Water Productivity of Irrigated Wheat and Maize in the Karkheh River Basin of Iran

A. S. Qureshi[1], T.Oweis[2], P. Karimi[3], J. Porehemmat[4]

Abstract

Karkheh River Basin (KRB) is the third largest and most productive river basin of Iran. The major agricultural issue of KRB is low water use efficiencies. Farmers' irrigation practices are aimed at maximizing crop production through excessive use of irrigation water resulting in huge water losses. As the opportunities for water resources development in KRB are very limited, improving the productivity of existing water resources is the most attractive option to produce more food for the increasing population. This paper analyzes water productivity of irrigated wheat and maize in the KRB. The results reveal that farmers having access to groundwater tend to apply higher irrigation amounts. Relatively higher crop yields in irrigated areas are also linked to higher nitrogen use, which can create serious problems of groundwater contamination in future. Due to excessive use of groundwater and fertilizer, production costs have increased resulting in low gross margins (farm incomes). The study suggests that increase in charges for surface water use removal of subsidies on electricity will discourage excessive use of water for agriculture. Furthermore, farmers should be trained to optimize irrigation water and fertilizer application in order to save scarce water resources and reduce production costs and increase farm returns. These steps are of great importance for ensuring sustainability of irrigated agriculture and to alleviate poverty in rural areas of KRB.

Keywords: Karkheh River Basin, Iran, water productivity, gross margins, groundwater irrigated wheat, irrigated maize.

INTRODUCTION

Amongst global resources, water is emerging as the most critical and misused natural resource. It is an important input to agricultural production and an essential requirement for domestic, industrial and municipal activities. Increasing population and standards of living are contributing to steep rise in demand for fresh water. The consequent wastage, over-exploitation, pollution and depletion of fresh water pose a serious threat to the food security of increasing population. Recent studies indicate that one third of the population of developing countries lives in absolute water scarcity, in the sense that they do not have

[1] Head, IWMI-Iran Office. c/o Iranian Agricultural Engineering Institute (IAERI), P.O. Box. 31585-845, Karaj, Iran. E-mail: a.sawar@cgiar.org

[2] Director, Natural Resources Management, International Center for Agricultural research in Dry Areas (ICARDA), Aleppo, Syria.

[3] Research Officer, IWMI-Iran Office. c/o Iranian Agricultural Engineering Institute (IAERI), P.O. Box. 31585-845, Karaj, Iran. E-mail: p.karimi@cgiar.com

[4] Director General, Soil Conservation and Watershed Management Research Institute (SCWMRI), Tehran, Iran. E-mail: jahanpor@yahoo.com

sufficient water resources to meet their agricultural, domestic, industrial and environmental requirements in the year 2025 (Seckler et al., 1998a) Seckler et al., 1998b). In semi- (arid) areas where opportunities for the development of new water resources are limited and costs rise, increasing the productivity of existing water resources seems realistic target. Improving agricultural water productivity is central for both economic and social development. Therefore there is every motivation to designate more efforts to increase the productivity of water in agriculture to meet the future food demand of increasing population (Sarwar and Bastiaanssen, 2003).

Irrigated agriculture has played an important role since 1960s in feeding the growing world population and is expected to continue in future as well (Cai and Rosegrant, 2003). However, water availability for irrigation in developing countries (now over 90% of water resources are used for irrigation) has to be reduced due to increasing demand of water from non-agricultural sectors. The situation in KRB is not much different from other parts of the world where about 93% of the total withdrawals are diverted to meet agricultural requirements. In the absence of sufficient surface water resources, groundwater use in the basin has increased many folds over the last two decades. The future of irrigated agriculture, which produces more than 60% of the total grain production, is threatened by low crop yields, low water use efficiencies and increasing salinity and water-logging problems. Average water productivities of annual crops such as wheat and barley are 0.5 kg/m^3, which are far lower than 0.9 kg/m^3 for neighboring Syria (Oweis et al., 1999).

KRB has traditionally been the central point of agricultural activities in Iran. Adequate water resources and favorable climatic conditions make it suitable to grow wide range of crops. Increasing population pressure over the last three decades has resulted in over-exploitation and degradation of natural resources, making it most vulnerable and poor areas of the country. KRB has now become a water short area and increasing incidences of drought has further compounded the problem. As a result, livelihoods of rural communities are at stake. Considering the present pace of deterioration, it is envisaged that situation will be further degraded in the near future.

In KRB the possibility of increasing water resources is very limited. Therefore additional crop production will have to be accomplished by increasing the productivity of available water resources (Keshaverz et al., 2003). For this purpose, a better perception of the water related interactions that occur across spatial and temporal scales, and within different locations in the same basin is imperative. These analyses are inevitable for better understanding of existing limitations to land and water productivity in different sub-basins of the KRB. This paper analyzes the current status of land and water productivities of irrigated wheat and maize in 5 sub-basins of the KRB. Factors affecting land and water productivity are evaluated and ways of improvements are suggested.

Study area

Karkheh River Basin (KRB) is situated in the west of Iran and covers a surface area of about 51,000 km^2 (Figure 1), out of which 55% is comprised of mountains and 45% of plains (Shahram et al., 2004). The climate of KRB is mainly semi-arid with large variations in the average annual precipitation between southern and northern regions. In the southern region, average annual precipitation is about 150 mm whereas in the northern region it can go up to 750 mm. Due to extremely high temperatures, about 65% of the rainfall is directly evaporated without any beneficial use. Evaporative demand of KRB is very high. Class A pan evaporation in the basin ranges from 2000-3600 mm per year, out of which 50% occurred just in three summer months.

The water resources of KRB comprise of both surface water and groundwater. The volume of water generated by the average annual rainfall in the basin is 24.9 x 10^9 m^3, out of which 5.1 x 10^9 m^3 is flood and surface water, 3.4 x 10^9 m^3 infiltrates to ground water and the rest 16.4 x 10^9 m^3 is lost directly to atmosphere. The quality of river (surface) water is generally good, though it varies both seasonally and along the path downstream, reaching up to 3 dS/m near the final outlet. The Karkheh basin comprises of 5 major sub-basins i.e. Gamasiab, Gharasu, Saymareh, Kashