and facilities and farmers' inadequate skills in proper water management have led to higher consumption of water (even three times more) relative to the farm size.

Evaluation of the relationships between WP and consumed water; yield; initial soil salinity; initial ground water salinity; groundwater depth; and farm sizes of the selected fields indicated that there is no clear and direct correlation between WP and these factors. In other words, combinations of these factors are affecting WP and managerial factors are more effective than basic physical factors.

Table 2: Amounts of irrigation water consumed in different farms

Field	Irrigation event	Applied water ($m^3\ ha^{-1}$) 1st	2nd	3rd	4th	Total water applied ($m^3\ ha^{-1}$)
F1	Volume	1447	702	960	-	3109
	Date	Dec. 27, 2006	Feb. 3, 2007	March 26, 2007	-	
F2	Volume	1310	897	1253	-	3460
	Date	Nov. 24, 2006	Feb. 12, 2007	March 13, 2007	-	
F3	Volume	1123	939	-	-	2062
	Date	Jan. 5, 2007	March 7, 2007	-	-	
F4	Volume	1149	863	879	901	3792
	Date	Dec. 4, 2006	Feb. 8, 2007	Feb. 27, 2007	March 23, 2007	
F5	Volume	1419	878	1230	-	3527
	Date	Nov. 12, 2006	Jan. 29, 2006	March 7, 2007	-	
F6	Volume	524	576	599	612	2311
	Date	Nov. 12, 2006	Dec. 3, 2006	Feb. 9, 2007	March 19, 2007	
F7	Volume	2453	1804	1676	-	5933
	Date	Dec. 27, 2006	Feb. 20, 2007	March 19, 2007	-	

Table 3: Applied water, crop yield, and water productivity of wheat in different studied fields

Field	Water applied ($m^3\ ha^{-1}$)	ET* (mm)	Yield ($kg\ ha^{-1}$)	WP** ($kg\ m^{-3}\ ha^{-1}$)	WP*** ($kg\ m^{-3}\ ha^{-1}$)
F1	3109	517	2392	0.77	0.46
F2	3460	522	1022	0.30	0.20
F3	2062	477	1336	0.65	0.28
F4	3792	505	1453	0.38	0.29
F5	3527	553	3032	0.86	0.55
F6	2311	553	4851	2.10	0.88
F7	5933	517	1431	0.24	0.28

Therefore, sources of inefficiencies and the limiting factors affecting WP in southern part of L-KRB are combined and can be classified into four main categories as follow:

- Socio-cultural problems governing the region leading to low motivation for investment in irrigation management and on-farm improvement activities by the farmers.
- Limitations that are out of farmer's management control and authority, e.g., irrigation intervals and rationing, and shortage of agricultural inputs (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 should be supported by the government.
- Managerial problems and limitations that have relatively simple solution and do not need much investment and can be accomplished easily.

The main objective of this research was to find out the managerial problems and limitations observed in the farms studied. The results indicate that, these limitations are not similar and vary depending on the farmer, location of the farms. Some of these limitations are explained in below:

- Traditional common irrigation in the area is a mixture of border-basin irrigation method. The long borders (till 400 m) are divided into different basins (12–15 in wide). Every basin receives its water from the previous basin. The water remains for long times in the first basins before flowing into the next basins. This causes long time water stagnation in the basin and stuffiness of the seeds. As usually the inflow rate is too high, there is erosion and movement and washing off of the seeds. As there is not enough control on cutoff time, large amounts of water concentrates in the lower parts and creates surface waterlogging. It is recommended that by using a farm ditch alongside the border and proper intakes each basin can be made to receive its water individually.

- Problems in water intake and conduct of water into the irrigation plot are other issue that result in many efforts from farmer and waste of time. Finally, it causes poor water management and waste of water. It is recommended that by construction of temporary and low-cost intake structures (gates, etc.) to facilitate water intake and improve water management.

- Improper shaping of the plots with regard to land slope causes uneven water distribution in the basin.

- Improper land preparation and agronomic practices (weed control, planting date, etc.).

Considering the above limitations and problems, the following solutions are recommended:

- 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 shaping 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.

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Evaluation of the Best Management Practices for Improving Water Productivity in the Salt-prone Areas of Lower KRB

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Abstract

Waterlogging and soil salinity are the major threats to water productivity and sustainable agricultural production in the southern parts of lower KRB. In this area, mainly Dasht-e Azadegan plain (DA), heavy soil texture and recharge from upstream areas provide the conditions for water logging that is aggravated by low irrigation efficiency of irrigated agriculture. In DA, available data and surveys show that the problem of soil salinity is magnified due to lack of farmers' knowledge and skills, inadequate drainage networks, and absence of new and improved farming and irrigation practices. This study was performed in the downstream areas of LKRB located in the DA plain (Sosangerd region) in the Khuzestan province. The main objective of research was to find out cost effective and short-term solutions for solving these problems and improving agricultural water productivity (WP). The specific objectives were to investigate and compare water productivity under different irrigation and management methods (i.e., traditional versus improved border-basin irrigation method) and to investigate the effect of different cultivation and sowing methods on wheat water productivity. Results showed that border irrigation with centrifugal sowing method provided the highest water productivity, i.e., 1.6 kg m^{-3}. Among the applied irrigation methods, improved border irrigation had the maximum water productivity (1.36 kg m^{-3}), while the farmer managed treatment (traditional border-basin irrigation method under centrifugal sowing with 350 kg ha^{-1} seed) resulted in the lowest water productivity (0.61 kg/m^3). Based on our results, both improved basin or border irrigation methods can be recommended for enhancing water management and WP in the studied area. However, the basin irrigation method is more adaptive to the prevailing conditions and sustainable and is recommendable for this area.

Keywords: Water productivity, salinity, Karkheh, Water management

Introduction

KRB (KRB) is one of the main agricultural basins in Iran. Despite favorable potentials with respect to climate, soil, and water resources, the overall agricultural water productivity is relatively low, especially in the lower and downstream areas of KRB (about 0.6 kg m^{-3}). This is mainly due to the harsh climatic environment in the southern parts of the basin and the lack of sound agronomic, water, and salinity management practices.

Based on review of 84 references on WP during the past 25 years, Zwart and Bastiaanssen (2004) found out that the average WP of wheat is 1.09 kg m^{-3}.The range of WP is wide and varies between 0.6–1.7 kg m^{-3}.

Fahong et al. (2004) by comparing basin and furrow irrigation on wheat concluded that cultivation of wheat on basin surface with flood irrigation causes surface sealing, irrigation efficiency reduction, and fertilizers losses. They found that furrow irrigation of wheat lead to 17% reduction in water consumption, increased irrigation efficiency (21–30%), increased fertilizer efficiency, and reduced crop disease.

It is estimated that about one million ha are irrigable in KRB, of which about 380,000 ha are currently under irrigated agriculture annually. About 340,000 ha of additional available arable lands will be brought under irrigation following completion of irrigation networks under Karkheh Dam in the Lower KRB.

Salinity poses one of the most serious threats to food production and sustainability of natural resources in Iran. The existence of noticeable areas with saline/sodic condition in various parts of the country, especially in KRB, reflects the fact that there are many factors affecting the mentioned phenomenon. Due to heavy soil texture and high evaporation demand of the L-KRB, water logging and soil salinity are the major threats to water productivity and sustainable agricultural production in this area.

Huge government investments in the development of irrigation networks in the L-KRB and intensive water consumption and agricultural activities will cause many changes in the surface and groundwater hydrology, and in overall climatic parameters of the region (ET, relative humidity,…). On the other hand, frequent droughts and recent trends in excessive use of water in the upstream of KRB, due to expansion of irrigated areas and supplemental irrigation techniques that will be practiced in the upper dry-land areas, will pose a tough challenge to sufficient planned supply of water for the developed areas under Karkheh Dam in the L-KRB.

The soil texture in the area is mainly heavy with low hydraulic conductivity. The overall natural drainage is very low and there is natural tendency for soil waterlogging and consequently by salinity problems. In this condition, the installation of drainage networks may seem as a rapid solution for the salinity-waterlogging problem. However, the trend of previous actions in this regard indicate that expansion of drainage networks will not be in parallel with the irrigation networks development in the region. Therefore, the mitigation of salinity and waterlogging hazards and agricultural water productivity (WP) improvement in the L-KRB should be tackled by soil, water, and crop management and overall it is a complex issue that needs integrated planning and measures.

The L-KRB is typically hot and almost arid, and agricultural production is essentially dependent on irrigation. This area is designated for further development following the model of the adjacent Dez irrigation district.

However, in the L-KRB (mainly Dasht-e Azadegan plain, DA) heavy soil texture and recharge from upstream areas provide the conditions for waterlogging that is aggravated by low irrigation efficiency of irrigated agriculture in the region.

Waterlogging and soil salinity are the major threats to water productivity and sustainable agricultural production in the DA plain (Hajrasuliha, 1970). Wheat is the main cultivated crop in the L-KRB with average yield of 1.5 t ha^{-1}. Irrigation management practices are traditional and the region suffers from poor water management that is partly due to lack of modern irrigation infrastructure and on-farm improvement activities. Therefore, sound solutions that can be adopted by the farmers are necessary. It is evident that the basic approaches to solve this problem will mainly be the construction and or 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 and may not become effective in near future. Therefore, there is no doubt that research activities related to water-table management, soil salinity control, irrigation water management, selection of suitable crop varieties, and improved agronomic practices will help improve agricultural water productivity and farmers' livelihood in this region. It will ameliorate the current situation without requiring heavy investments.

Overall, soil salinity and waterlogging, in addition to the other sources of inefficiencies in agricultural WP improvements, are the major limiting factors in the L-KRB. These problems are somewhat due to physical characteristics of the region, but are mainly man-made problems and can be managed by proper measures, including infrastructure activities (hardware) and to greater extent by the water management (software) measures. This study was performed in the downstream areas of L-KRB located in the DA plain (Sosangerd region) in the Khuzestan province. The main objective of research was to find out cost effective and short-term solutions for solving the problems[2]. According to this necessity, the following targets were identified in this research:

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

Materials and Methods

This research was conducted during cropping season of 2006–07 in DA plain that is located at the farthest southern part of the delta of Karkheh River, 20 km west of Ahwaz. The area is located between 47' 55" to 48' 30" E longitude and 31' 15" to 31'45" N latitude and is 3 to 12 m above mean sea level. Soil texture of the trial site was silty clay loam to clay-loam with average soil pH of 7.8 and average soil salinity at depth of 0–90 cm equal to 10.5 $dS.m^{-1}$. The source of irrigation water was Karkheh River. The EC of groundwater and irrigation water were 11.3 and 1.4 $dS.m^{-1}$, respectively. Sowing and harvesting dates were in November and May, respectively.

Groundwater depth at the beginning of the growing season, before starting rainfall and irrigation recharges was 237 cm and in winter, following recharge from irrigation, raised and varied between 35 to 98 cm from soil surface.

The research treatments were as follow:

T1= border irrigation + sowing by centrifugal broadcaster + one pass disc
T2= border irrigation + sowing by seed drill (TAKA type)
T3= border irrigation + sowing by three rows bed seeder (Barzegar-e - Hamedani type)
T4= basin irrigation + sowing by centrifugal broadcaster + one pass disc
T5= basin irrigation + sowing by seed drill machine (TAKA type)
T6= basin irrigation + sowing by three rows bed seeder (Barzegar-e - Hamedani type)
Tc= traditional irrigation and sowing method by farmer (as control)

The dimensions of the border and basin of the treatments were selected as 160 m x 10 m (for T1, T2, T3) and 40 m x 10 m (for T4, T5, T6), respectively. 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 choose borders' length according to their farm dimensions (usually 100–400 m) and then divide borders to several basins with 30–70 m length, depending on their field topography. They fill the first basin and then transfer water to the second one, and so on thereafter. The width of borders were usually between 5 to 14 m.

[2].KRB has been selected as one of the nine bench mark basins of the CGIAR Challenge Program on Water and Food (CPWF). One of the CPWF ongoing projects addresses interventions for the improvement of on-farm agricultural water productivity in KRB. This project is carried out jointly by the International Center for Agricultural Research in the Dry Areas (ICARDA) and Agricultural Extension, Education and Research Organization (AEERO). The objectives of the project are to develop biophysical interventions to improve the farm and basin water productivity and the sustainable management of the natural resource base, and to develop appropriate policies and institutions supporting the project interventions to help the poor communities for the improvement of their income and livelihoods. Moreover, the project aims at strengthening and enhancing the capacity of National Agricultural Research and Extension Services (NARES) of Iran.

Chamran wheat variety was sown in all the treatments. The seed rate was 250 kg in treatments sown by centrifugal broadcaster and managed under optimized irrigation (T1, T4). In other treatments (T2, T3, T5, T6) seed drill (TAKA) sowed the seeds and three rows bed seeder (Hamadani) used 180 kg ha^{-1} of seed rate. In the control treatment (Tc), which was sown by centrifugal broadcaster and managed by the farmer, the seed rate was 350 kg ha^{-1}. Other farming practices were the same for all treatments. In Table 1 and Figure 1 soil chemical characteristics measured before planting and watertable depths fluctuations during cropping season respectively are presented.

Crop yield and yield components were measured through sampling (20 samples) from field before harvest. The amount of applied irrigation water was measured by WSC flumes. There was no difference between the farmer and optimum management treatments in terms of interval and number of irrigation. In fact, the difference was in how to manage water flow on the land and the method of irrigation, both of which directly affected water consumptions.

Table 1: Soil chemical characteristics measured before planting

Soil depth (cm)	EC (dS/m)	pH	O.C (%)	P	K	Fe	Zn	Cu	Mg
				mg.kg^{-1}					
0-30	11.1	7.7	0.4	5.1	166	3.8	1.3	0.6	5.2
30-60	9	7.9	0.1	2.2	88.7	2.5	0.1	0.4	1.2
60-90	11.4	7.9	0.1	1.8	59	3.2	0.1	0.5	1.5

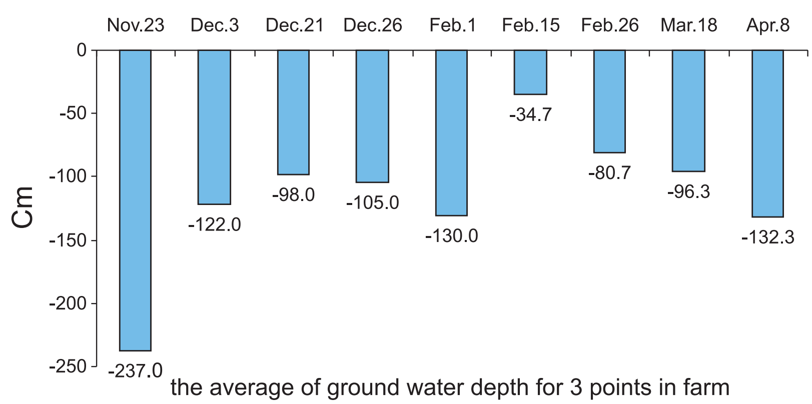

Fig. 1. Variation of the groundwater depth (average of three points) during growing season

Results

In Table 2, the amount of water applied under the two irrigation management options, i.e., farmers' and the proposed improved management are provided. Although the number of irrigation in the entire growth season were equal for both irrigation management options, the water consumption in optimum management on an average was 35.6% less than the farmer's management (Table 3).

The results showed that the border irrigation with centrifugal sowing method (T1) provided the highest water productivity, being 1.6 kg m^{-3}. Among the applied irrigation methods, the optimum border irrigation had the maximum water productivity (1.36 kg m^{-3}), while the farmer managed treatment (traditional border-basin irrigation method under centrifugal sowing with 350 kg seed used) provided the minimum of 0.61 kg m^{-3} water productivity (Table 4).

There was no significant difference (α=0.05) in yield between applied treatments with control treatment. Although the consumption of seed used in TAKA and Hamadani sowing method was 50% less, the seed germination percentage was more than centrifugal method (Table 5).

Table 2: Amount of applied water under the two irrigation managements (Farmer's and improved management).

Irrigation Management option		Irrigation water consumed (mm)			Sum
		1 st irr.	2 nd irr.	3rd irr.	(mm)
Farmer management	Depth	119.6	108.1	92.8	320
	Date	Nov. 24	Feb. 8	Mar. 4	
Optimum irrigation management (border and basin)	Depth	70.4	68.5	65.7	205
	Date	Nov. 24	Feb. 8	Mar. 4	

Table 3: Reduction percentage of water consumed in optimum treatments compared to the control treatment (farmer management).

Irrigation event	Reduction (%)
1st irr. (Nov. 24)	41.1
2nd irr. (Feb. 8)	36.6
3rd irr. (Mar. 4)	29.2
Average	35.6

Table 4: Yield, applied water and water productivity (WP) of studied treatments.

Irrigation method	Sowing method	Yield (kg ha^{-1})	Applied Water (m^3 ha^{-1})	WP (kg m ^{3})	WP (Avg. of irrigation treatment) (kg m^{-3})
Basin-border (farmer)	Centrifugal (350 kg seed ha^{-1})	1953	3205	0.61	0.61
Optimum border	Centrifugal (250 kg seed ha^{-1})	2590	1618	1.60	1.36
	Taka (180 kg ha^{-1})	2434	1774	1.37	
	Hamadani (180 kg ha^{-1})	1901	1729	1.10	
Optimum basin	Centrifugal (250 kg seed ha^{-1})	2730	2394	1.14	1.04
	Taka (180 kg seed ha^{-1})	2521	2417	1.04	
	Hamadani (180 kg seed ha^{-1})	2198	2344	0.94	

Table 5: Seed consumption, number of shrub and sprouting percentage of the treatments

Irrigation method	Sowing method	seed consumption rate (kg ha^{-1})	Number of shrub m^2	Sprouting percentage	Yield (kg ha^{-1})
Basin-border (farmer)	Centrifugal (350 kg ha^{-1})	350	247	34	1953
Optimum border	Centrifugal (250 kg ha^{-1})	250	341	56	2308
	Taka (180 kg ha-1)	180	262	60	
	Hamadani (180 kg ha^{-1})	180	286	65	
Optimum basin	Centrifugal (250 kg ha^{-1})	250	387	63	2483
	Taka (180 kg ha^{-1})	180	332	75	
	Hamadani (180 kg ha^{-1})	180	353	80	

Conclusions and Recommendations

Both Improved Basin or Border irrigation methods can be recommended for the improvement of water management and WP in the studied area. However, the Basin irrigation method is more adaptive and sustainable because:

- It requires low levels of land leveling and uniform slope along the irrigation plot.
- It is more adoptive to farm micro relief caused by common cultivation practices.
- It is more adoptive to the socio-cultural conditions of the area.
- It requires less labor (considering shortages in agricultural labor in the area).
- Of the lack of land leveling and low levels of on-farm improvement activities at present situation.
- It requires less control on flow considering high rate of flow variation and control; and
- it provides pre-cultivation leaching opportunities (considering high levels of salinity and its variation in the wheat farms of the area).

Because of 50% reduction in seed consumption, the high rate of seed germination and better flow of water use of seed drill machine (TAKA type) or three rows bed seeder (Barzegar-e - Hamedani type) are recommended.

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CHAPTER IV

Participatory Processes, Livelihoods, and Socioeconomics in KRB

Integrated Watershed Management for the Dry Mountains of Iran - Adapting worldwide 'lessons learned' to Iranian conditions

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Abstract

After about five decades of watershed management worldwide, there are a lot of valuable 'lessons learned'. Interestingly, there is a high coherence in the 'keys for success' around the world. We summarized them here under five categories: type of interventions, participation and local institutions, watershed governance, role of government, and required research. Many of them are relevant for the Iranian context, but they need to be tested and possibly adapted to the specific conditions of dry mountains and for the institutional context of Iran. A framework for designing an alternative watershed management approach for Iran was developed and is being tested at two benchmark sites at upper KRB. This proposed approach emphasizes collaboration with local communities and stimulates stakeholder interaction. On the other hand, considering the scarcity and fragility of the natural resources in dry mountains, there needs to be a balance between the ecological limits for providing ecosystem services and the needs of the local communities. It is expected that a number of win-win situations can be identified, but also that, in other cases, trade-offs between ecosystem conservation and ecosystem-use will have to be made. The purpose of this paper is to review past experiences with watershed management worldwide and to suggest future directions for Iran.

Evolution of watershed management approaches worldwide

Watersheds are commonly used as operational units for natural resources management in mountainous areas for several reasons. On one hand, watersheds are distinct units where several bio-physical processes (water flow, erosion, nutrient flows, vegetation regeneration, etc.) and socioeconomic processes (irrigation, grazing, nutrient management, etc.) usually interact in a more or less closed geographic area. This makes it an appropriate scale for managing natural resources. On the other hand, there are also some important communication and public awareness benefits. Watersheds are usually easily understood ecosystems, and the condition of streams (i.e., quantity and quality) at the outlet of the catchments is a suitable proxy-indicator for the condition of the natural resources in the catchment and the quality of life in the watershed. Considering, these advantages, watershed management projects have been implemented all over the world over the last 50 years. However, watershed management underwent a significant evolution over this period (FAO, 2006).

The first generation of watershed management approaches were technology-driven watershed projects (or "Techno-sheds"). The objective was to find technological fixes for 'watershed problems'. The concerned problems were usually forest degradation, erosion, or downstream sedimentation and flooding. Technological fixes were searched to fix these problems. These projects were usually led by foresters, water and irrigation engineers. These projects were mainly popular during the 1960s up to 1980s, although they are still surviving till today in some places. Although these projects were often technically sound, the disadvantage of this approach was that local farmers did not feel any ownership of the interventions. Moreover, the technologies were often not appropriate for the local conditions (e.g., high labor demand to build and maintain structures, no considerations for local tenure arrangements, lack of markets for new crops, etc.). At best, local people were hired as laborers to help to implement some infrastructure. Once the land management measures needed maintenance, villagers were waiting for the government agencies to fix 'their' structures. As a consequence, many of these interventions did not survive long after the end of the projects. This realization led to a next generation of watershed management projects.

The second generation of watershed management approaches can be called the "participatory watershed management approaches". These projects used a real bottom-up approach. Instead of letting engineers to decide about the problems and solutions, local communities were the main source of information. The local livelihood problems were used as an entry-point to reflect about alternative ways to use the natural resources in the watershed. Solutions were defined by combining local knowledge and outsider expertise, and implementation was done as much as possible by the local communities. Only when certain required interventions were beyond the capacity of local people, the outsider expertise and funds were used. Such kind of projects were initiated originally by NGOs during the 1980s, but after observing their success, several donors and government agencies started to use this approach from the 1990s onwards. This approach overcame the problems of the first generation of WM projects, and is definitely a big step forwards. However, some new problems emerged at places were participatory watershed management projects were very successful. At some locations in India, it was observed that excessive water harvesting in the upper reaches of the catchment led to downstream shortages. In some extreme cases, the catchment became closed, as no water flowed out the catchment any more. This insight led a next generation of watershed management projects.

The third generation of watershed management approaches are the "Collaborative watershed approaches". The problem mentioned above made it clear that watershed management often have implications beyond the focused catchment. Also, it was realized that some improvements of natural resources management (sustainable grazing, equitable water use, payment for environmental services, treatment of sewage water) can only be achieved, when other agencies (e.g., agencies with legal responsibilities, municipalities, Ministry of Energy) are involved in the watershed planning process. Such projects involved true multi-stakeholder processes, and combined 'bottom-up' and 'top-down' approaches. Such an approach required professional facilitation skills and good networking. This approach started around 2000 and is now being tested at many places around the world.

The three generations of watershed approaches are not completely independent approaches. Actually, every new generation was an expansion and refinement of the previous generation (Fig 1).

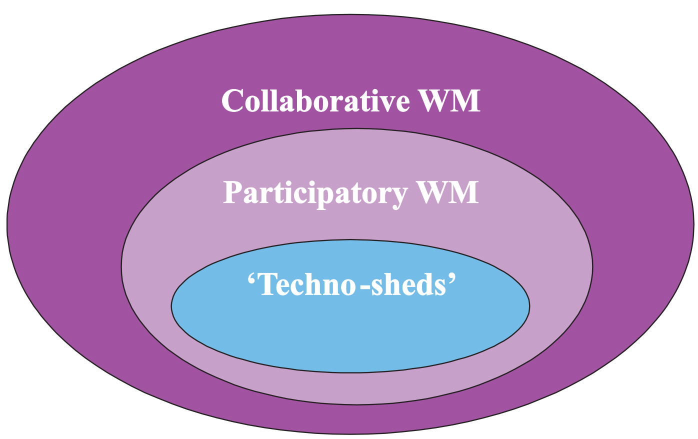

Figure 1: Relation between the three generations of watershed management approaches.

Keys for successful watershed management

As there is now more than 50 years of experience with watershed management projects worldwide, several groups tried to identify 'keys for successful watershed management'. In this article, we review six major studies from all over the world:

- *India*: Kerr *et al.,* 2002.
- *Asia & Latin America*: Bruneau (IDRC), 2005.
- *African Highlands Initiative*: German *et al.,* 2005; 2006.
- *The Philippines*: Catacutan and Duque, 2006.
- *Canada*: Veale, 2003.
- *Iran*: Sharifi, 2002.

These review studies show the huge diversity of watershed management projects around the world, which proves the flexibility of the approach to different climates, land and water use, politics, culture & social values, and scales. But what is very striking is that the 'keys for success' are surprisingly similar around the world. We group the 'keys for success' according to five common themes that run throughout these six review studies:

1. Type of interventions

The most important lesson learned regarding the type of WM interventions is that they should combine income generation and economic diversification with benefits at the watershed level. In areas were poverty is prevalent, the most successful sequencing is to improve access to economic assets first, before improving the natural capital.

Common property resources (CPRs) are very common in mountainous watersheds (e.g., rangelands, biodiversity, surface water, groundwater), and are often very important for the poorest of the local communities. Successful interventions on CPRs are mostly based on collective action of local communities.

Finally, the benefits of watershed management interventions should not be piecemeal or only become apparent in the long-term. In order to be convincing to all stakeholders, the benefits should be substantial and attributable to watershed management interventions. Benefits not only include the ones which are directly useful for the local communities, but also the ones that are useful for downstream users (or other stakeholders – e.g., tourists). There are successful schemes ('payment for environmental services') where downstream users (e.g., a power plant) are paying the upstream land-user for clean and regular water supply.

2. Participation and local institutions

Trust building is the basis for any successful project between different stakeholders, and this is achieved only by 'meaningful' participation and collaboration. This means participation throughout all part of the project (starting from the design to implantation, and evaluation). During this process, different partners will make decisions together on an equal basis, will work together (based on complementary advantages), and share costs of the desired interventions. However, during participatory processes uniformity of households is often assumed. Past experiences highlighted the importance to consider diversity in the target communities. The weakest community members often need special support in negotiations (e.g., for sharing water rights, payment for environmental services), and special attention should be given to make the voice of women heard in decision making. Also, it is important to be flexible in the used approach depending on the site-specific livelihood systems (e.g., approach for nomad communities is quite different than for settled communities).

Participatory watershed management is very much helped if credible local institutions are available. However, most local institutions are often ill-equipped to deal with the challenges of designing, negotiating, monitoring, and sanctioning of trespassers or 'free-riders'. Also the transaction costs for designing and implementing solutions (e.g., mechanisms for upstream-downstream cost & benefits sharing, social fencing) must be manageable and cost-effective. Therefore, external assistance and supervision is often required, especially at the start. Local institutions need to be strengthened in order to enhance their local decision making capacity and their capacity to initiate community-initiated change. Quite often, NGOs have proven instrumental in enhancing the institutional capacity of community-based organizations.

On the other hand, some organizations proposed a pragmatic approach by, for example, focusing on communities which already have strong local institutions and show willingness to manage their natural resources in a more sustainable way (e.g., agreement not to grow water-demanding crops in the future).

3. Watershed Governance

One study (Kerr et al, 2002) compared the performance of the different watershed management approaches. They found that the poorest performing approach was the technocratic, top-down approaches. The participatory approaches performed much better, but the combined approach of participatory and technocratic solutions were even better. Very promising are the collaborative approaches, which are used in multi-stakeholder forums at catchment or basin level. However, they require some essential features (Figure 2):

- MSFs are very conducive in facilitating linkages and enhance communication between stakeholders. This requires professional facilitation skills, which are not always easy to find.
- MSFs should be legitimate, so they can be an accepted forum for dialogue, conflict resolution and planning. Legitimacy can be improved by involving the relevant government bodies and relevant research agencies from the beginning. In this way, MSFs will also assist in bridging the gap between research, policy and executive agencies.
- The decision making framework should be clear from the beginning. This framework should be solid enough to cope with vested interests and to deal with inequalities. On the other hand, in a successful MSF, different actors play different roles. This should be defined early in the process, and should be based on comparative advantages
- A MSF should develop a clear and shared vision, goals, objectives and actions at the early stage of a WM project. On the other hand, there is a risk that such exercises can lead to unrealistic expectations. It is therefore important to manage these expectations and bringing them to realistic levels, in order to avoid `disappointments'.
- Planning should be proactive (in contrast to the more common 'reactive planning'), and should include a solid and participatory monitoring and evaluation system. A reflective approach (e.g., share 'lessons learned') will accelerate the learning curve of all involved.
- There should be sufficient time and resources available to find acceptable social arrangements.

4. Role of Government

In the new generation of collaborative approaches, the government is not the overall controlling agent, but this does not mean that the role of government agencies is marginalized, rather the opposite. The big difference with technocratic approaches is that the role of government agencies is shifting from 'delivering and implementing solutions', to providing an enabling environment for collaborative watershed management approaches to foster. government agencies can do this by the following actions:

- Overcome disciplinary planning and fragmented mandates by horizontal and vertical coordination of government agencies.
- Minimize bureaucracy in WM planning.
- Provide political endorsement of multi-partner watershed forums and their decisions.
- Develop an enabling legislation.
- Devolve authority so that decisions can be made at the lowest appropriate level (the 'subsidiary principle').
- Provide or develop sustainable funding sources for WM programs.
- Replace input subsidies that promote excessive and unsustainable use of ecosystem services (e.g., groundwater, grazing land), by 'smart subsidies' and economic instruments that enable farmers to use sustainable farming practices (e.g., soft loans, micro-finance, payment for environmental services, and fines for unsustainable uses).
- Ensure (private or communal) land tenure or land-use security (either private or collective), as these are major determinants for popular participation in watershed management.
- Strengthen capacity building and increase awareness in the field of sustainable management of watersheds.
- Encourage public-private partnerships, where appropriate.

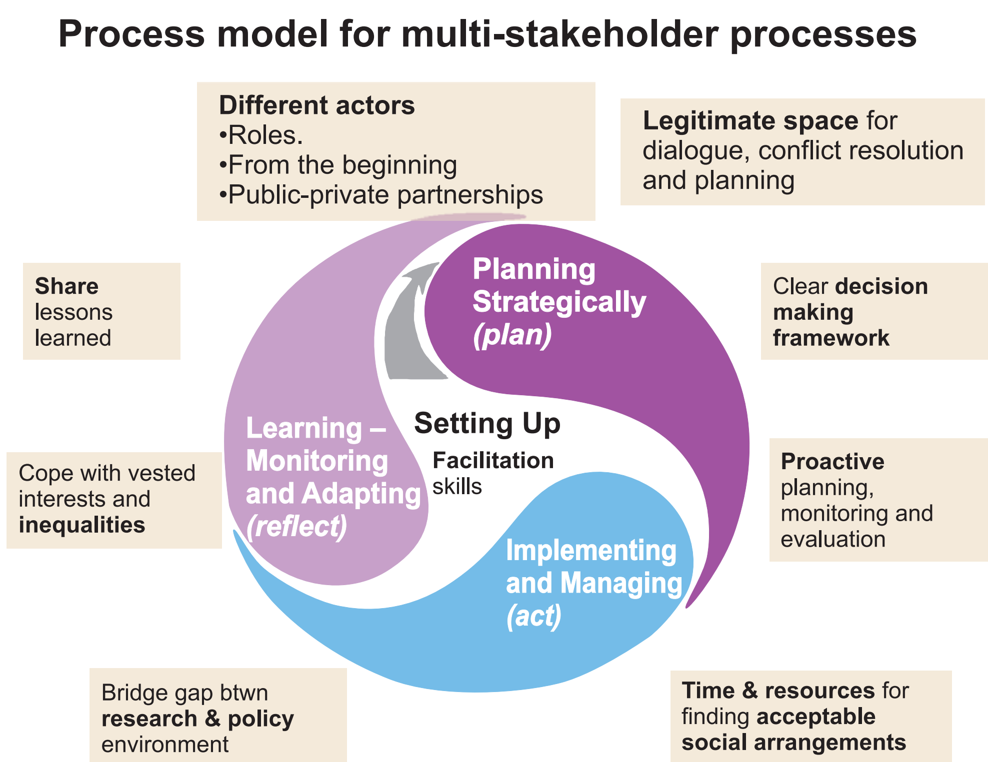

Figure 2: Essential features for successful multi-stakeholder forums at catchment or basin level.

5. Required research

Last, but not the least, what is the role of research agencies in this new generation of WM approaches? Research agencies are not the best positioned to lead such processes, but their technical expertise and analytical skills make them very useful partners to support such a process.
However, in order to make their contribution most effective, they need to reorient their research, in terms of the content of research and their approach.
Besides the traditional watershed management research, there is a high demand for research to contribute in the following areas:

- Consistent data-sets, and define common language and approaches.
- Holistic landscape and catchment approaches.
- Better understanding of the relationship between livelihood (and poverty) versus natural resources.
- The role of women in natural resources management.
- Better understanding of power dynamics in NRM.
- Legal, economic, social and communication tools for sustainable NRM.
- Risk mapping and risk assessment.
- Useful and practical decision support tools.
- Best management practices, especially simple and low-cost technologies.
- Quantify benefits of IWM.
- Simple and meaningful indicators for monitoring for progress.

In order to deliver the above required research outputs, the traditional approach of research agencies need to be adapted. They need to replace their "supply approach" by a much more demand and problem-oriented action research approach. This will require much stronger interdisciplinary interaction, and use of nested scales. Research will become a more efficient and desired partner if it manages to link successfully with development partners (e.g., development agencies, NGOs, CBOs) and to widely disseminate its research findings.

Challenges for watershed development in semi-arid mountains

Watershed management has a long tradition, but has mainly been tested in temperate and tropical areas. Testing in dry areas has been very limited, and due to its often unique features, we expect that watershed management in dry areas to have some own characteristics. Most semi-arid mountain areas have experienced rapid population growth over the last decades. Due to its fragile ecosystem (especially its fragile vegetation, shallow soils and limited surface water), increased land-use pressure (e.g., overgrazing, cultivation, wood mining and water overexploitation) leads to degradation processes (such as pollution, erosion, and floods). The hydrological cycle in dry mountains is also very distinct, as they face erratic and often intensive precipitation, and drainage networks are often intermittent (with interruptions especially at footslopes and colluvial fans). In addition, policies and institutional settings are often disciplinary oriented, and not conducive for the sustainable management of the natural resources.
In the semi-arid mountains of Iran, watershed degradation has been accelerated during the last 50 years due to fast population growth, mechanization of plowing, nationalization of rangelands and water resources, and decline of traditional management systems. The major hotspots of degradation in the watersheds of the Zagros Mountains are:

Vegetation degradation:

i. Overgrazing of suitable rangelands with livestock numbers almost three times the sustainable production capacity

ii. Deforestation due to cutting for firewood, overgrazing and plowing within forest landscapes.
iii. Conversion of rangelands at footslopes to arable rainfed land.

Land degradation:

i. Gully systems due to concave overgrazed areas, along slope tillage at footslopes, and due to poor drainage systems from roads and rural infrastructure.
ii. Marl areas are special hotspots for gully erosion, due to their susceptibility to erosion.
iii. Soil fertility loss in rainfed agricultural land due to water erosion

Water degradation:

i. Over-use of surface water, and water use conflicts between communities.
ii. Water pollution, due to domestic sewage and manure depots close to streams.
iii. Spring floods in narrow valleys.

Although watershed management in Iran started during the 1950s and is considered an important national priority, its implementation is suffering from conflicting national priorities (e.g., food self sufficiency versus natural resources conservation), uncoordinated, sectorial government actions, focus on structural works, top-down approaches, and lack of community participation (Sharifi, 2002). On the positive side, some successes have also been achieved, human and institutional capacity for watershed management has expanded in Iran, and a lot of lessons have been learned during the last decades (Sharifi, 2002). So far, there have been only very few examples of participatory and integrated watershed management in Iran (Rimaleh and Hableh Rud catchments, Lorestan and Tehran provinces). There is an urgent need to develop and implement new watershed management approaches that combine ecosystems approaches with participatory, multi-stakeholder processes.

A framework for developing an alternative, integrated watershed management approach for dry mountains in Iran

The purpose of the 'Livelihood Resilience Project' (part of the 'Water-and-Food Challenge Program') is to develop a more holistic and participatory watershed management approach in cooperation with multiple stakeholders who are concerned with watershed management in Iran. The testing is taking place at two benchmark watersheds (Honam watershed in Lorestan province and Merek watershed in Kermanshah province), which are considered representative for the upper KRB in the Zagros mountains of Iran. The followed approach includes the following steps, as described below:

1. Diagnostic analysis of the benchmark sites
2. Multi-stakeholder process
3. Problem-solving phase at benchmark level:
   i. Spatial interactions and spatial planning principles
   ii. Watershed governance
   iii. Participatory development of new technological options
   iv. Community-based integrated watershed management
4. Design of watershed management principles for dry mountains

1. Diagnostic phase of the benchmark sites

A rapid integrated diagnosis is necessary to clarify the interaction between livelihoods and natural resources. The available natural resources (physiography, soil, water, vegetation and biodiversity) are quantified, and their use (land-use, irrigation, domestic water usage, grazing, etc.) and dynamics (hydrological evolution, soil erosion, nutrient flow, vegetation successions, etc.) over time are assessed. This exercise serves to identify the bio-physical potentials and limitations of the catchments areas. At the farmer community level, it is important to understand the diversity of livelihood strategies and the ways communities cope with drought spells and land degradation.

2. Multi-stakeholder analysis and process

The second phase of the diagnosis is to get involved with the concerned stakeholders. Besides the farmer communities, they include catchment management authorities, governmental agencies, NGOs, Islamic local councils, and local members of parliament. A stakeholder analysis will identify their mandates related to watershed management, their capacities and interests, their visions about the desired future and ecosystem services of the concerned watersheds, and their relationships with other organizations. To obtain a sustainable watershed management strategy, it is vital to recognize the interactions and power relationships between the different stakeholders.

3. Problem-solving phase

The problem-solving phase needs to find a balance between the potential service provision of the natural resource base and the needs of the local population for food, fuel, water, fodder, and nutrients. This requires a good understanding of agro-ecological zones, water resources, land and range capabilities. This phase contains four interrelated pillars that need to be constituted in an integrated, participatory manner: (a) improved institutional arrangements for watershed governance, (b) integrated spatial planning, (c) development and (d) testing of technical interventions for private land, and community-based management of natural resources. A decision support system can be useful for assisting the decision-making process.

a. Watershed Governance

Multi-stakeholder discussions and interactions will enable the identification of the diverse services that are expected from the concerned watersheds, which can lead to the development of a commonly-agreed desired state (or 'vision'). Useful tools to enhance stakeholder interaction are SWOT (strengths, weaknesses, opportunities and threats) and IPA analyses. The expected results of stakeholder interaction are the collective learning through a series of consultations and workshops, and the agreement for suitable institutional arrangements and working relationships between them. It is essential that the existing institutions and their communication lines are strengthened and that existing policies are reviewed and adjusted. Possible improvements are better integration between different disciplines; or better interaction between communities, extension, executive sector and research agencies.

Such an exercise will enhance the partnership between communities and the government agencies, and will provide important inputs for strategic planning of watershed management and help in the defining of principles for watershed management.

b. Spatial analysis and planning for semi-arid catchments

Sustainable management of watersheds requires inter-sectorial spatial and temporal analysis, which considers simultaneously the production, environmental and socioeconomic functions, and the downstream services of watersheds. Examples of spatial optimization questions are:

- Which spatial arrangement of vegetative resources within rangelands can lead to good grazing opportunities for communities, reduced erosion and sediment yields, and improved biodiversity?
- Which croplands could be more productive when returned to a natural vegetation cover?

- What type of dryland fields are preferred for planting perennial crops or for implementing soil and water conservation measures?
- How to increase water productivity and water quality at the catchment level based on ecological and socioeconomic considerations?

All these issues require intensive interactions between stakeholders and scientists. The focus of this research is the footslopes of the hills at the benchmark sites, as they are most prone to land degradation. One tool that will be used is the WATEM/SEDEM model, which will be used to look at tradeoffs between land-use change (1975–2002), soil loss (from tillage and water erosion) and wheat and barley yields. This will be analyzed spatially at the benchmark level. Other processes will be analyzed at a more qualitative level.

c. Participatory technology development for private land

Farmers constantly require new, sustainable technological options that support livelihood resilience and strengthen the natural resource base under a dry and unpredictable climate. Existing technologies and/or innovations are selected and tested via a participatory technology development (PTD) approach (Anthofer et al, 2007). Potential options for dry mountains are: nutrient management (e.g., azotobacter) for barley and wheat, more water-efficient dryland and agronomic management (e.g., improved chickpea varieties and management), rangeland rotations, water harvesting and supplementary irrigation.

d. Community-based management for common property resources

Common-property resources (such as range, groundwater and surface water) usually suffer from the "tragedy-of-the-commons syndrome", especially if these resources are nominally property of the state. There are many examples around the world where such resources are managed in a sustainable way, but only under enabling institutional circumstances. They are well described as the 'design principles' by Ortsom (1990). In essence, sustainable management of these resources requires a certain control by the community, and a guarantee that their efforts for taking care of the natural resources will benefit them in the long run.

In two villages of the benchmark sites, a community-based planning exercise is planned. Conflict resolution about water use between the two villages is expected to be a topic of discussion. The Forest, Rangeland and Watershed Management Organization has committed itself to support some of the requirements of the community-based watershed management plan, if the plan is of sufficient standard. For some of these activities, professional facilitation skills are required to guide the processes to a satisfactory result. Such skills are often rare, and usually need to be developed locally.

5. Design of watershed management principles for dry mountains

The findings and the 'lessons learned' of the previous steps will be the base to develop the watershed management principles for dry mountains. In other words, the principles will be based on field experiences, and translated into more generic terms to make them more widely applicable. They will not be the 'final principles', as they can be further refined, but they will have the advantage that they have been ground-tested. The next step will be to investigate what they mean at higher levels of planning and decision making (or outscaling). These principles could then be used to design all alternative strategies for watershed management planning in Iran. The strengths and challenges of this bottom-up upscaling approach will be analyzed.

It is expected that this approach will enhance the adaptive capacity of mountain communities, extension and researchers. In this way it is hoped that livelihood resilience can be strengthened to cope with the challenges of making a living in the dry mountains of Iran, while reducing land degradation processes.

Stakeholders workshop to identify focus areas for watershed management in Iran

An initial step of the stakeholder analysis will be further elaborated. A two-day regional workshop was organized in Kermanshah to reflect on focus areas for watershed management in Iran with concerned stakeholders (Table 1).

Table 1: Stakeholders of upper KRB.

1. Basin people
2. Natural resources office
3. Watershed Management office
4. Soil and Water Office (Agricultural Organization)
5. Water Board of Ministry of Energy
6. Fishery
7. Domesticated animals center
8. Pest and disease combat center 9. Environmental office
10. NGO's
11. Village's cooperation office
12. Veterinary center
13. Rural road office
14. Water and Sewage office
15. County government
16. Village governmental Office
17. Governor
18. General governor 19. Healthcare center
20. Imam Khomeini Charity foundation
21. Welfare office
22. Town Council
23. Education office
24. Member of parliaments
25. Karkheh Watershed Management Office

Approach

Seventy stakeholders from the four major provinces of upper KRB, namely, Kermanshah, Lorestan, Hamadan and Ilam, participated in the workshop. First, the major findings of the biophysical and socioeconomic studies were presented. During the presentations, the participants were requested to note down the strengths, weaknesses, opportunities and threats (SWOT) of present watershed management in Iran. At the end of the first day, participants were divided in four groups and one fourth of the filled forms were given to them to select the five most important issues related to each S, W, O and T. All the suggestions of S, W, O and T were collected on a large poster, and each participant had three (ranked) votes to indicate the three most important issues. All the issues were ranked based on the scores and brought together in 1 sheet. In a next step, participants were asked to vote just once for the most important issues. The first 14 most important issues are 'reworded' in Table 2.

Results of stakeholder exercise

The requirement for coordination, establishment of a holistic system for resource management and indicators for monitoring and evaluation are ranked by participants as the three most important issues (Table 2). This reflects a strong need for a more collaborative and holistic watershed management approach for Iran. Research can play an important role in developing indicators to measure the level of success of IWM programs, but also the involvement of many stakeholders can ensure that indices include environmental, social and economic aspects.

The need for a '*Catchment Management Authority*' was considered very important for the successful implementation of IWM.

Such an organization is missing for the time being in Iranian catchments. Such an organization could help to overcome the fragmentation of (possible contradictory) sectorial interventions. Catchment Management Authorities should be able to make new rules and to enforce them. Examples of such issues are: balancing livestock and rangelands capacity, and land-use restrictions for sloping rangelands and steep slopes. They could also encourage water-efficient technologies, such water harvesting.

The involvement of communities is generally accepted as an essential precondition for successful IWM programs. Also the necessity to give special attention to women concerns and women participation was highlighted. In community-based watershed management projects, the participation process should give enough attention to incorporate the voice of women. This might require special training. More than 80% of the pastures and forests belong to the government and are very prone to the 'tragedy-of-the-commons syndrome'. This problem could be resolved if responsibility and accountability would be given to responsible communities.

Table 2: Suggestions for improved watershed management in Iran, based on the SWOT analysis.

Priority	Important suggestions for integrated watershed management (IWM) for Iran
1	Stakeholders coordination from the beginning until after the implementation of projects, and encouraging teamwork
2	Developing criteria and indicators for IWM
3	Establishing a holistic system for watershed management
4	Land use planning studies
5	Community participation
6	Forests and rangelands protection, and balancing livestock with rangelands capacity
7	Prevention of both ecosystem degradation and disruption of environmental balance
8	Job creation to reduce stress on natural resources and to control soil erosion
9	Water harvesting for water use efficiency and for improving livelihood resilience
10	Training land users and developing their skills
11	Encouraging women participation
12	Using religious motives for the benefit of natural resources protection
13	Utilize government support for privatization
14	Control farm expansion on steep slopes

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Participatory Technology Development - Challenges and Opportunities

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Abstract

The conventional agricultural research approach in Iran may produce high-quality outputs within agricultural disciplines, but for complex, heterogeneous agro-ecological systems prevailing in dry mountainous areas and watersheds, alternative ways for research and development are required. Within the Livelihood Resilience Project in the upper KRB, the concept of 'Participatory Technology Development' was employed for the first time in Iran to overcome shortcomings of the conventional research setup, to foster research in partnership with farmers and communities and to provide a platform for inter-institutional and inter-disciplinary collaboration between different research institutes, and between research and other actors like the agricultural extension service, NGOs and community-based organizations. This study documents the shift from a conventional research approach towards a participatory, multi-stakeholder one. Therefore, the focus of this project is the research *process* rather than the research *outcomes*.

Keywords: Participatory Technology Development, farmer-to-farmer cross visits, on-farm experimentation

Introduction

Water and land resources in watersheds of dry mountains are important factors affecting the livelihoods of people. Their management is quite complex and diverse and several stakeholders at different scales are involved and compete for these scarce resources. The lack of comprehensive, integrated management strategies has often resulted in failures to resolve perceived problems by the local communities. However, with the adoption of demand-driven and participatory methods, researchers can contribute to improve the situation. Changes in the perception of collaboration with farmers and a shift from single disciplinary biophysical research to integrated research methods, considering the social environment and the economic framework, have shown to increase the overall impact of research efforts.

The Conventional Research Paradigm in Iran

In Iran, agricultural research and their implementing institutes are considerably fragmented and follow the conceptual distinction of crops, livestock, trees, soils and socioeconomics. This conceptual breakdown structures skill development, institutes within the agricultural research organization, research objectives and discipline-specific methodologies, and planning and evaluation processes. Researchers have to submit a research proposal to the scientific committee of their respective research institute which evaluates the proposal from a disciplinary point of view. This setup impedes the promotion of integrated and sustainable land and water management approaches. The structure of government line ministries also reflects this conceptual fragmentation of the natural world. For example, irrigation water from the water resources to the main irrigation channels is provided by the Ministry of Energy, while the distribution of the irrigation water from the main channel up to farmers' fields falls into the responsibility of the Ministry of Jihad-e Agriculture. Environmental protection is embedded within the Ministry of Environment although there are overlapping issues with agricultural production and the utilization of water resources.

In addition to disciplinary biases which form agricultural research, there is a bias towards plot and farm-level research and a focus rather on individuals than on common property resources such as water or rangeland. There is also an emphasis on agricultural production in isolation from other aspects of livelihoods and in the failure to consider social consequences of farming activities beyond the plot and household boundaries (e.g., influence on neighboring fields and farmers and on downstream users).

It can be summarized that despite excellent research outputs produced by different disciplines, there is a lack of coordination between research institutes as well as links to other stakeholders in the agricultural sector to achieve a wider-scale impact.

Integrated Natural Resource Management (INRM) as an alternative research paradigm

Integrated agricultural research for development has emerged as an alternative research paradigm, seeking to integrate biophysical research with social, policy and institutional research. This paradigm appears to be promising in embedding technology-related research into political and administrative processes at various scales. Integrated Natural Resource Management (INRM) has emerged as an alternative concept for adaptive and integrated management of natural resources at different scales (Thomas *et al.,* 2003; Hagmann *et al.,* 2002; van Noordwijk *et al.,* 2001). It is defined as "an approach to research that aims at improving livelihoods, agro-ecosystem resilience, agricultural productivity and environmental services" (Anon, 2002). INRM looks at the interactions and trade-offs of the biophysical and social aspects that characterizes the use of natural resources. In that way, it has the potential to serve as an integrative framework for research and development.

Participatory Research

The failure of the conventional research paradigm in many countries is increasingly recognized (German, 2006; de Grassi and Rosset, 2003). While showing some success in largely homogenous and resource-rich environments, this approach has not been successful in addressing the complexity of small-scale resource-poor farming households in marginalized areas. The non-adoption of research outputs (Rogers, 1995; Stoop, 2002; Scheuermeier *et al.,* 2004) is well documented. It may be explained by farmers' lack of knowledge and scarce resources, non-compatibility of the promoted technologies with farmers' goals, household and physical resources, and the limited political influence of resource-poor farmers on the research process (Nederlof and Dangbégnon, 2007). Therefore, there was a need to revise the roles of research, extension and the ultimate users of agricultural research, the farmers.

It is now increasingly recognized that researchers alone cannot take hold of the complexity and dynamics of local livelihoods and management practices (Scheuermeier *et al.,* 2004). Past experiences have clearly shown that farmers need to be involved in the process of technology generation at an early stage (Chambers and Ghildyal, 1985; Douthwaite *et al.,* 2001), starting from problem identification, to technology generation and finally evaluation of new technologies. In the end, it is the decision-making of the individual farmer and not the government or a national program, which decides whether a new technology is adopted or not. Furthermore, technology development and its adoption is not a linear process, but an interactive learning and development process for both farmers and scientists (Röling, 1996). Therefore, highly sophisticated and complex technology packages developed at research stations reflect rather scientists' imagination than be able to contribute improving the farmers' realities.

While in the conventional research paradigm researchers provide the only source of knowledge, in the process of participatory research, farmers contribute their intrinsic knowledge of local agricultural practices and innovations whereas researchers provide their scientific knowledge (Schulz *et al.,* 2001). This recognition resulted in alternative research and development approaches like Participatory Technology Development (Reijntjes *et al.,* 1992; Van Feldhuizen *et al.,* 1997).

The Livelihood Resilience Project

The Livelihood Resilience Project in the Karkeh River Basin in Iran tries to address these issues following a multi-stakeholder INRM and participatory approach. Initial research initiatives have been undertaken by various Iranian agricultural research institutes under the umbrella of the Agricultural Research and Education Organization (AREO) and with the support of ICARDA to assess the extent and causes of land degradation in relation to the availability and utilization of water in the basin. The current status of livelihoods in the representative communities including their coping strategies to reduce their vulnerability is being assessed. A gender analysis with focus on water-related issues has been conducted recently. The project also identified and assessed local innovations to manage land and water resources and to diversify income opportunities.

Changing the technology development approach

The Livelihood Resilience Project used the procedures and management structures of AREO. However, due to the project's aim to introduce new ways in research, it was not surprising that this could not be fully achieved by applying the conventional research structure.

Initial initiatives to test improved agricultural practices on-farm were carried out by different institutes after the approval from their scientific committees. However, promising local innovations which were identified by surveys were largely neglected and options were often assessed from a single perspective only. In mid 2006, a sub-project on 'Participatory Technology Development' (PTD) was launched to increase active farmer participation and to enhance inter-institutional linkages. This umbrella project was meant to overcome some of the above shortcomings. A new research partner, the Rural Research Center (RRC), was invited to take the lead of the PTD activity, with the assistance of ICARDA. This was a timely move, as RRC had recently received the national mandate to stimulate the use of participatory approaches in Iran. The PTD team has been building linkages between the different Iranian agricultural research institutes, and collaborates with Extension and a local NGO (CENESTA). Links with other ICARDA-managed projects have also been established: some activities of the water productivity project (PN 8) and the participatory plant breeding project (PPB) have been incorporated into the PTD framework.

The PTD process

During a workshop on 'impact pathway' in April 2006, the key actors of the project developed an impact pathway, a model of how the project sees itself achieving impact (Douthwaite *et al.,* 2003). The PTD component was embedded within the wider Livelihood Resilience Project. A one-week planning workshop followed at RRC, using problem and objective trees and transforming the results to a project planning matrix for the whole project period. Monitoring criteria were developed and a national and two provincial PTD teams for the two project sites were formed, comprising RRC staff and additional experts from different disciplines. A one–week training course on PTD was conducted with provincial staff, followed by several short follow-up sessions which included reflections on the work, introduction of new participatory research tools and agreements on how these tools could be used until the next follow-up visit. Hence, the process comprised theoretical learning, practical application and critical feed-back through reflections of the previous experience. In April 2007, a 'PTD traveling workshop' was organized. Members of the national and provincial PTD teams, as well as some of the collaborators of other departments and non-research organizations, were invited for one week to ICARDA headquarters to get exposed to some of the participatory land management work undertaken by ICARDA. This institutional cross-visit proved to be very effective since for many of the participants it was the first time that they could see participatory research in action and interact with both researchers and farmers. The experiences made during the first year show that skills in participatory methods cannot be obtained by one time training sessions only. Continuous follow-up and reflections on success stories and failures are essential for success.

Since the PTD component was initiated rather late trying to overcome some of the previous shortcoming of the conventional research approach, it did not follow the chronological steps of PTD, namely, problem and needs assessment, group formation, planning, experimentation, and monitoring and evaluation (Van Veldhuizen *et al.,* 1997). Rather, it tried to shift on-going activities into a more participatory direction trying to integrate activities of different research partners and other stakeholders.

The change process

Who selects who?

In the previous years, farmers were selected by the researchers for field trials according to certain criteria. The collaborating Extension Service and the Agricultural Service Centers often selected so-called 'cooperating farmers' who are usually the better-of farmers with more resources and better management skills. However, they often do not represent the diversity of farmers in the project area. In addition, they received incentives for their cooperation.

As of a first step of the PTD activities, existing 'best-bet' options were introduced to all farmers in four PTD pilot villages and explained by a team of researchers and extension staff and experienced farmers. It was explained that farmers were not asked to participate to work *for* the project, but that they were invited to participate *based on their own* interest and benefit. After clarifying the approach, farmers chose those technologies they were interested in. To make monitoring by farmers possible, the trials were kept as simple as possible. The learning process is on both sides. Farmers are actively involved in the entire research process, while researchers have to learn that participatory research is more than transferring complex field designs from the research station to farmers' fields.

Removal of incentives

During these first visits of the PTD teams to the villages the issue of incentives for farmer cooperation was heavily discussed. Governments have traditionally sought to achieve agricultural change through a combination of extension and subsidies. In Iran, there are heavy subsidies on fertilizers and other inputs as well as guaranteed prices for wheat to achieve self sufficiency. However, such approaches are now considered poorly suited to the challenges posed by sustainable agriculture (Vanclay and Lawrence, 1995). Subsidies create artificial cost-value ratios and may make farmers dependent on external payments. Hence, farmers may only show interest and finally adopt a certain technology for the incentives paid. However, technologies developed under such artificial conditions cannot be sustainable and prevent the development of technologies which are suited to the market situation. Therefore, within the PTD project, subsidies were not offered at all or were step-wise removed.

Changing field days to farmer-to-farmer cross visits

The conventional research paradigm is characterized by a pro-innovation bias (Rogers, 2003) and, therefore, field days are seen as opportunities to demonstrate the end-product of research to farmers. Researchers often try 'to sell' their idea to a wider number of farmers. The interaction is rather one-directional, limitations of the promoted technology are rather ignored and researchers often argue against the few critical voices. Farmers are also often hand-picked and represent the ones endowed with more resources.

Such classic field days with the aim to promote readily available technologies are now gradually shifted towards farmer-to-farmer cross visits, where the research team facilitates open discussions among farmers and where technologies are rather viewed as options than final solutions. Within the PTD process, farmer cross visits have a double function. At first, they are conducted to have a critical feed-back from average farmers which is taken seriously and may affect further experimentation. Secondly, they provide the basis for out-scaling successful technologies to other farmers and farming communities.

Changing of roles

To change the attitude of researchers from a dominating role to a more facilitating one is not easy. Many researchers fear the loss of control over 'their' trials and data. The institutional setup and requirements for publications is often counter-productive to applying participatory research methods. Moreover, many researchers are not aware of the different research methods available when applying participatory approaches and miss opportunities to gain new insights.

Changing of the experimental design

On-farm trials were gradually simplified within the PTD project and are now largely farmer-managed. The focus of data collection and analysis has shifted from comparing many different treatments towards the collection of site-specific parameters affecting the performance of the most promising options selected by farmers compared to the farmers' practice. These data collected on many farmers' fields help to identify bottlenecks of the investigated technologies. Only in later stages of the research process, researcher-managed trials become important again. In that way, the research direction is being reversed from general to specific research questions.

Conclusions

After one year of project activities, there is an increased awareness about the need to change the attitude towards farmers. Farmers are no longer seen as passive receivers of research results but as competent partners in a research-for-development process. At provincial level, linkages between different institutes and stakeholders have increased and certain activities are now jointly planned and conducted. There are also moderate signs of institutionalization of participatory research approaches. The activities of the PTD project are increasingly recognized as a promising approach at the higher AREO management level and not regarded purely as '*socioeconomic work*' as in the beginning. Several other research institutes have been asked by AREO to apply the PTD approach as well.

Changing a research paradigm is a long-term process which requires patience, persistence and dedicated staff willing to work outside the mainstream. In Iran, participatory approaches have just started to receive more attention. It is still a long way to go, but this project has made a promising start.

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Characterization of Production and Livelihood Systems of Rural Communities in Upper KRB

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Abstract

This paper presents a characterization of the livelihoods of rural communities and supporting production systems in two small catchments in the upper KRB (KRB) in Iran. The study is part of one of the projects of the CGIAR Challenge Program on Water and Food in KRB. We used rapid rural appraisal to classify the communities in the two catchments (Merek and Honam) by their natural resources endowments such as water, grazing lands and distance from main roads, and by their main sources of livelihoods. Secondary data on population and land use were also used. The villages in Honam were classified into three main production and livelihood systems and in four systems in Merek. The three systems identified in Honam were: (i) Mixed crop-livestock with high water endowment; (ii) Small ruminant-dominant free grazing system; and (iii) Mixed crop and livestock cattle-dominating system. The four systems identified in Merek were: (i) sheep-dominated mixed rainfed crop-livestock system; (ii) mixed irrigated and rain-fed crop livestock system; (iii) well-irrigated crop production system; and (iv) rainfed-dominated crop production system. One village was selected purposely as a representative of each production/livelihood system. The selected villages were visited and surveyed through rapid rural appraisals in which basic village information including village size, production patterns, importance of different activities in livelihoods, resources, services, constraints and potentials as the communities see them. The paper analyzes the information gathered and finds significant differences in the constraints, poverty levels, and opportunities in the different systems as well as differences in the potential impacts of policies in these communities.

Introduction

The main objective of this paper is to provide a clear description of the socioeconomic characteristics that defines the relationship between poverty and natural resources endowments, and description of access to services in rural areas in Honam watershed in Lorestan Province and Merek watershed in Kermanshah Province in the upper KRB. These two catchments were selected because they were the main sites for the adaptive agricultural research activities of the project. The two catchments consist of about 45 and 25 villages respectively. The socioeconomic characterization presented in this paper is part of a larger study which is applying more quantitative methods to measure rural livelihoods and their relationships with natural resources endowments and changes, and particularly water resources. The objectives of this paper is to present a detailed qualitative description and contrasting the current socioeconomic situation, the production systems, livelihood sources, perceived poverty levels, constraints and opportunities among different villages representing different production and livelihood typologies. The classification of the villages, which is based on stratification using biophysical characteristics as well as socioeconomic indicators, is used to develop representative scenarios for the quantitative analysis of rural livelihoods.

Methods

After reviewing secondary data and conducting rapid rural appraisals (RRA) in Honam catchment, as well as discussions with local extension and research staff, it was found that sources of income (livestock, horticulture, crops and off-farm employment), access to water, rangeland, market and services are different between villages in the selected regions. The study, therefore, adapted a stratified sampling procedure aimed to ensure that most representative conditions of the villages in the catchment are included. Since the villages are not homogenous this is achieved by purposely selecting few villages with contrasting biophysical and socioeconomic conditions.

The communities in Merek catchment were first subdivided into three different groups based on their geographical location, natural resources and production system. These groups were villages along the valley, villages near the forest and villages near rangeland areas. The valley region has more irrigated areas and the highest concentration of population with 23 villages. We selected one village from each, and then added a fourth village from the valley region to increase the representation of the greater systems diversity there due to the different level of water availability along the valley. The four villages selected in Merek catchment were Baghe Karambag, Sekher Olya, Mahdiabad Sofla and Kolehjoob. Sekher Olya is near the rangelands areas and Baghe Karambag is near the forest areas. The other two villages, Mahdiabad and Kolehjoob, are located in the valley.

We divided the communities in Honam catchment into three groups: upper, middle and down stream. These groups of villages are generally different in terms of importance of livestock and water availability. The upstream villages have more livestock, horticulture and dry land crops, the midstream villages have more mixture of rainfed and irrigated crops as well as livestock, mainly cattle, and the downstream villages have good access to water and have mainly irrigated crops and dairy cows. The three villages selected in Honam catchment were Peresk olya, Chahar takhteh and Siyahpoosh which represent the different livelihoods and production systems of the catchment described above. The selected villages are Peresk olya, Chahar takhteh and Siyahpoosh located in the upper, middle and down stream parts of the catchment respectively.

The selected villages were those with at least 40 households; small villages were excluded on the grounds that they may be affected by out-migration in the immediate future, making their stability uncertain, and also to avoid the small sample problem. The selected villages were visited and surveyed through rapid rural appraisals in which basic village information including village size, production patterns, importance of different activities in livelihoods, resources, services, constraints and perceived community potentials were collected.

The livelihood analysis of these two study areas requires detailed data on household production activities, incomes and expenditures in each village. Such data were later collected in formal surveys from the selected villages, which are representative of the typical production and livelihood characteristics of the two regions (results of the formal survey not reported in here). The selected villages and their basic characteristics are shown in Table 1.

Table 1. Characteristics of selected villages

Village	Number of households	Irrigated Area (ha)	Rainfed Area (ha)	Total (ha)	Irrigated Area (%)	Sheep heads	Goat heads	Dairy Cows heads	Total land per HH	Irrigated Area per HH	Cows per HH	Sheep & goats per HH	Production & livelihood systems
karambag	50	20	315	335	6	300	30	15	6.7	0.4	0.3	7	Dry land farming base
Sekher Olya	70	60	440	500	12	2000	200	20	7.1	0.9	0.3	31.5	Mixed farming system
Mahdiabad sofla	50	70	150	220	32	200	50	60	4.4	1.4	1.2	5	Valley less water
Kolehjoob	80	150	250	400	38	400	40	100	5	1.9	1.3	5.5	Valley abundant water
Peresk olya	95	150	350	500	30	2000	500	12	5.3	1.6	0.13	26.3	Upper stream
Chahar takhteh	45	100	200	300	33	500	100	50	6.7	2.2	1.1	13.3	Middle stream
Siyahpoosh	50	200	300	500	40	400	70	180	10	4	3.6	9.4	Down stream

Results

Analysis of selected villages in Honam

The three systems identified in Honam catchment are described below (see also Table 2).

(1) Mixed crop-livestock with high water endowment (Siyahpoosh)

This village represents the down-stream part of the catchment which has mixed crop livestock system with crops being more important than livestock due to the abundant water resources. The water resources also allowed development of fish farming. A wide variety of food and forage crops are cultivated under irrigation. Dairy cows are important and sheep are not important as this community has no rangelands. It also represents conditions of good services and proximity to markets as well as strong off-farm employment in the form of permanent government jobs. This probably represents an ideal situation for any rural community in developing countries. Their land is flat and so is not affected by soil erosion. There is no apparent water shortage.

The livelihood sources were mainly from irrigated crops and in the order importance they are wheat, red beans, chickpea, alfalfa, clover, soybean, rapeseed or canola and sugar beet. Livestock, mainly dairy cows, is the second source of livelihoods with most families having 1 or 2 cows. Most families have 1 or 2 of their members with permanent government job. It is a very important source of income.

In this village, 40% of the households are classified as economically better off with both crops and livestock. Each household has 10 ha land, 3 cows, a tractor, 20 sheep, and with one person working in the government. Some 35% of households are in the middle income category and depend only on crops; they have 3–4 ha land and 1 cow. The poor households are perceived to account for 25% of the households with small land and few sheep or without land and cows. Most of those who fall in this group are laborers. Women help in planting, harvesting, seeding, and weeding. Also, they have a considerable role in managing livestock, especially in feeding and milking.

(2) Small ruminant-dominant free grazing system (Peresk Olya)

This village represents villages that heavily depend on sheep production, which is partly dependent on the utilization of mountain grazing lands. But the households in this village have relatively smaller land holdings and cropping is not a major source of livelihoods. The climate of the village in the winter is very cold for crop growth when water is abundant. In spring and summer, when the climate is more suitable for crop production the village faces water shortages, because the water flow in the spring drops significantly. The village has relatively the lowest irrigated area (26% of the cultivated land) among all the villages in the valley. Most of the irrigated crops are horticulture. Horticulture is the dominant crop production and the most important after sheep production. Barley is the most important field crop.

The main livelihood sources in the village are livestock (sheep) and horticulture (trees). The village mainly relies on sheep production. The sheep production system highly integrates open grazing of mountain rangelands for 3 months (April–June), utilization of crop residues for 3 months (July–September) and hand feeding for 5 months in the winter (October–February). Sheep are not milked, but the lambs are let to suckle freely. This production system allows two lambings per year. The spring lambs (lambing February/March) are fattened by the free grazing of the mountain ranges and are sold when they are abut 4 months at 40–60 kg, depending on the condition of the grazing land and the weather. The fall lambs (lambing September) are hand-fed and fattened separately from the rest of the flock and sold in February.

The village relies heavily on common grazing lands in the mountains where men take small ruminants for about 3 months. In the past, the whole family would go with livestock during the mountain grazing period, but now the households are settled and only men take sheep out to the mountain rangelands. This is the reason why they no longer make dairy products from sheep.

The village has 21% better-off households with about 60–100 heads of sheep, and 3–4 ha land. The middle group of households have about 30–60 heads of sheep, about 1 ha land. About 32% of households are in this category. In the poor category, 47% of the village's households, each family has about 30 heads of sheep and no land. Women help in planting, weeding and harvesting of crops, especially chickpeas and lentils and also in gathering fruits. As mentioned earlier the village depends heavily on sheep and women have a main role in feeding, milking and cleaning sheep pens when sheep are not on the rangelands and utilize crop residues and hand feeding.

(3) Mixed crop and livestock cattle dominating system (Chahar Takhteh)

This village represents a relatively higher natural resources endowed environment, but with shortages of water during summer. It represents mixed crop and livestock system with dairy cows the main source of income. Wheat is the most important crop and it has very few horticultural crops. This village also represents important urban-rural interaction where migrated households, who settled in towns, return to the land during cropping season and share-crop with or rent land to small holder households in the village. This is an important interaction as urban households try to supplement their income from farming.

About 70% of the land is rainfed, whereas irrigated land accounts for about 30%. But there is shortage of water in spring and summer and also there are no wells in the village.

Most households have few milk cows and some have sheep. Only those who live in the village have livestock, the non-residents do not have livestock. For about 5 months, they graze in the rangelands close to the village, then use the crop residues for 2 months and are fed in the yard during the winter months (5 months). Sheep and calves are sold to middlemen who take animals to markets.

The main livelihood sources are: (1) dairy cows with each household having 2–3 cows; (2) crops (wheat, barley in that order, and barley may be the first in the dry year); and (3) sheep and off-farm jobs. Most people have sheep, but they do not migrate to mountain rangelands which are located far from the village. Some people work as laborer in Aleshtar and other cities, but generally this community complained about high unemployment even for educated people. This village has experienced large migration of households to towns. Currently, the residents of the villages account only for 40–45% of the owners of the agricultural land of the village and about 60–55% are non-residents, who live in towns and cities and come back during cropping season. With these large non-resident land owners, share cropping is commonly practiced in the village. The share cropping rule of 50:50 is used with input costs split equally.

About 20% of households are considered better-off. They have 4–5 ha of irrigated land, 60 sheep, and 4 cows. Also, someone with 12 ha of 50% irrigated and 4–5 cows is also considered rich. The middle category have 1–2 ha land, 40 sheep, 2 cows and about 40% of the households are classified as middle income group. Those with no land, no livestock, who are renting land or working as farm labor or those with 2 cows and 10 sheep can also be classified as poor. About 40% are classified as poor. Women help with planting, fertilizer application, weeding and harvesting. Also, women graze animals in the nearby range lands, and have a main role in feeding, milking, and cleaning livestock's shed.

Access to services in Honam villages

Table 3 shows the access of Honam villages to school, telephone, electricity, TV, water, and health clinic.

Table 2. Characteristics of Honam villages

Characteristics	Peresk Olya	Chahar Takhteh	Siyahpoosh
Natural resources	- Mountain rangelands support sheep for 3 months (April- June) - small land holdings - Water shortages in spring and summer - Limited irrigation 26% - Sloppy lands, erosion risk	- land with good quality soil - Irrigated land is 30% faces shortages in spring and summer - No wells for ground water exploitation - Rely only on grazing areas close to the village, no access to mountain ranges	- There is abundant water, no water short age perceived. - Land mainly flat, soil erosion not a problem.
Production system	- Mainly sheep production system - Horticulture 70% of crop land (90% walnuts) - Field crops 70% barley	- Mixed crop livestock with field crops (mainly wheat 70% & barley 30%), sheep and cows. - One fish farm	- Irrigated system with wide range of crops wheat, red beans, chickpea, alfalfa and clover, soybean, rape seed, sugar beat & cows.

Main livelihood sources off-farm employment	- mainly Sheep, followed by horticulture Off- farm employment is not important income source	Mainly dairy cows, followed by crops Some off- farm jobs exist but not a main source of income.	Mainly crops, followed by cows. Off- farm employment in government jobs is important
Market access	18 km from main road and 23 km main town	6 km from main road and 11 km main town	Lies on the main road and close to major town (5 km) market
Service	- Poor veterinary services - Government provided low interest credit for building homes to avoid effects of earthquake	- Drinking water not connected to houses, so drink from springs.	Services satisfactory as very close to road.
Poverty estimated by local communities	- Better- off are 21% & are those with 60-100 heads of sheep, and 3-4 ha; - Middle income is 32%, with 30-60 heads of sheep & about 1 ha land. - Poor are 47% & have no more than 30 heads of sheep and no land.	- Better- off are 20%, and have 4-5 ha of irrigated land, 60 sheep & 4 cows. - Middle income are 40% & have 1-2 ha, 40 sheep & 2 cows. - Poor are 40% with no land, no livestock, & sharecrop, rent land or work as farm labour and in construction. Those with 2-3 cows and 10 sheep are also poor.	- Better off are 40% with both crops and livestock; 10 ha, 3 cows, tractor, 20 sheep, one person working in the government job. - Middle income are 35% depending only on crops; 3-4 ha & 1 cow. - Poor are 25% with small holding and few sheep or no land, no cows, & work as labourers.
Opportunities	More water use efficient practices for horticulture, water harvesting on the slopes for trees, post harvest cleaning and packaging of crop products, expanding sheep production, carpet making for women?	Investment on dairy cows (up to 10) can lift people out of poverty. - Investment in wells for increasing irrigated land and fattening.	- Dairy cow production. - Value addition activities through post harvest processing (cleaning, packaging and labeling) of the rich products of the region particularly legumes such chickpeas, beans and lentils.

Table3. Access to services in Honam villages

Village	Primary school	Secondary school	High school	Distance to High school	Telephone connection	Electricity connection	TV connection	Water connection	Health clinic
Siyahpoosh	Yes	Yes	No	5 km	Yes	Yes	Yes	Yes	Yes
Chahar takhteh	Yes	Yes	No	10 km	Yes	Yes	Yes	Yes	Yes
Peresk olya	Yes	Yes	No	22 km	Yes	Yes	Yes	Yes	Yes

Analysis of selected villages in Merek

The four production and livelihood systems representing the Merek catchment are described below.

(1) Sheep-dominated mixed rainfed crop-livestock system (Sekher Olya)

This village represents a mixed crop-livestock system with dominantly rainfed farming and sheep production. Most of the land is rainfed with only about 10 percent under irrigation by qanat systems or by wells. The main irrigated crops are wheat, sugar beet and corn. Rainfed crops include wheat, barley, chickpeas and lentils. Water availability and rainfed crops are affected by weather fluctuations. Most people have sheep with an average of 50 heads per household. Sheep are milked and milk processed for making butter oil for home consumption and for sales. The main sales from sheep, however, are lambs for meat. Sheep graze for 3 months in the rangelands and use the crop residues during the summer.

The livelihoods strategies are balanced between crops (50%) and livestock with sheep being the dominant livestock (90%) and cows contribute to only 10% of the overall village income. The main sources of risk and vulnerability of livelihoods are drought which affects water availability and crop yields, price risk mainly for corn and chickpeas, and marketing-related problems in sugar beet, which is caused by delays in collection by the factory.

About 10 percent of the households in the village are classified as poor, 60% as middle and 30% as well-off according to the community defined indicators. Based on farmers' views, a well-off family has about 100 sheep, 5 cows, 15 goats and 20 ha land. The middle households have around 25 sheep, 1 cow, 10 goats and 4 ha land. The poor households do not have livestock and they have about 2 ha land or less. New and young families are considered among the poorest. Some 6 households work in non-agricultural activities such as driver, shopkeeper, and construction worker.

There are specific policies that directly affect the livelihoods of rural households in the village. Firstly, stable food crops such as wheat and sugar beet receive inputs subsidies (seeds, fertilizers, pesticides, etc.) which are not extended to vegetable crops and feed crops, such as corn, as well as horticultural crops. This makes the later crops less competitive in the market compared to stable food crops. Secondly, stable food crops also have stable prices, guaranteed by the government procurement agency, which is not the case for vegetable and feed crops. The prices of the later crops fluctuate with market conditions, exposing risk to farmers and again makes them less competitive compared with stable food corps. Thirdly, expansion of wells is currently prohibited due to the fear of declining water tables. This later policy is probably justified, given the common nature of groundwater and the over-exploitation that often occurs. However, a knowledge-based policy is needed to ensure the optimal use of natural resources for current and future generations.

Women participate in all agricultural activities including irrigation, harvesting and weeding, especially for chickpea. Also, they have a considerable role in keeping livestock and they do milking and feeding and cleaning of animal sheds. Women at the village gather weeds from fields for animal feed, except for grazing animals in the rangelands. They make butter oil from sheep milk, which is well known and popular nationally.

(2) Mixed irrigated and rain-fed crop livestock system (Mahdiabad Sofla)

In this village agriculture is more important than livestock. The crop land is mainly (67%) rainfed and 33% of the cropland is irrigated.

There are no rangelands. The village lies on the Merek River and has 9 wells. There are no qanats. The villagers have built a small barrier along the river which raises the water level and that is diverted to a channel which distributes the water to the fields. The village has 1 km cement canal and 2 km of earthen canal. Irrigated crops are wheat, sugar beet, corn, alfalfa. The rainfed crops are wheat, barley and chickpea. There is almost no horticulture in the village, except for about 4 ha of walnuts. On the whole, there are 200 sheep, 60 dairy cattle (10 improved, 30 local, 20 crossbred), and 50 goats in this village.

Sources of livelihoods in the village are about 80% agriculture (40% rainfed and 60% irrigated) and 20% livestock (8% sheep, 12% dairy cattle). Based on very simple estimates of welfare in the village, which is based on local perceptions, about 40% of the households is poor because of few livestock and little land. The middle and rich category comprised about 40 and 20% of the households in the village, respectively. Rich households are those who have 5 ha irrigated land and 15 ha of rainfed land, 4 dairy cows, and 5 beef cattle. The middle category has 1 ha irrigated land, 2 ha of rainfed land and 2 dairy cows. The poor are those with only 0.5 ha irrigated land, 1 ha of rainfed land, 1 dairy cow or none, and working for other people.

Women work on agricultural lands in weeding and harvesting chickpea and sugar beet. The village does not have rangelands. Therefore, the women do almost all livestock management such as milking (both cows and sheep), feeding and cleaning animal sheds. Women also sell cow’s milk to a milk collector and then receive the money monthly from the same collector. This shows that government cow milk collection is well organized.

(3) Well-irrigated crop production system (Kolehjoob)

This village is mostly based on agricultural activities; about 50% of its area is under irrigation and 50% rainfed. There are neither qanats nor streams in the village. Therefore, all the water for irrigation comes from the 25 wells. The main products in the village are wheat, sugar beet, chickpea, corn and barley. Livestock has a low role in the total village's income. There are about 400 sheep, 40 goats, and 100 dairy cows (80 domestic and 20 crossbred).

Sources of livelihoods are: 90% crops (30% irrigated wheat, 15% rainfed wheat, 30% sugar beet, 10% corn, 15% rainfed chickpea) and 10% livestock (50% dairy, 50% sheep). Based on interviews, about 20% of the village's households is poor because of landlessness for cropping and only few livestock. The middle and rich categories consist each of about 40% of the village's households. Rich people have 5 ha of irrigated land, 4 ha of rainfed lands, 10 dairy cows, and 50 sheep. The middle households have 3 ha of irrigated land, 1 ha of rainfed land, 5–6 dairy cows, and 20 sheep. The poor households have 1 ha of irrigated land, 0.5 ha of rainfed land, 4–5 sheep, and 0–1 cow.

(4) Rainfed-dominated crop production system (Baghe Karambag)

The main agricultural activity in the village is rainfed production. The crop land is mainly rainfed (90%) and only 10% is irrigated. The important crops are rainfed wheat, barley and chick pea, and only a little sugar beet and lentils. Based on village estimate, about 45% of all land is rainfed-wheat, 10% dry barley, 30% dry chickpea, 5% irrigated wheat and, 5% sugar beet. Also, there are few livestock in this village compared with other villages in the region. In the village, about 80% of income comes from crops (less than 10% from irrigated crops) and 20% from livestock. About 40% households is poor because of small land and few livestock resources. The middle income category is 30% of the village's households and the rich group is 30% of the households. The well-off households have 6 ha of rainfed land and about 40 sheep. The poor households have 0.25 ha only and most of them work in other's farms and towns. The activities of women are like other villages. In addition, women also take animals to the rangelands, which are unique for this village.

Table 4. Characteristics of Merek villages

Characteristics	Sekhere Olya	Mahdiabad Sofla	Kolehjoob	Baghe karambag
Natural resources	- Mountain range-lands for sheep for 3 months - Limited irrigation (10% by qanat and wells) - part of rainfed fields sloppy and risk of erosion	- Irrigated land is 33% - water from river and wells for ground water exploitation - no rangeland	- 50% irrigated - water only from wells - no rangeland	- 90% rainfed - access to jungle - rangeland near village
Production system	- Mixed sheep production system and field crops (mainly rainfed) - Rainfed crops (wheat, barley and chick peas) - irrigated crops (wheat, sugar beet, corn)	- Mixed crops and livestock with mainly focus on crops. - Rainfed crops (chick pea, barley and wheat) - Irrigated crops (wheat, barley, corn and sugar beet).	- Mixed crops and livestock (90% crops and 10% livestock) - Rainfed crops (chick pea and wheat) - Irrigated crops (wheat, corn and sugar beet).	- Irrigated system with wide range of crops wheat, red beans, chickpea, alfalfa and clover, soybean, rape seed, sugar beat & cows.
Main livelihood sources	- mainly Sheep, followed by rainfed crops	Mainly crops(80%), followed by livestock (12% cows and 8% sheep)	Mainly crops(90%), followed by livestock (5% cows and5% sheep)	Mainly crops (80%), followed by livestock.
off-farm employment	Off- farm employment is limited to construction workers	Some off- farm jobs exist but not a main source of income.	Some off- farm jobs exist but not a main source of income.	Off- farm employment in construction and others are important.
Market access	15 km from main road and 40 km main town	10 km from main road and 36 km main town	9 km from main road and 35 km main town	15 km from main road and 43 km main town
Service	- Poor veterinary services - No telephone	- No telephone	- No telephone	- No telephone

Poverty estimated by local communities	- 10 percent of the households are poor, 60% middle and 30% well- off. - well off family have 100 sheep, 5 cows, 15 goats, 20 ha land. Middle households have 25 sheep, 1 cow, 10 goats and 4 ha land. Poor no sheep, no cow, 0-2 ha land.	- 40% of households are poor with only 0.5 ha irrigated, and 1 ha rainfed, 1 dairy cow or none. - The middle is 40% with 1 ha irrigate, 2 ha rainfed, and 2 dairy cows. - The rich is 20% with 5 ha irrigated and 15 rainfed, 4 dairy cows.	- 20% poor because of no land and only few livestock. -40% middle with 3 ha irrigated, 1 ha rainfed, 5-6 dairy cows, and 20 sheep. - 40% rich with 5 ha irrigated, 4 ha rainfed, 10 dairy cows, and 50 sheep.	- 40% poor because of small land and few livestock resources. - 30% middle - 30% well- off households have 6 ha rainfed and about 40 sheep.
Opportunities		- Need electric pub for the wells to increase irrigated area - Deep wells for sprinkler irrigation.	- Processing facility for processing products. - Dehumidifier for corn after for preserving. - Electric pumps	- Need loans for fattening of mainly sheep. - They can do post harvest processing of check pea if there is enough finance.

Table4. Access to services in Merek villages.

Village	Primary school	Secondary school	Distance to S. school	High school	Distance to H. school	Telephone connection	Electricity connection	TV connection	Water connection	Health clinic
Kolehjoob	Yes	No	1 km	No	7 km	No	Yes	Yes	Yes	Yes
Mahdiabad Sofla	Yes	Yes	-	No	8 km	No	Yes	Yes	Yes	Yes
Sekhere Olya	Yes	No	2 km	No	4 km	No	Yes	Yes	Yes	Yes
Baghe karambag	Yes	No	4 km	no	12 km	No	Yes	Yes	Yes	No

Rural institutions

A number of important informal institutions that support the livelihood systems of the communities are identified. They include:

- ***Pooling livestock for sharing labor:*** Collective action on pooling small ruminants and sharing the herding labor either by a rotational system or by hired labor is practiced. This is a good system which can be used for expanding into other mutually beneficial collective action. The approach is a way of reducing cost and accessing natural resources, in this case, natural rangelands.
- ***Crop sharing***: Many households have permanently settled in towns, but still hold land in the valley. These land lords make share-cropping arrangements with small land holders on fifty-fifty basis, while the land owner provides the land and the tenant provides the labor needed. The costs of purchased inputs are also shared equally. This should be included in the questionnaire so that the urban-rural interaction can be captured very well.

The policy environment

Positive achievements: A number of development achievements through progressive government policies during the past years were identified. Among them were:

Policy challenge: In spite of the above mentioned achievement, challenges that are facing policy makers were also identified. They include the following:

1. *Inputs provision.* Distribution of agricultural inputs is becoming very difficult and taking most of the time of extension services. This is exacerbated by the imbalance between supply and demand due to the subsidized inputs and the preferential allocation of inputs to strategic crops, while farmers may divert that to other crops. Farmers on their part complained about the lack of sufficient and timely input distribution. Farmers complain that they do not get their due share of subsidized fertilizer or pesticides from the government cooperative stores. Therefore, they are forced to buy these inputs from the market. Basically, the demand for subsidized inputs is higher than the supply. This creates production and allocation inefficiencies, but also creates over-use of chemical inputs with long term environmental consequences.
2. *Small holder finance.* The supply of adequate financial services that provide loans to farmers is a challenge because the banks have rules that do not recognize small farmers' conditions and demand collateral and cumbersome procedures that cannot be met by small farmers.
3. *Land fragmentation* was considered a big challenge in the villages.

Opportunities

1. *More effective water management practices*. According to our observations at Peresk olya, the possibility of creating small check dams along the spring to raise water levels to create enough volume for pumping water for irrigating trees with drip irrigation may allow them to expand the areas under trees. This is an option that has to be evaluated carefully from all aspects; economic feasibility as well as water supply aspects. These will be simple techniques that will not require expensive structures and will potentially allow the community to use greater share of the water in the spring and summer.
2. *Improving irrigation practices.* Irrigation is applied using the traditional surface method. Water conserving techniques could improve water productivity and income.
3. *Farmers' Knowledge on crop water requirement.* It is not clear whether farmers have knowledge about the water requirements of trees in this environment. Extension has already demonstrated in another location in Honam valley that tree crops such as almond and grapes need water only in the first year and can produce under this climate without irrigation. Observing from a distance, it was clear that these demonstrations have water harvesting structures such as terraces. Similar practices were observed along slopes elsewhere in the KRB during this trip. The economic feasibility was not presented and need to be verified.
4. *Targeting smallholder finance for clear asset building.* Access to loans can allow households to invest in dairy cows; about 10 cows can lift rural households from poverty. Also, loans can help them to practice fattening.
5. *Women's income generating activities.* If women have facilities, they argued that, they can make carpets, knitting, tailoring for other people, etc., and earn additional income.
6. *Expanding the experience in aquaculture.* It is argued that fish pools did not spread in the region, because farmers are conservative. They consider fish farming bad for health and avoid contact with the water discharged from fish pools. They also discourage people who try to get licenses for fish pools. Therefore, it is necessary to give complete and correct information to them by extension experts.

7. *Better marketing of sheep dairy products.* Consumers want pasteurized dairy products. But dairy sheep milk is not collected for processors because sheep are grazing unreachable places in the mountains during the season. As a result, dairy sheep products do not meet market standards. Therefore, dairy sheep products, except ghee, are not marketed. Samples of ghee sold in the shops were also considered of substandard quality. It appears that a good market development and awareness of producers and traders as means to link producers to the processing industry could exploit this sector and revive the marketing of high quality dairy sheep products. One shop-keeper said that there is a demand for pasteurized sheep yogurt. Another problem was that producers mix sheep milk with goat milk, which lowers the quality and standards, further reducing its marketability.

Risks

Drought was stated as the most important risk factor. Price of non-grunted products fluctuates at different times of the year. Also, some part of risk were also related to the poor marketing services, particularly the delivery of sugar beet to the factory, which causes a lot of losses.

Conclusion

The characterization of rural communities based on production systems, natural resources endowments, and livelihood systems revealed clear differences in the rural communities within small upper catchments of KRB. The community characterization revealed differences in natural resources endowments, production systems, access to services and employment opportunities, and poverty levels. These differences are important both in understanding current livelihood systems as well as clarifying the potential impacts of different development policies. Availability of water for irrigation was a significant differentiating resource that has clear impacts on rural livelihoods. However, traditional water management practices prevail and there is a room for improving water use efficiency by using better water management techniques. The potential for exploitation of groundwater, which is now banned, also exists in some catchments. Furthermore, work is needed to determine suitable abstraction rates as well as rules for groundwater utilization. Agricultural productivity can be enhanced with: (i) better water management, (ii) replacement of current input subsidies with better input availability, and (iii) targeting of credit services to finance asset building and poverty reduction options for smallholders.

Socioeconomic Characteristics, Different Water Uses and Status of Irrigated Cereals in Lower KRB (Azadegan and Sorkheh Plains)

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Abstract

This study was implemented in the Azadegan (DA) and Sorkheh (DS) plains in the lower KRB during 2006–07. The general objective of this research was to study the effects of economical factors on water use efficiency in irrigated cereals under farmers' condition in L-KRB. The study mainly dealt with distinguishing the socio-economic characteristics, different water uses, water prices for cereals, and situation of irrigated cereals.

In the first phase of project implementation, library studies were conducted to collect basic information on socio-economic parameters and the general situation of cereal cultivation in the target regions. In the next phase (field studies), 166 farmers were selected as samples using a stratified random sampling method. In this step, required data were collected from 166 farmers in DA and DS plains through filling of research questionnaire and by the involvement and contribution of experts from the local Agricultural Extension Centers of Ministry of Jihad-e Agriculture. About 18% and 82% samples were selected from DS plain (6 villages) and DA plain (8 villages from the area under Rural Extension and Services Centers), respectively.

According to the results, the total population of DA and DS plains are 112945 and 6126 people, respectively. About 51% and 49% of the total population of the DA and DS plains live in the urban and rural areas, respectively. Employed population in DA plain was 25.8% in 2003. Rate of literacy in DA and DS plains were 64.4% and 60.9%, respectively. The coefficient of mechanization in the Khuzestan and DA plain are 0.63 and 0.56 (hp ha^{-1}), respectively. The average yield of irrigated wheat in the DA and DS plains are 2700 and 3600 kg ha^{-1}, respectively. In DA plain, irrigation system is a combination of traditional and modern systems. Based on cropping pattern of irrigated area, future water consumption requirement is expected to be 831.2 million cubic meter per year (M m^3 yr^{-1}). Currently, the water consumption in the area is 742.7 M m^3 yr^{-1} (89%).

In the DS and DA plains, the average age of farmers were 45.1 and 44.7 years, and average number of children was 5.1 and 6.1 people per household, respectively. The experience of farmers in agriculture was 25 and 24.3 year, respectively. Owned contribution of irrigated crop to household income was 96.9% and 79.5%. About 7% farmers of DS plain and 52% farmers of DA plain participated in the extension program. Owned land area of irrigated wheat and maize were 19.1 and 13.3 ha, respectively, in DS plain and owned land area of irrigated wheat and barley were 18.2 and 8.6 ha, respectively, in DA plain. In the DS plain, the average cost of wheat and maize production estimated to be 2420042.7 and 2837659.3 Rials ha^{-1}, respectively. The average water consumption for wheat and maize were 7328.5 and 14880.1 m^3 ha^{-1}, respectively. The average cost of water for wheat and maize were estimated to be 386533.3 and 422850 Rial ha^{-1}, respectively. The average yield of wheat and maize (improved variety) were 4246.7 and 5703.7 kg ha^{-1}, respectively. In the DA, the average yield of wheat (improved variety) and barley yield (local variety) were 2575.1 and 1855.9 kg ha^{-1}, respectively.

Keywords: Socioeconomic, production, Dasht-e Azadegan, Dasht-e Sorkheh, water, cereal, Karkheh

Introduction

Since the water supply has always been limited and the demand for water has been increasing in Iran as the population grows, planning for optimal use of water resources has specific importance. About 93% of the renewable water resources of the country is used in agriculture, but, the

agricultural production is insufficient.
KRB (KRB) is located in the west to south – west of Zagroos ranges in Iran. KRB is located between 56°, 34¢ – 58°, 30¢ North Latitude and 46°, 06′ – 49°, 10′ longitude. The area of the basin (inside Iran) is 50764 km^2. Out of which 27645 km^2 are mountains and 23119 km^2 are plains and hills. The mountainous areas of this basin are mostly in the eastern and central parts. The plains are mostly in the northern and southern parts cover almost 45% of the basin area.

Water in the KRB is limited and becoming scarcer as population and demand are increasing. The productivity of rain-fed agriculture is low, conventional irrigation management is poor, cropping systems are sub-optimal, and policies and institutions are weak. However, Iran's agricultural strategy identifies water productivity improvement as a top priority. The KRB reflects, in many aspects, the problems of water management in other basins in the region.
In the Khuzestan province, the average volume of water delivered to the cereals is 7910 m^3 ha^{-1} and the average price of irrigation water and pumping costs, in irrigation networks of Avan plain, are 0.30 US $\$.m^{-3}$ and 0.125 US $\$.m^{-3}$, respectively.
The general objective of this research is to study the effects of economic factors on water use efficiency in irrigated cereals under farmers' condition in Lower KRB. The study mainly dealt with distinguishing of socioeconomic characteristics, different water uses, water prices for cereals, and situation of irrigated cereals in the Azadegan and Sorkheh plains (DA and DS) in the L-KRB.

Methodology

The study implemented in the DA and DS plains in the Khuzestan province during years 2006–07. Library studies were conducted to collect basic information on socioeconomic parameters, amount of different water uses and general situation of cereals cultivation in the target regions. A comprehensive questionnaire for assessing socioeconomic aspects of water use efficiency (WUE) of irrigated crops in the plains were prepared and developed. The questionnaire included questions and required information on the issues such as: farmer's general information; land use (cropping pattern) by type of land tenure characteristics; soil characteristics; water resources; cropping system (including the method of irrigation, lands preparation and planting methods and their costs, methods of fertilizer, pesticide and herbicide application and their costs, method of harvest and its cost); agricultural inputs (except water) and their costs, water inputs (including the total area irrigated, water right, irrigation scheduling (interval) and timing, irrigation costs); Competition and shortages of water; agricultural crop yield and price outputs; socioeconomic condition; and other related factors. Overall, the questionnaire dealt with the following topics and pivots:

- Location of the farm
- Farmer's general information
- Land use (cropping pattern) by type of land tenure characteristics
- Soil characteristics
- Water resources
- Cropping systems
- Agricultural inputs and cost (except water)
- Water inputs
- Agricultural crop yield and price outputs
- Socioeconomic condition and other factors

Results

The climate of DA and DS plains is warm and semi-arid. Based on 2003 data, the average annual rainfall of DA and DS plains were 219.6 and 335.2 mm, respectively. There is no rain during June-September. The rain occurs mainly during December-March. The average annual temperature of region is 22.9°C and maximum absolute annual temperature is

51.8°C. The average annual humidity and evaporation are 47% and 3099 mm, respectively.

The total population of DA and DS plains are 112945 and 6126 people, respectively. About 57795 people (51.2%) of the DA and 55150 people (48.8%) of the total population of DS plains live in the urban and rural areas, respectively. The employed population in DA plains was 25.8% (19283 people) in 2003. The rate of literacy in DA and DS plains are 64.4% and 60.9% respectively. Table 1 shows some socio-economic characteristics of the DA and DS plains.

The coefficient of Mechanization in the Khuzestan province and DA plain are 0.63 and 0.56 (hp ha^{-1}), respectively. Table 2 provides some information on the number of agricultural instruments and machinery in the DA and DS.

According to the information in target regions (2004), the planting area of irrigated wheat in the DA and DS plains were 50050 ha (15.1%), 5000 ha (1.5%), of the total planting area of irrigated wheat in the Khuzestan respectively. Irrigated wheat production in DA and DS plain from the total irrigated wheat production in Khuzestan were 135135 tons (11.8%), 18000 tons (1.6%), respectively. The average yield of irrigated wheat yield in the DA and DS plains were 2700 and 3600 kg ha^{-1}, respectively. Table 3 information on planting area, yield and total production of common cereals in the DA and DS plains are presented.

Table 1: Some socioeconomic characteristics of the DA and DS plains in the L-KRB

Total population (people,%)				Rate of Literacy (%)		Average size of land holding (ha)			Employed population (people)
DA			DS	DA	DS	DA			DA
Urban	Rural	Total	Rural			Rustic	Mechanized	Segments	
57795 (51.2%)	55150 (48.8%)	112945	6126	64.4	60.9	17.6	9.8	2	19283 (25.8%)

Sources: 1-Agricultural Planning and Economic Research Institute, Ministry of Jihad-e Agriculture, 2003. 2- Statistics Center of Iran, 2003.

Table 2: Number of agricultural instruments and machinery in the DA and DS plains

DA plain						DS plain				
Disk and Plough	Spraying fertilizer	Spraying poison tractor	Kinds of Thresher	Cereals planting instruments	The rest	Disk and Plough	Spraying fertilizer	Spraying poison tractor	Kinds of Thresher	The rest
1800	530	400	257	117	916	356	195	96	17	781

Source: 1-Management of Jihad-e-Agriculture, in DA Plain, 2003. 2- Extension and Agriculture Services in DS Plain, 2004.

Table 3: Planting area, production and yield of irrigated cereals in the DA and DS plains compared to the Khuzestan province and the whole country

Target	Planting area (ha)			Production (ton)			Yield (kg ha^{-1})		
regions	Wheat	Barley	Maize	Wheat	Barley	Maize	wheat	barley	maize
DA plain	50050	5020	120	135135	8534	624	2700	1700	5200
DS plain	5000	88	2541	18000	176	19820	3600	2000	7800
Khuzestan	331335	27646	59207	1149239	51435	396697	3469	1860	6700
Country	2547632	597494	273903	9750305	1935013	1924128	3827	3239	7025

Source: 1-Management of Jihad-e-Agriculture, in DA plain, 2003. 2- Extension and agriculture Services in DS plain, 2004.

The major surface water resource in the DA plain is Karkheh river. Irrigation system is a combination of traditional and modern systems. In DA plains, based on the cropping pattern of irrigated area, water requirements is estimated to be 831.21 M m^3 yr^{-1}. Currently, the water consumption in the area is 742.7 M m^3 yr^{-1} (89%). The rate of water consumption in the forms of pumping, network, and groundwater are 490.6, 245.1, 7 M m^3 yr^{-1}, respectively. Irrigation method in DA plain for wheat and barley are furrow and border irrigation and for maize, it is furrow irrigation.

The share of water consumption in DA plains for agriculture, drinking, green space, industrial and fish production are estimated to be 742.7, 19.1, 1.22, 1.37, and 6.1 M m^3 yr^{-1}, respectively.

Based on information (Sources: Agricultural Planning and Economic Research Institute, Ministry of Jihad-e Agriculture, 2003.; Ministry of Energy, Khuzestan Water and Power Authority, 2003) the net, gross and total volume of water required for the 72105 ha of planting area in DA are 3458.3 m^3 ha^{-1}, 11527.8 m^3 ha^{-1}, 831.21 m^3 ha^{-1}, and 30 million m3 ha^{-1}, respectively.

Avan plain is one of the plains in the L-KRB and the irrigation networks are well established. Considering the availability of data and similarity of this plain to DA and DS plains, some information on the allocated water, prices and tariffs of irrigation water in this plain are presented in Table 4.

As already stated, the main objective of this research was to study the effects of economic factors on WUE of irrigated cereals under farmer conditions in areas of L-KRB in the Khuzestan province, Iran. Following the preparation of the research questionnaire, 166 farms in DA and DS were selected using stratified random sampling method. Moreover, to the above mentioned data, the required information were collected through filling of research questionnaire and by involving the contributions of experts from the local Agricultural Extension Centers of Ministry of Jihad-e Agriculture in the DA and DS plains.

The total number of samples in both DA and DS were 166 farmers. Thirty farmers (18%) and136 farmers (82%) were selected from DS and DA plains, respectively. Farmers samples in DS were Selected from 6 villages including Salar Shahidan (23%), Fath (23%), shahid Fallahi (13%), Mehajerin (13%), Esteglal (13%) and Ghods (%13). In DS, the average distance between farms to villages were 4.1 km, The average age of farmers were 45.1 years; the number of children were 5.1; and the number of children active in the farm were 2. The education level of farmers was between preparatory and secondary. The experience of farmers in agriculture was 25 years. About 7% of the farmers participated in extension program. Owned contribution of irrigated crop to household income was 96.9%. Owned land area of irrigated wheat and maize were 19.1 and 13.3 ha, respectively. The number of plots for wheat and maize area were 3 and 1.8, respectively.

The average cost of wheat and maize production was estimated at 2420042.7 and 2837659.3 Rials ha^{-1}, respectively. The average water consumption for wheat and maize were 7328.5 and 14880.1 m^3 ha^{-1}, respectively. The average cost of water for wheat and maize were estimated 386533.3 and 422850 Rials ha^{-1}, respectively. The average of wheat and maize yield (improved variety) were 4246.7 and 5703.7 kg ha^{-1}, respectively. In Tables 5 and 6, the characteristics of sample farmers and farms and cost of production in the DS are provided, respectively.

Table 4: Water rates of irrigated cereals in irrigation and sanitation networks of Avan plain in L-KRB (year 2004–05)*

Agricultural Products	Volume of allocated water ($m^3\ ha^{-1}$)	Modern network		Average tariff of the well water (rials m^{-3})
		Average price of irrigation water (rials m^{-3})	River pumping costs (rials**m^{-3})	
Cereal	7910	29	13	3.5
Wheat	6463	37	14.4	3
Barley	5366	23	17.4	3.5
Maize	11902	26	7.8	4.1

*Source: Irrigation network of Karkheh and Shavour, 2005. **: 1US$ almost is equal to 9600 Rials

Table 5: Characteristics of sample farmers and farms in the DS Plain

Indexes	Average	Max	Min
Age (year)	45.1	70	32
Number of children	5.1	10	1
Number of children active in farm	1.9	4	0
Experiences (year)	24.9	50	10
Owned land tenure (ha)	22	65	4
Percent of income sources from on-farm	95	100	60
Contribution of irrigated crop to household income (%)	96.9	100	70

Table 6: Cost of production and cost of water in the DS Plains

Indexes	Average		Max		Min	
	Wheat	Maize	Wheat	Maize	Wheat	Maize
Owned area (ha)	19.1	13.3	55	40	4	3
Number of plots	3	1.8	6	4	1	1
Amount of water consumption ($m^3\ ha^{-1}$)	7328.5	14880.4	8200	16200	6000	12000
Cost of water (Rials. ha^{-1})	386533.3	422850	420000	440000	329200	401200
Grain yield (kg ha^{-1})	4246.7	5703.7	6000	8000	3000	3000

The farmers sample in DA plain were selected from 8 area under Rural Extension Services of Jihad-e Agriculture Centers, including Shahid Chamran Center (20.6%), Shahid Alamolhoda Center (14%), Hovizeh Center (14%), Bostan Center (14%), Rafie Center (12.5%), Allaho Akbar Center (11%), Valfajer Center (8.8%) and Extension Centers of Sableh (5.1%).

In DA plains, the average distance between farms to village was 2.6 km, the average age of farmers was 44.7 years; the number of children were 6.1; and the number of children active in farm were 1.0. The experience of farmers in agriculture was on an average 24.3 years. About 52% farmers participated in extension program. Owned contribution of irrigated crop to household income was 79.5%. Owned land area of irrigated wheat and barley were 18.2 and 8.6 ha, respectively. The number of plots for wheat and barley areas were 2.5 and 1.2, respectively.

The average of wheat yield (improved variety) and barley yield (local variety) were 2575.1 and 1855.9 kg ha^{-1}, respectively. In Tables 7 and 8, the characteristics of sample farmers and farms and cost of production in the DA are provided respectively.

Table 7: Characteristics of sample farmers and farms in DA plain

Indexes	Average	Max	Min
Age (year)	44.7	75	23
Number of children	6.1	18	0
Number of children active in farm	1	11	0
Experiences (year)	24.3	60	3
Owned land tenure (ha)	20.8	100	1.5
Percent of income sources from on-farm	89.5	100	10
Contribution of irrigated crop to household income (%)	79.5	100	10

Table 8: Cost of production and cost of water in DA plain

Indexes	Average		Max		Min	
	Wheat	barley	Wheat	barley	Wheat	barley
Owned area (ha)	18.2	8.6	100	40	1	1
Number of plots	2.5	1.2	8	3	1	1
Grain yield (kg ha^{-1})	2575.1	1855.9	7000	3000	1000	1000

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CHAPTER V

Basin Studies

A Land Suitability Study under Current and Climate Change Scenarios in KRB

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Abstract

Assessing the suitability of an area for crop production requires a considerable effort in terms of information collection that presents both opportunities and limitations to decision-makers. A GIS has been used to match the suitability for winter wheat based on the biological requirements of a crop and the quality and characteristics of land within the KRB, Iran. The methodology integrates land quality attributes that most influence crop suitability, including long-term average annual precipitation, accumulated temperature, soil and topography data. Good management is assumed, including the use of appropriate crop varieties, fertilizers and sowing date; social and economic factors are excluded. The overall suitability is assessed by the Most Limiting Factor Approach (MLFA), which is preferred over a GIS model which provides weights to individual attribute scores. The results indicate that under current climate conditions 8.7%, 7.6% and 28% of the area are 'highly', 'moderately' and 'marginally' suitable for winter wheat, whereas the remaining 55.7% can be considered unsuitable. Under climate change scenarios, the suitability of land for winter wheat showed considerable variation. Under a scenario of both increases in temperature and precipitation, 'highly and moderately suitable' areas increased, but under a scenario of decreased precipitation, 'highly suitable' areas decreased as much as 91%. The methodology could readily be adapted for other soil and climatic conditions.

Keywords: Land suitability, Winter wheat, Most Limiting Factor Approach (MLFA), GIS

Introduction

Atmosphere is the "vehicle" of climate and the plant is the "vehicle" of agriculture (Thran and Broekhuizen, 1965). It is therefore not possible to pass judgment on the suitability of the climate for agriculture, and the various production sectors, until we have ascertained the effect of the numerous climate features on the growth of crops and farming activities. Even fairly small variations, such as those occurring in a single climate element, may exert an obvious influence within the complex interactions of zone and climate.

There is mounting evidence for real global climate change (WMO, 2000) and global mean temperatures are now about 0.6°C higher than 130 years ago (CCIUK, 1998). The years 1997 and 1998 were the warmest years since 1860 (WMO, 2000). If present trends continue, the average temperature of the planet will increase by 2.36°C by the end of the 21st Century (Mcginty *et al.*, 1997), and land use changes become unavoidable due to the interactions of regional climate with soils and specific crops. Especially winter wheat is sensitive to both the water stresses and temperature trends predicted by climate change experts.

It has long been recognized that land suitability is assessed as part of a 'rational' cropping system (FAO, 1976) and optimizing the use of a piece of land for a specified use (Sys *et al*., 1991) should be based upon its attributes (Rossiter, 1996). Furthermore, land may be considered either in its present condition, or after specified improvements. Although criteria may vary, they are essentially based on climate, soil, topography, and water availability; consequently these are the most important categories of natural environmental information required for judging land suitability. Rounsevell *et al.,* (1996) report that adequate modeling of agronomic system perturbations to climate change requires multiple approaches, including (i) an assessment of general agroclimatic indices (e.g. thermal time), (ii) information from crop models (either at specific locations or across a whole country), and (iii) the use of land suitability assessments combining spatial information on climate and soils to determine potential suitability. Such an integrative approach has been used to assess the spatial distribution of winter wheat and grassland suitability to climate sensitivity (Brignall and Rounsevell, 1995; Rounsevell *et al.,* 1996).

This paper describes a climate-soil-site model to assess climate change impacts on land suitability for rainfed winter wheat, focusing on the potential effects of temperature increase and precipitation change on the land suitability in KRB, Iran. Assessments are made for the present-day climate (defined as 1973–1998) and scenarios of future climate by 2025 with GIS maps generated through a Most Limiting Factor Approach (MLFA).

Material and methods

Study area

The KRB is located in the west of Iran, between 30° 58' to 34° 56' N and 46° 06' to 49° 10' E (Fig. 1). The area is about 50,700 km2, with considerable variation in elevation, from a minimum of 3 m above sea level in Dasht Azadeghan to a maximum of 3,645 m in Karin Mountains. The population of the area is around 4 million and is concentrated in the main cities and towns: Kermanshah, Khoramabad, Malayer, Songor, Kamyaran, Nahavand and Sosangerd; otherwise the KRB is rural.

Soils

The original 1:1,000,000 digitized Soil Map of Iran (Banaei, 2000) was clipped to the KRB outline. The Soil Map of Iran is a soil association map, in which the soil components are classified according to Soil Taxonomy. The association contains listings of dominant, associated and included soils, but no percentages. Each mapping unit is also classified as a SOTER landform. Landsat satellite imagery and comparison with the Shuttle Radar Topographic Mission (SRTM[3]) digital elevation model confirmed that boundary delineation of the soil mapping units matched landforms well in most places. Therefore the map was accepted as a framework for identifying major soil types within a broad physiographic framework, thus eliminating the need for defining a separate landform framework based on a digital elevation model for the KRB.

The soil classes of the Soil Map of Iran were then regrouped in accordance with their major properties with respect to ‘usability’ into ‘soil management domains’ (SMD). The regrouping of the soilscapes into SMDs was based on the dominant soil type (Table 1). The classes ‘Dune land’, ‘sandy soils’, ‘saline soils’, ‘badlands’ and ‘urban’ were taken out from the new soil map and added to the corresponding General Theme layers in the AEZ map. The class ‘Marsh’ was taken out of the new soil map and added to the land use category ‘wetlands’. The areas with classes that were taken out of the new SMD classification were reclassified as ‘n.a.’ (not applicable).

[3] *http://srtm.csi.cgiar.org/SRTM_FAQ.asp*

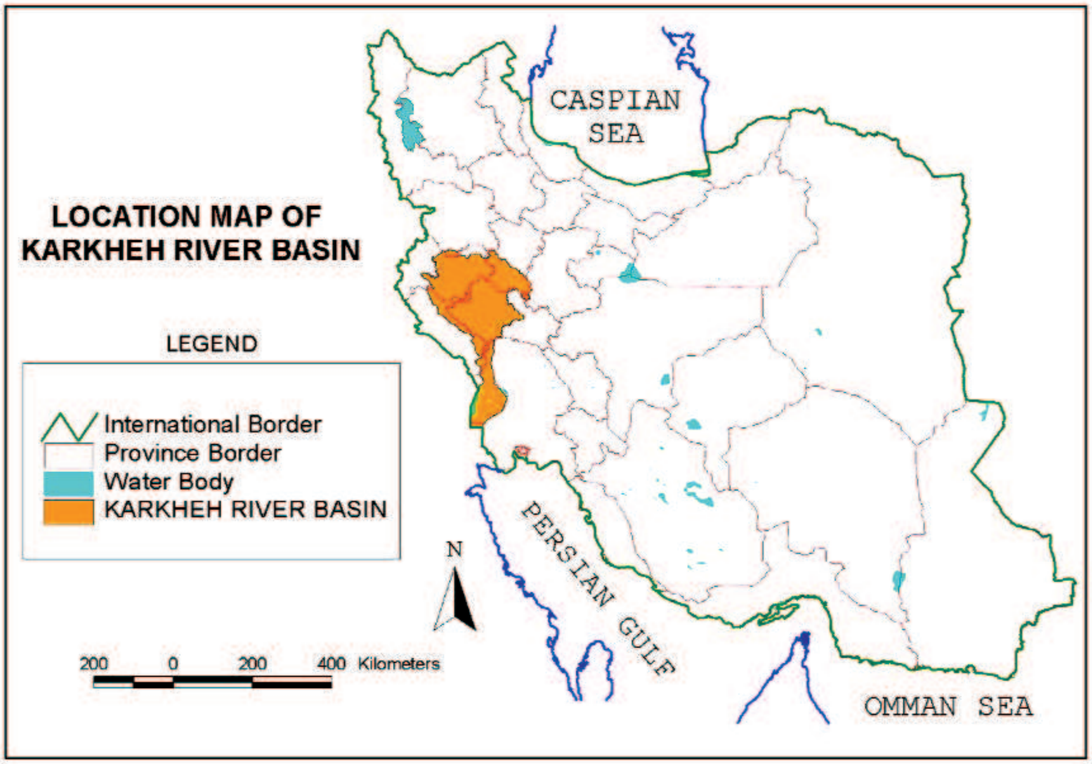


Figure 1. Location of the study area in the west Iran.

Table 1. Old and new soil classes.

Old classes: dominant soils	AEZ code	Soil Management Domain (SMD)	SMD Code
Marsh	Marsh		n.a.
Calcic Ustochrepts, Calcixerollic Xerochrepts, Typic Calciustolls	Well_Drained_Agri_Soil	Well drained, calcareous soils of plains, suitable for agriculture	1
Aridic Ustifluvents, Typic Torrifluvents, Typic Ustifluvents, Fluventic Xerochrepts	Alluvial_Soils	Alluvial soils	2
Typic Endoaquepts, Aquic Calcixerolls, Typic Fluvaquents, Typic Halaquepts	Poor_Drained_soils	Soils with deficient drainage	3
Typic Haplogypsids	Gypsiferous_Soil	Gypsiferous soils	4
Aridic Ustorthents	Poorly_Developed	Poorly developed soils of arid regions	5
Rock outcrop	Rock outcrop	Rock outcrops or very shallow soils	6
Dune land, **Psamments	Dune land; Sandy soils	Sand dunes	n.a.
Typic Haplosalids	Saline_Soil	Saline soils	n.a.
Badland	Badlands	Highly eroded badlands	n.a.
Urban	Urban	Urbanized areas	n.a.

(Source soil information: Soil and Water Research Institute, 2000)

Topography

Topographical maps are used to select site slopes and altitude information relevant to land suitability. This study used a landform panorama Digital Terrain Model (DTM) of raster format, 10 m resolution, supplied by the FRWO, Iran.

Climate

The most important climate characteristics are temperature, precipitation, radiation balance, wind, relative humidity and evaporation. A database of point climatic data covering monthly averages of precipitation, minimum and maximum temperature was made available for the main stations in Iran, covering the period 1973–1998, by the Organization of Meteorology, based in Tehran.

Climate change scenarios

Several climate scenarios based on general circulation models (GCM) were selected for use in the study area. Scenarios that assume a temperature increase were considered acceptable, as this is consistent with the analysis of historical climatic data over the last 30 years in the study area. Analysis of precipitation trends did not show such increases, so three options have been applied; one consistent with current average precipitation conditions, one 20% less and one 20% more. Scenarios are as summarized:

- Scenario 1 = +20% precipitation,
- Scenario 2 = -20% precipitation,
- Scenario 3 = +1.5 °C,
- Scenario 4 = +1.5 °C and +20% precipitation,
- Scenario 5 = +1.5 °C and -20% precipitation.

Land suitability

The overall suitability is expressed in three classes: highly suitable (HS), moderately suitable (MS) and marginally suitable (MG). Moderately suitable and marginally suitable land were expected to have a crop yield of 60–80% and 40–60% of the yield under optimal conditions with the lower limit corresponding to inputs consistent with actual farm input practices, and the upper limit with improved practices. Unsuitable (U) land was assumed to have severe limitations, which could rarely or never be overcome by economic use of inputs or management practices (FAO, 1976; Dent and Young, 1981).

Highly suitable areas have a high potential production and sustainability of yield from year to year. In average years there is an opportunity for establishment at or near the optimum sowing time, while harvesting is rarely restricted by poor ground conditions. Even in wet years working conditions are acceptable and do not prevent crop establishment yet there are normally sufficient soil water reserves to meet the average requirements of the crop. Moderately suitable areas can allow high or moderate potential crop production, which can be lower in years when soil-water is insufficient to sustain full growth, or when crop establishment is unsatisfactory due to untimely sowing or poor soil structure. Marginally suitable areas are those with variable potential production from year to year, with considerable associated risks of low yields, high economic costs, or difficulties in maintaining continuity of output, which are due to the climate interacting with soil properties or disease and pest problems (Jarvis et al., 1984; Jones and Thomasson, 1987). The criteria, which were applied for unsuitability, in this study area, were based on slope and soil properties rather than on climate. Dent and Young (1981), assumed that under rainfed agriculture, expected crop yields (as a percentage of yields under optimal conditions) were more than 80%, 40–60%, 20–40% and less than 20% in high, moderate, marginal and unsuited areas, respectively. Because in the present study, evaluation is based on an average of 25 years of climate data, we may also assume that expected crop yields are close to the potential production during more than 80%, 40–60%, 20–40% and less than 20% of years for high, moderate, marginal and unsuited areas, respectively.

Temperature

Average accumulated temperature above 0°C between January and June (the first 6 months of the year) is applied, as recommended by McRae (1988), as a good measure of the heat energy available for plant growth. Also, this variable is used for management practices. It has been found, in Western Europe, that the best response to fertilizer application in the spring is when 200 day °C have accumulated. Scheunemann *et al*. (1990) forecasted the date and duration of the harvest times in fruit vegetables, such as pickling cucumber, bush bean and tomato by this method. In China, He *et al*. (1998) found the large variation in dormancy (that adversely affects plant growth and yield) was caused primarily by differences in the accumulated temperature sum.

Slope

Slope, an important element of landform, plays an important role where mechanization is concerned. Sys *et al*., (1991) believe that on slopes steeper than 20% mechanization becomes impossible and that for slopes less than 20% there are still important variations in productivity according to variation in slope. Navas and Machin (1997) state that, in order to avoid soil erosion and other problems derived from the use of machinery, only land with slopes below 8° should be used.

Crop characteristics

Crop-specific properties such as the physiological and phenological crop parameters for winter wheat were gathered from literature review, particularly from Jarvis et al., (1985), MAFF (1988), and Sys *et al*., (1993). Climatic, edaphic and site requirements for selecting land suited for the cultivation of winter wheat are shown in Table 2.

Table 2. Land suitability requirements for winter wheat.

Land characteristic	Requirements for suitability rating			
	Highly suitable (HS)	Moderately suitable (MS)	Marginally suitable (MG)	Unsuitable (U)
Accumulated Temperature (January-June)	>1750°C	1500 to 1750°C	1200 to 1500°C	<1200°C
Average precipitation (October-June)	> 450 mm	350-450 mm	250-350 mm	<250 mm
SMD	1, 2	3	4, 5,6	n.a
Slope	0-5%	5-8%	8-20%	>20%

Geographical Information Systems (GIS)

The GIS methodology used in this study transforms spatial input data in a specific modeling procedure for land suitability assessment into spatial outputs. Digitized maps, the geographical distributions of soils, topography and agroclimatic regions were captured together with attribute data (e.g. SMD). Overlaying was carried out using ArcGIS software. The results are presented as tables and maps. Overall suitability is recognized by the Most Limiting Factor Approach (MLFA) illustrated in Fig. 2. This method utilizes the concept of "most limiting factor" which corresponds to Liebig's "Law of the Minimum". An example path is displayed in dotted lines. Here, a combination was deemed "highly suitable" in the first four factors. However, soil depth was found to be "moderately suitable" and the slope "unsuitable".

The sieving process therefore reported the combination as "unsuitable" in terms of overall suitability (dotted line). This method was used in preference to a weighted spatial GIS model derived from scoring attributes (cf. Cook, 1991), because it is seldom clear how to derive the weightings of successive overlays in a consistent and objective manner.

Results

Changes in mean annual and extreme temperatures and precipitation were calculated in accordance with the selected climate change scenarios. Temperature increase applied to the year 2050 was assumed 1.5 °C more than the current mean temperature. The distribution of mean annual temperatures was based on the 1973–98 temperature record for the study area.

Slope

First suitability was assessed in terms of topography. Elevation alone did not affect land suitability since the whole study area was highly or moderately suitable for the crop under consideration. Slopes affect land suitability very much. About 22% of the area was marginally suitable, with slopes between 8 and 20%; and 35% of the study area had very steep slopes (> 20%), which were unsuitable for crop production in general (Table 3, Fig. 3).

Accumulated Temperature

Table 3 shows that the accumulated temperature criterion was not found to be a limiting factor for cereals. Approximately 66% of the study area was found to be 'highly suitable', whereas only a small area (7%) was in the category 'unsuitable'. The

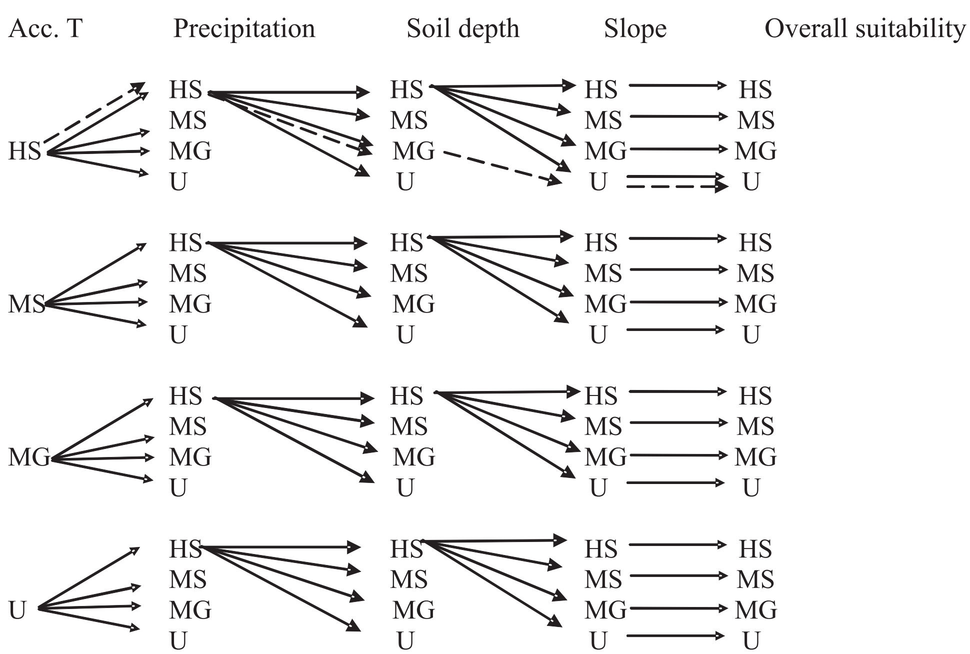


Figure 2 Most Limiting Factor Approach (MLFA) used in GIS overlays of single maps to determine overall land suitability for the crops. Acc. T: accumulated temperature, HS: highly suitable, MS: moderately suitable, MG: marginally suitable and U: unsuitable. The dotted line refers to the example in the text.

lowest accumulated temperature in the study area was 1000 °C above 0 °C between January and June.

Precipitation

Highly suitable and moderately suitable areas were 50.4 and 31.7%, respectively (Table 3). Only 13.7% of the study area is unsuitable with 4.3% of the area in the marginal category.

Soil management domain

Soil management domain is an important limited variable for winter cereals within the study area. Only 28% of the study area is highly suitable and 1.7% moderately suitable and the remainder was marginally suitable (54.4%) or unsuitable areas (16.1%) (Table 3).

The overall suitability for land suited to winter wheat growing under water-limited (rainfed) conditions is also presented in Table 3. Nearly 8.7% and 7.6% of the study area was found to be highly and moderately suitable, respectively. The remainder was marginally suitable (28%) or unsuitable (55.7%). This overall suitability map for winter wheat was produced by an overlay of maps of accumulated temperature, precipitation, slope, soil management domain.

Under the scenarios of temperature increase, there is a shift from marginally and moderately suitable areas to moderately and highly suitable areas. A comparison of climate change impacts shows that 'highly and moderately suitable' areas increased in all scenarios except the scenarios with decline in precipitation (Table 4).

Table 3. Accumulated temperature, average precipitation, SMD and slope suitability for winter wheat.

		Highly suitable	Moderately suitable	Marginally suitable	Unsuitable
Accumulated temperature	Area (*1000 ha)	3398	826	582	364
	Area (%)	65.7	16	11.3	7
Average precipitation	Area (*1000 ha)	2605	1636	221	707
	Area (%)	50.4	31.7	4.3	13.7
SMD	Area (*1000 ha)	1437	89	2812	832
	Area (%)	27.8	1.7	54.4	16.1
Slope	Area (*1000 ha)	2090	200	1169	1887
	Area (%)	39.1	3.7	21.9	35.3
Overall suitability	Area (*1000 ha)	450	391	1449	2879
	Area (%)	8.7	7.6	28	55.7

Table 4. Percentage area of suitability classes for winter wheat by climate change scenarios. T = temperature, P = precipitation.

T P	No Change	0.0 °C +20%	0.0 °C -20%	+1.5 °C -	+1.5 °C +20%	+1.5 °C -20%
Highly suitable	8.7	11.2	0.8	9.2	13.3	0.8
Moderately suitable	7.6	19.2	10.5	20.8	12.8	10.5
Marginally suitable	28.0	14.0	32.2	15.2	21.1	33.1
Unsuitable	55.7	55.7	56.5	54.7	52.8	55.6
Total	100	100	100	100	100	100

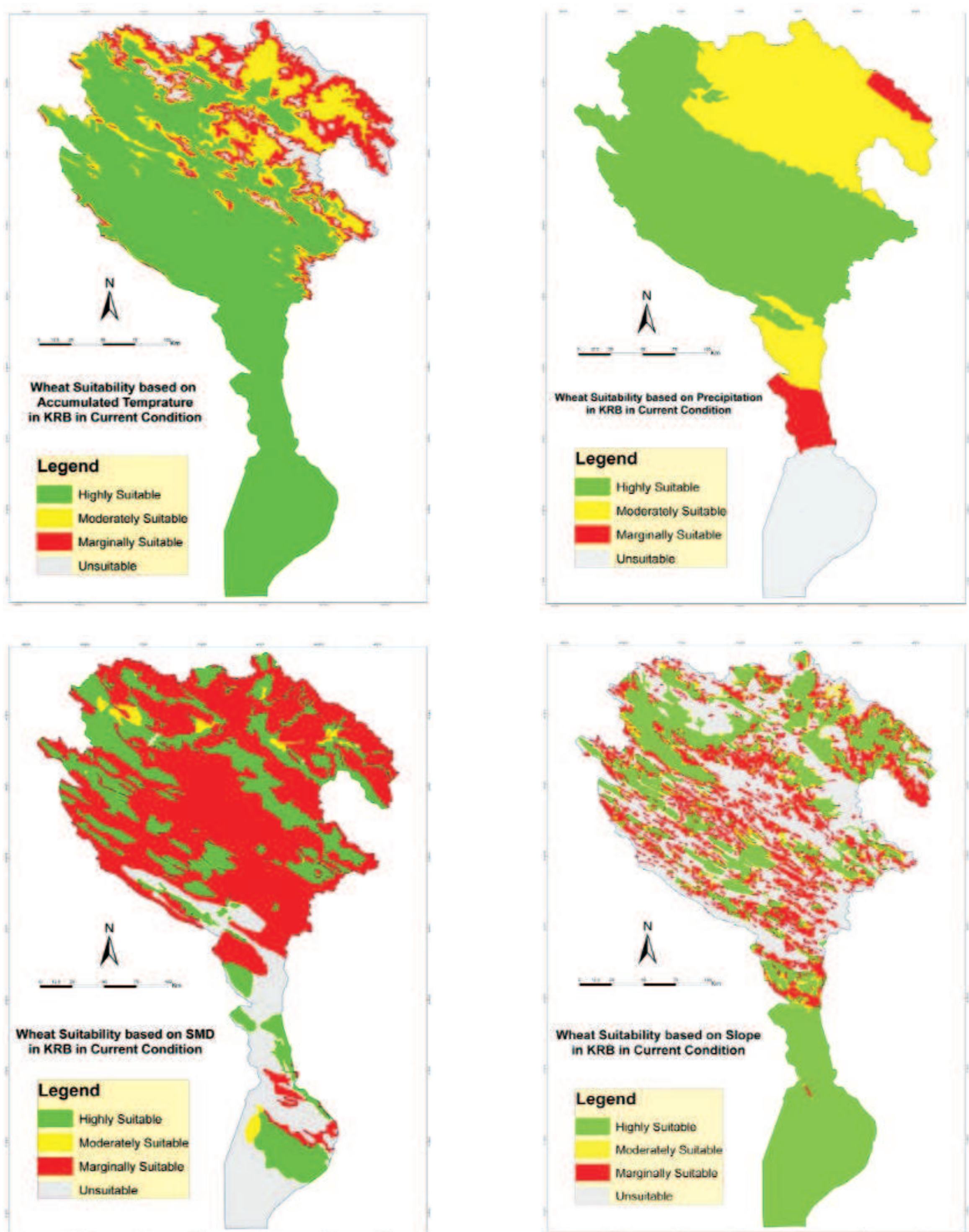


Fig. 3. Suitability for wheat in KRB based on the accumulated temperature, precipitation, soil management domain (SMD) and slope.

Figures 4 and 5 clearly show the effects of climate change scenarios on land suitability for winter wheat in the study area under the envisaged climate change scenarios. Figure 4a summarizes any increase or decrease in areas with different suitability classes in terms of absolute areas, and Fig. 4b summarizes the percentage change in area. By increasing temperature alone (Scenario 3, T+1.5 °C),, the highly and moderately suitable areas increased by 6% and 176% respectively. Increasing both temperature and precipitation (Scenario 4, T+1.5 °C & P + 20%) increased highly and moderately suitable areas by 53% and 69%. If temperature increases are accompanied with precipitation decreases (Scenario 5), highly suitable areas –decrease by 90%. The main reason for this is water stress risk, not the direct effect of temperature. In Scenario 2, a 20% decrease in precipitation caused the highly suitable area to decrease by about 91%.

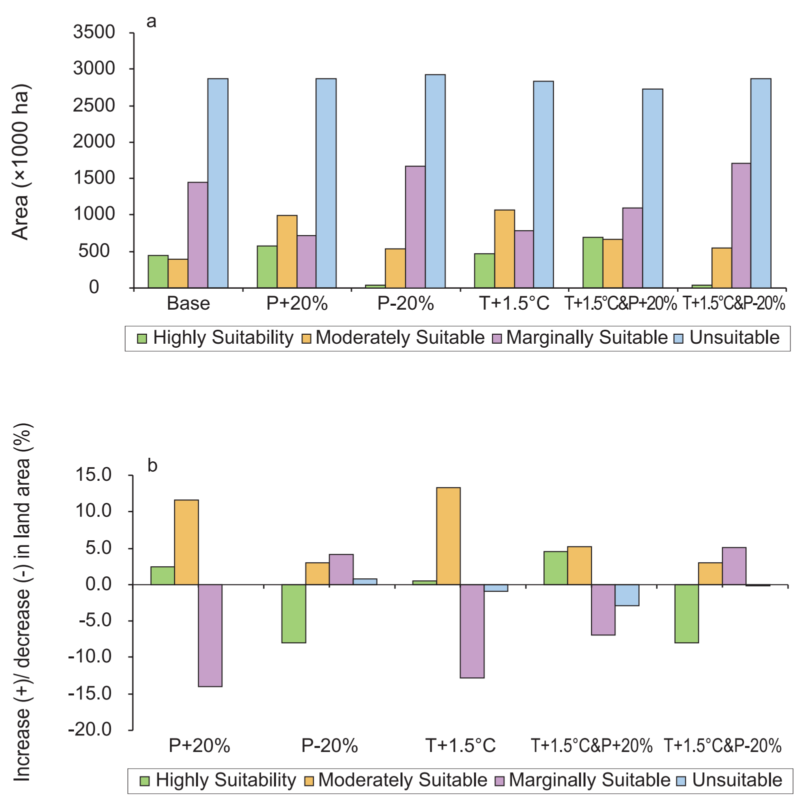
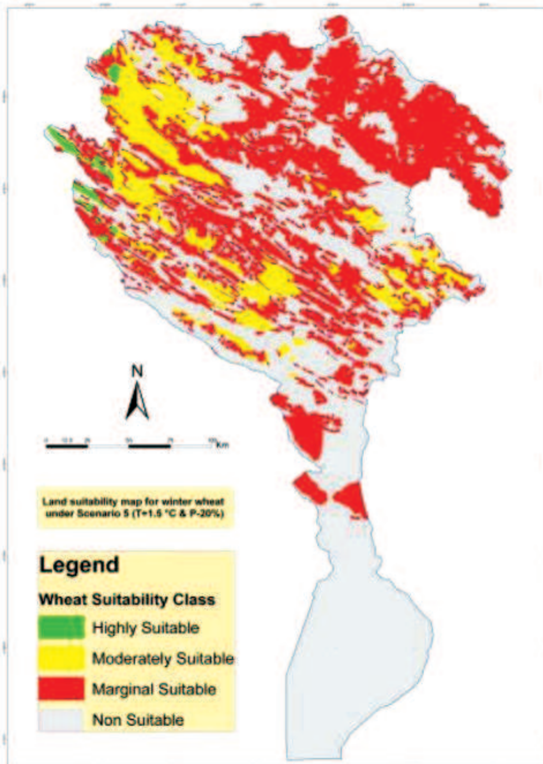
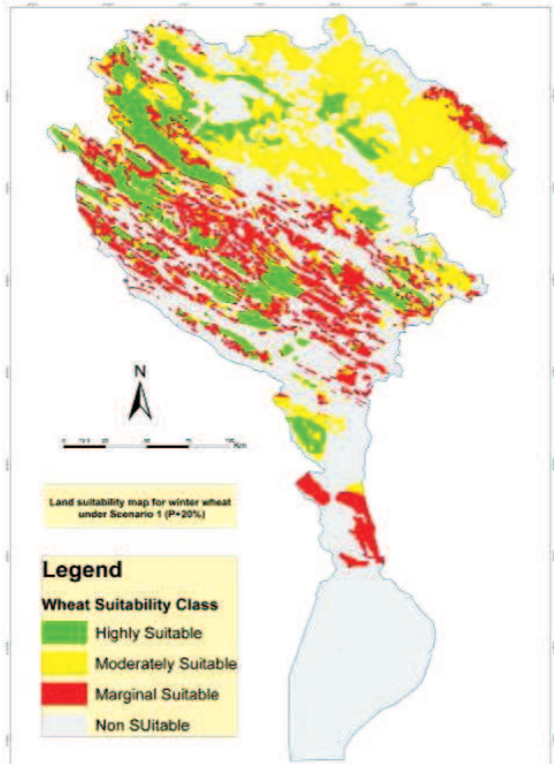
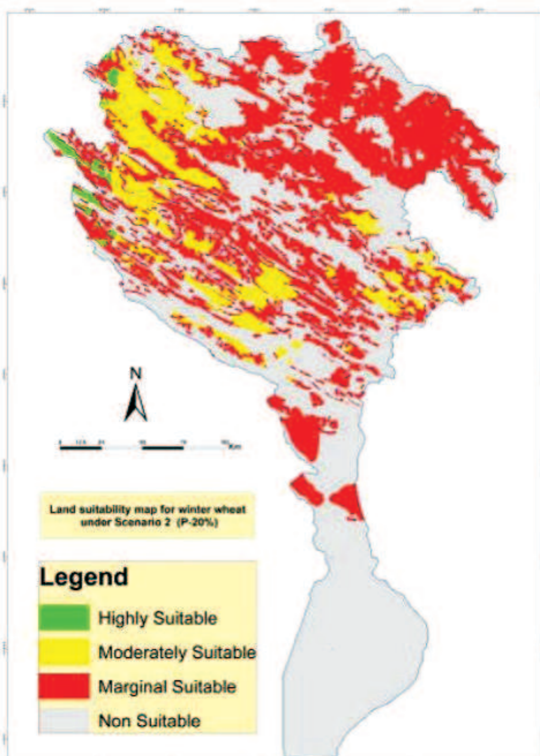
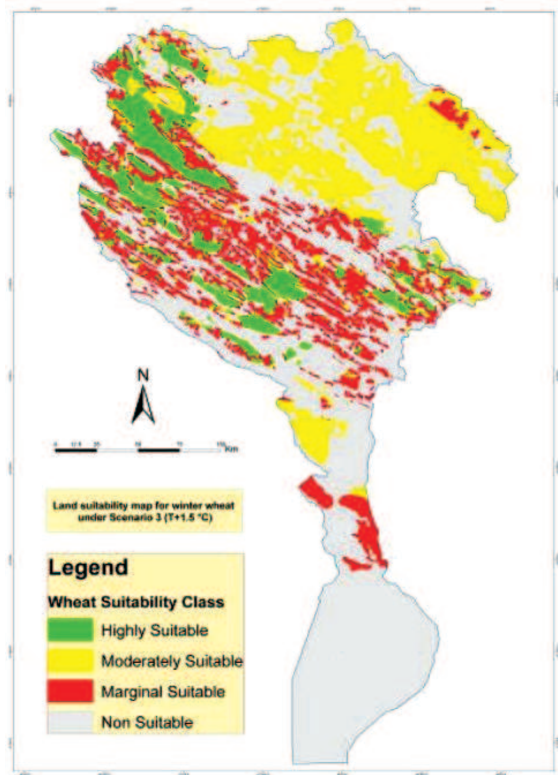


Fig. 4. Effect of climate change scenarios on land suitability for winter wheat in the study area: (a) absolute surface area (b) percentage increase (+) or decrease (-) of surface area compared to current condition.


N
Km
Land suitability map for winter wheat under Scenario 5 (T+1.5 °C & P-20%)
Legend
Wheat Suitability Class
Highly Suitable
Moderately Suitable
Marginal Suitable
Non Suitable


N
Km
Land suitability map for winter wheat under Scenario 1 (P+20%)
Legend
Wheat Suitability Class
Highly Suitable
Moderately Suitable
Marginal Suitable
Non SUitable


N
Km
Land suitability map for winter wheat under Scenario 2 (P-20%)
Legend
Highly Suitable
Moderately Suitable
Marginal Suitable
Non Suitable


N
Km
Land suitability map for winter wheat under Scenario 3 (T+1.5 °C)
Legend
Wheat Suitability Class
Highly Suitable
Moderately Suitable
Marginal Suitable
Non Suitable

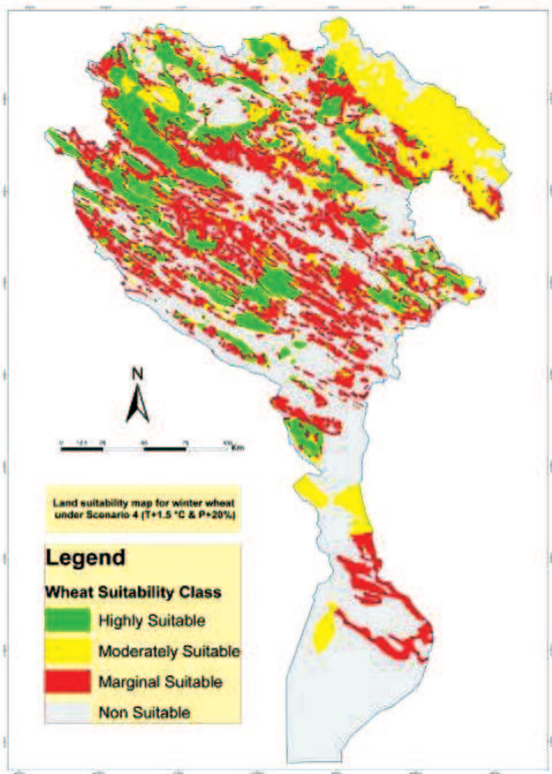


Fig. 5. Winter wheat land suitability under 5 different climate change scenarios in the study area.

Discussion and Conclusions

Land suitability for winter wheat is determined by climate, soil and topographic variables. Combining physical land evaluation models in a GIS improves land evaluation models and enables an analysis more relevant to policy-making than the original non-spatial basic data.

In general, the climate in the study area is favorable for arable crops such as winter cereals, oilseed rape and food legumes. There is adequate opportunity for autumn cultivations and some, if limited, opportunity for spring cultivation. Although the summer water deficit is large, and valuable crops may be irrigated where necessary, drought does not significantly reduce overall cereal yields.

Climate change scenarios have been used to estimate the distribution of suitability for rainfed winter wheat using the baseline climate as the mean for the period 1973 -1998. The general trends show that land classified currently as highly, moderately or marginally suitable is likely to increase in area as a result of an increase in temperature, with or without precipitation increase. However, these lands will decline in area with decreased precipitation, as a result of increasing water stress.

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Assessment of Different Scenarios of Supplemental Irrigation at Upstream Sub-Basins of Karkheh Basin on Flows of Karkheh Dam

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Introduction

The Karkheh River, with about 43000 km2 of area and 900 km length, supplies water to the region. Any upstream water project may affect downstream areas. It is necessary to evaluate the present basin scale water balance and different management recommendations of the Challenge Program projects on the basin scale water balance and to explore the effect of different water management scenarios (supplemental irrigation) on the quantity of water along the Karkheh River (KR). Runoff mapping of the present situation of Karkheh basin through GIS will be prepared by the surface water balance method that creates mean annual runoff. The future situation will be simulated by assuming various scenarios of supplemental irrigation in the upstream sub-basins of Karkheh and by determining the water demand and developing new runoff maps. The potential of supplemental irrigation in the upstream Honam and Merek sub-basins will be obtained from other ongoing supplemental irrigation projects. By applying the D8 model to the new runoff maps, actual flows will be calculated along the river. By comparing the flow of Karkheh in two situations, impacts of scenarios on stream flow will be evaluated along each sub-basin and subsequently for the whole the basin.

Methodology

Runoff mapping of present situation

The first step in evaluation is modeling the present situation of water distribution (preparing grid map of runoff) on Karkheh basin. This process is called runoff mapping of Karkheh basin. The discharge of gauged watersheds will be distributed in grid cell on the surface of the basin and calibrated with observed data. By using the eight direction pour point model (D8), the amount of distributed runoff will be accumulated along the river. The surface water balance and soil water balance methods are two GIS-based methods for making runoff mapping.

Two independent water balance models exist to model different components of the hydrologic cycle: a soil-water balance, and a surface water balance. These models are constructed using a geographic information system (GIS). The GIS provides a framework for storing and manipulating spatial data and facilitates modeling on control volumes of various sizes and shapes. The surface water balance model is steady-state and uses an empirical relationship to estimate mean annual runoff and evaporation in ungauged areas.

- A precipitation grid map that was already prepared
- A digital elevation model (DEM) that was already prepared
- Gauged stream-flow data, and other data sets will be used to generate spatially distributed maps of mean annual runoff and evaporation.

In the process of creating these maps, gauged watersheds delineated then drainage analysis on a terrain model is performed to watersheds delineation automatically.

Selecting gauging stations for analysis

All monthly flow records for the water years 1975–2004 were extracted from the Tamab Database. The key attributes available for each station record are latitude, longitude, starting year, ending year, 30-year mean monthly flows, and 30-year mean annual flows.

From the list of 106 stations, the stations operating during the entire 1975–2004 period were selected, and it yielded a set of 53 stations. Although these gauges have incomplete records for the period, 1975–2004, the average of the 30-year mean flows were approximated by using a linear regression and an adjustment based on a nearby gauge with a complete record for this period. The following equation was used for making flow adjustments:

$$Q_{\delta,30} = Q_{a,30} \times \frac{Q_{\delta,30}}{Q_{a,30}} \quad (1)$$

In Equation (1), station b is a station with incomplete records covering x years (x < 30) of the period from 1975–2004 and station a is a nearby station with complete records for this period.

Dem processing and watershed delineation

ArcHydro and ArcSwat extention in ArcGis9 were used to derive several datasets that collectively described the drainage patterns of the Karkheh catchment. Raster analysis is performed to generate data on flow direction, flow accumulation, stream definition, stream segmentation, and watershed delineation. These data are then used to develop a vector representation of catchments and drainage lines from selected points. The utility of the ArcSwat tools is demonstrated by applying them to develop attributes that can be useful in hydrologic modeling.

Terrain pre-processing uses DEM to identify the surface drainage pattern. Once pre-processed, the DEM and its derivatives can be used for efficient watershed delineation and stream network generation. This function creates a grid in which each cell carries a value (grid code) indicating to which catchment the cell belongs. The value corresponds to the value carried by the stream segment that drains that area, defined in the stream segment link grid. Catchment polygon processing function converts a catchment grid into a catchment polygon feature. Figure 1 shows all the 53 delineated and corrected watersheds.

Determining mean precipitation and net inflow

Given a grid of precipitation values and a grid of watersheds, a table of the mean precipitation in each watershed, provided the two grids are defined with the same cell size. The grid of mean annual values is shown in Figure 2.

Based on computed 30 years mean flows for each station, the net measured inflow (outflow minus the sum of inflows) for each of the 53 watersheds was computed. To make a comparison of the runoff characteristics among different size watersheds, the net measured inflow [cm] was normalized by the watershed area and expressed in [mm $year^{-1}$].

Expected runoff

A plot of the average runoff per unit area (mm) versus average rainfall (mm) for all delineated watersheds is shown in Figure 3.

Fig. 1. Delineated watersheds.

A trend of increasing runoff with rainfall is clear, but there are a number of outliers from the general trend. These are the points that merit further investigation. Most of the outlying points are from watersheds with significant anthropogenic influence in the form of urbanization, reservoirs, agriculture, or diversions for municipal use. A few of these outliers result from unusual hydrogeology. This results in runoff lower than expected in the watershed where recharge is occurring and higher than expected runoff in the spring-fed stream of an adjacent watershed. Heavy recharge and re-emergence of this same water as spring flow within a watershed may also limit evaporative losses and result in higher than expected runoff values. These observations regarding outlying points led to the hypothesis that a set of criteria could be used to define the runoff expected under conditions of minimal human influence and in the absence of large groundwater transmissions

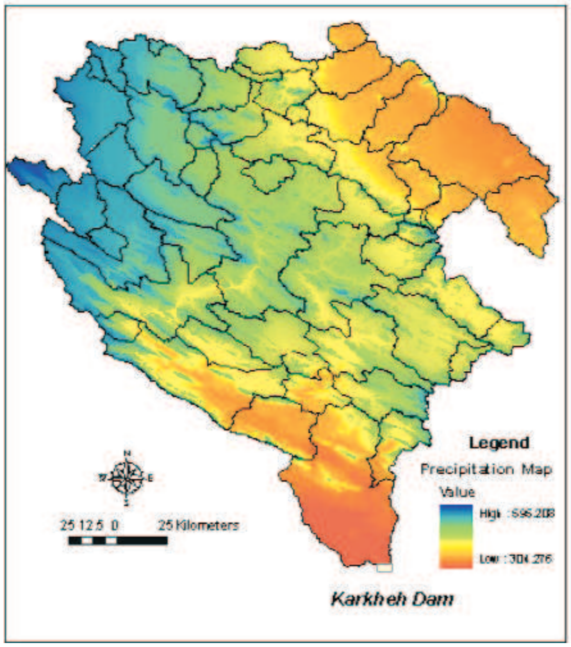

Fig. 2. Grid of mean annual precipitation.

Many sets of criteria, used and selected as a reasonable set that produces a subset of watersheds with a more definitive relationship between rainfall and runoff in Maidment (1997) paper :

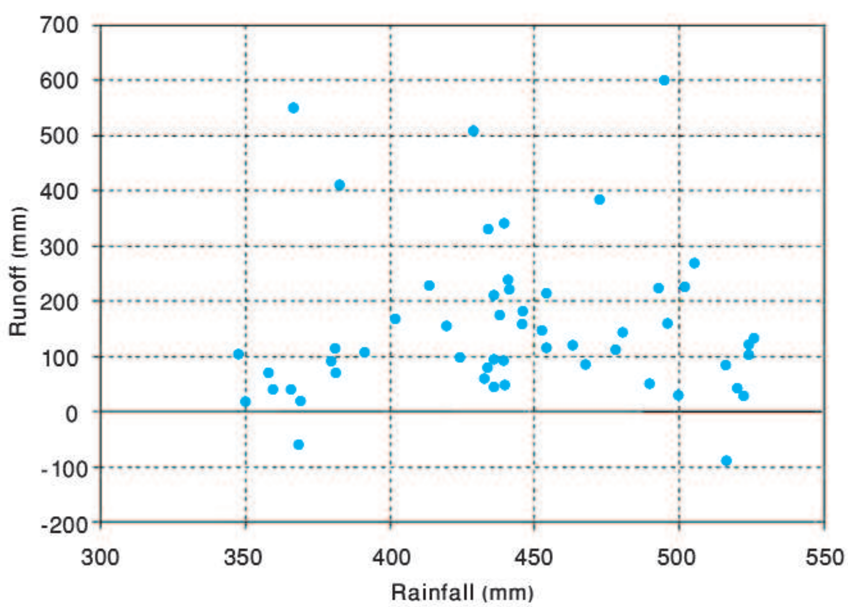

Fig. 3. Runoff vs. Rainfall for all watersheds.

- net measured inflow is greater than zero
- the fraction of the drainage area that is urbanized is less than 0.1
- the annual recharge is less than 51 mm $year^{-1}$
- the reservoir evaporation [mm/watershed area] from reservoirs impounded before 1990 divided by the rainfall [mm] is less than 0.1

In this research, lack of data caused last two above mentioned criteria could not be applied. Some basins behave abnormally. For example, the rainfall value is less than runoff value that these points omitted. After these criteria are satisfied, some distinctive outliers from the general trend remain. Some of these points represent data for a spring-fed river and may be due to channelization of this river, but this is only a speculation. This point was not considered when deriving the expected runoff function.

A function that minimizes the sum of squared errors was fit to the remaining data points. Figure 4 shows this selected set of 30 watersheds and Figure 5 is a plot of the data points for these watersheds with the fitted function. In theory, with increasing rainfall, one might expect the slope of the rainfall-runoff curve to keep increasing until a value of 1 is reached, indicating that the maximum amount of evaporation possible has been reached. At this point, the only difference between the precipitation and observed runoff would be the potential evaporation. The amount of annual rainfall needed to reach this theoretical slope of 1 is certainly beyond the range of rainfall values in this data set. By the choice of selection criteria, the notion is that the expected runoff function can be used to estimate natural runoff in all areas, except major groundwater recharge and discharge zones.

Criticisms of the expected runoff curve are easy to come by. The concept of expected runoff is artificial and the precise form of the curve is subjective. The criteria used in developing this curve were specifically chosen to eliminate data points that do not fit the trend, an approach that certainly will not please statisticians. In their defense, the criteria used to derive the expected runoff curve are based upon real, physical data that define the concept itself. In addition, the information from the outlying points was not discarded; this information was used to create a map of actual runoff. The fact that data from watersheds ranging in size from 40 to 40,000 km2 follow the same trend, implies that the behavior represented by the expected runoff curve is scale-independent, which is an interesting result. Using the inference of scale-independence, the expected runoff function was applied to the precipitation grid to create a spatially distributed map of expected runoff. This runoff function is not suitable for application in urban areas, because the data from watersheds with considerable urbanization were not used in its development.

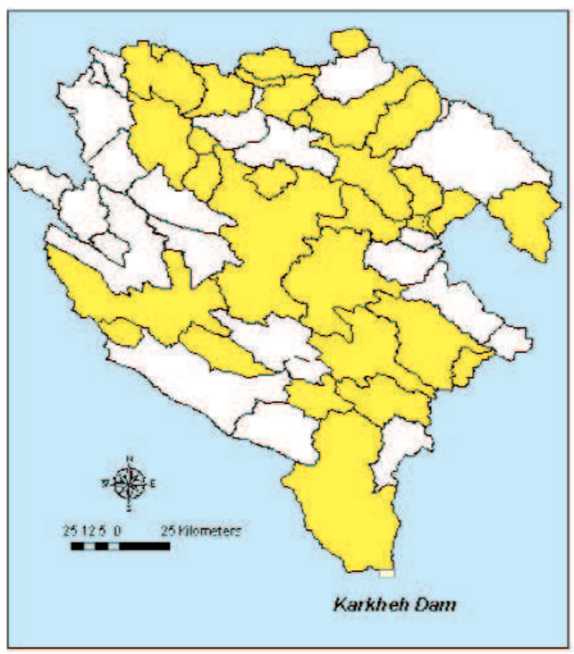

Fig. 4. 30 selected watersheds.

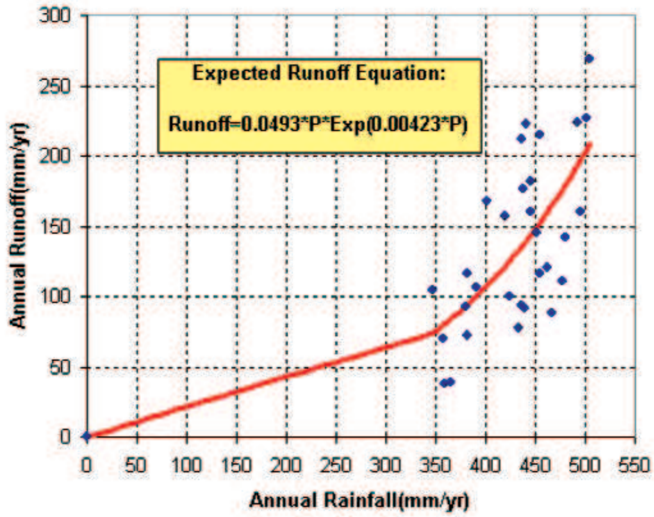

Fig. 5. Runoff vs. Rainfall for selected watersheds.

Mapping actual runoff and evaporation

A grid of actual runoff was created by combining net runoff information at the watershed scale. To create the actual runoff grid, an adjustment grid was created in which all cells in a given watershed were assigned the value of measured runoff per unit area less the watershed mean expected runoff, and this adjustment grid was added to the expected runoff grid. The expected runoff grid, the adjustment grid, and the actual runoff grid are shown in Figures 6, 7, and 8, respectively. The expected runoff map reflects the precipitation variation across the state. The expected runoff values range from less than 50 mm yr^{1} in south KRB to about 360 mm yr^{1} in the wettest part of northwest KRB.

The adjustment map shown in Figure 7 highlights areas with unusually large (dark blue) or small measured runoff (dark red). Logical explanations exist for many of these "extreme" adjustment areas. For example, the dark red areas are likely caused by large agricultural diversions in these areas. The dark red areas are likely due to large amounts of recharge. The large dark blue spots are caused by the emergence of springs. One drawback in using this type of runoff map is that the effect of springs is averaged over the entire watershed in which it emerges so it appears that a large area is generating excess runoff when the excess runoff is primarily due to a point discharge from groundwater. The accumulated runoff maps that will be described later may provide a more realistic representation for this type of flow phenomenon. Several dark blue or dark red areas are likely caused by inter-watershed transfer of water for municipal and industrial use. Another possible explanation for the dark blue areas, but not for the dark red areas, is that extensive urbanization has increased the runoff coefficient.

A map of losses was created by subtracting the actual runoff map from the precipitation map. Creation of this map assumes that the annual change in water storage is zero. This map of losses, shown in Figure 9, is equivalent to a map of actual evaporation in locations where inter-watershed transfers are negligible.

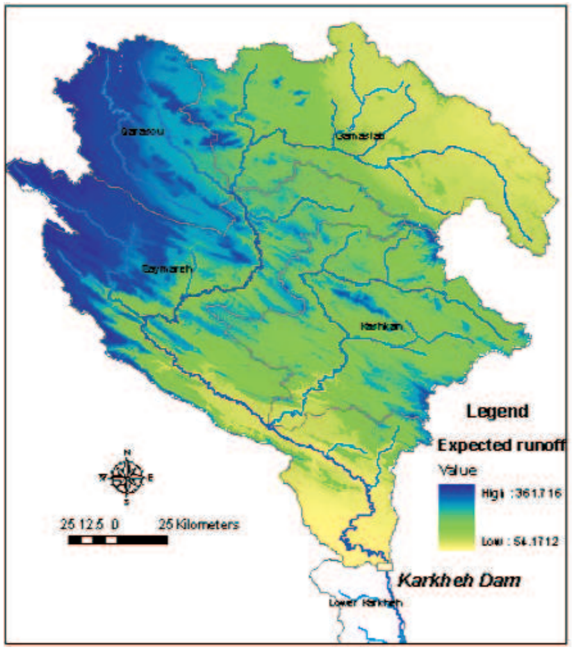

Fig. 6. "Expected" mean annual runoff.

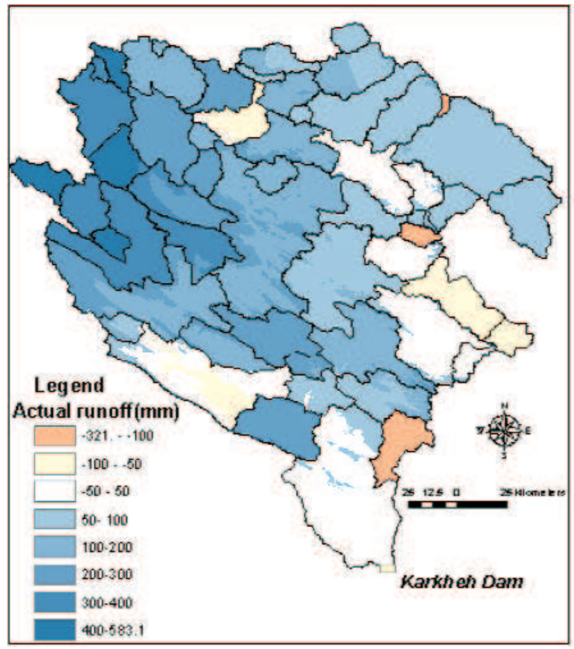

Fig. 8. Actual mean annual runoff.

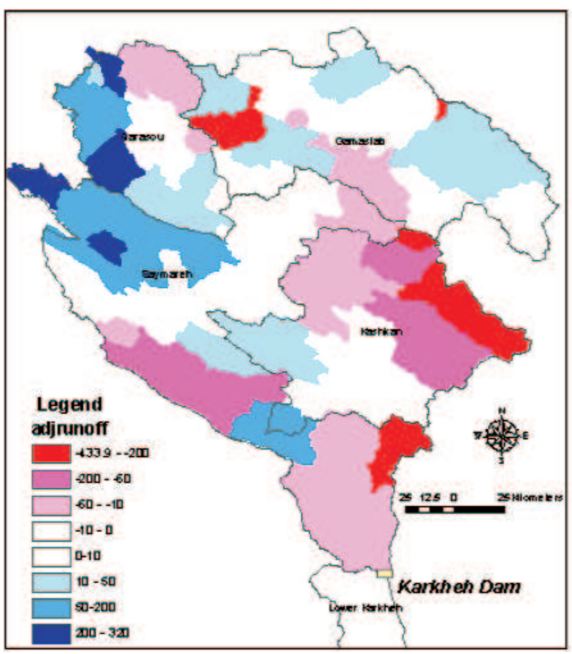

Fig. 7. Observed runoff - mean "Expected" runoff.

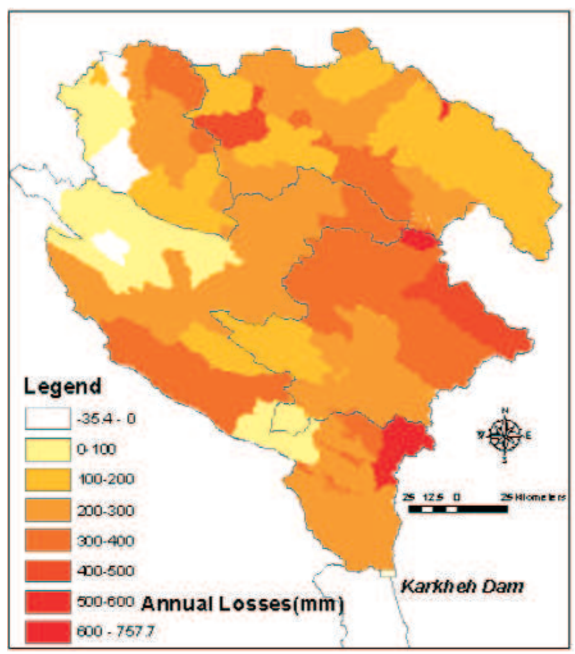

Fig. 9. Annual losses: Rainfall - Runoff.

Accumulation of flow
The eight direction pour point model (D8) is a basic model that underlies watershed and drainage network delineation with grid processing. The assumption is that the water in a given cell will flow towards only one of its neighboring cells, whichever cell lies in the direction of steepest descent. A flow direction function applied to an elevation grid yields a grid of flow directions. From this grid of flow directions, a drainage network is derived. The flow accumulation is the number of cells upstream of any given cell in the drainage network.

Before defining the drainage network using the eight direction pour point model, several processing steps will be taken in order to create a "hydrologic" DEM from the raw DEM.

By applying a flow accumulation function to the runoff maps, the expected and actual flows will be calculated at each DEM cell along river.

Study of various scenarios for supplemental irrigation management at upstream of Karkheh
According to on-farm water balance relationship of upstream selected stations and according to iso potential map of supplemental irrigation on KRB, various sub-basin scenarios of supplemental irrigation management in the upstream of KRB will be considered and proportional water demand will be determined in grid based maps.
The shortage of runoff will be determined in areas (cells) of basin that have potential of developing supplemental irrigation based on the ISO potential map and result of two water productivity stations located upstream of Karkheh. The water balance parameters of two stations have been calculated already and the relationship between increasing of ET and actual ET and decreasing of runoff and related curves is ready. The amount of runoff decreasing will be calculated through GIS in cells that mentioned above.
The grid of future situation runoff map will be created by subtracting the long term runoff grid from the water demand and loss grid. As supplemental irrigation has no recharge to river, by determining the water demand new runoff maps will be created. This grid can be interpreted as a grid of future situation that will occur after applying the various sub-basin scenarios of supplemental irrigation management at upstream of Karkheh.

Assessment
- By applying a flow accumulation function (D8 model) to the new runoff maps, actual flows will be calculated at each DEM cell along the river. Two flow profiles will be compared along the river. By comparing the flow profiles of Karkheh in two situations, the assessment of environmental impacts of scenarios on stream flow will be evaluated along the river.
- By now, collecting gauged flow data for 106 gauges and automatic watershed delineation has been completed.

Detection of land use change in KRB using multi-temporal satellite imagery

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In an environment characterized by arid and semi-arid conditions, dissected topography, susceptibility of geological formations to soil erosion, scarce water resources, and conflicts between nomadic and settled land-users, population growth has had a significant impact on the natural resource base and land use change in the KRB.

In addition, from a policy perspective, two events have further shaped the nature of land use change in the basin:

- The establishment of the Natural Resource Protection Law in 1962, which considers all lands as public lands and under control of state government (except old arable lands)
- The victory of the Islamic Revolution in 1979 and ensuing emphasis on agricultural self-sufficiency and development

Existing reports, data records, field surveys and interviews with local communities and experts indicated an extensive change in the land cover of the KRB. In order to quantify the changes as reported from these qualitative, localized or informal sources, remote sensing and GIS overlay capabilities have been used. Using supervised classification methods, validated through field checks, and a common land use/land cover (LULC) legend, the changes in LULC were assessed by comparison of Landsat MSS imagery of 1975 with Landsat ETM+ image of 2002. The image interpretation indicates that in 2002, 32.4% of the KRB was covered by rangelands, 23.8% by irrigated crops, 18.6% by rainfed crops, 18.5% by forests. In comparison with 1975, this constitutes a 50% increase in irrigated farming areas and a 100% increase in dry farming lands. These increases in cropland have mostly come at the expense of the rangelands and forests. The imagery indicates a 25% decrease in forest cover, but there is also field evidence of forest degradation in terms of its ability to regenerate, with more sprouting and less seed regeneration.

Future work on land use change, using remote sensing, will focus on quantifying the relationships with the reported increases in sediment rates in rivers and dam reservoirs, and with population growth rates.

CGIAR Challenge Program on
WATER & FOOD

Benchmark river basins

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

Improving On-farm Agricultural Water Productivity in the Karkheh River Basin Project (CPWF PN 8)
Strengthening Livelihood Resilience in Upper Catchments of Dry Areas by Integrated NRM (CPWF PN 24)

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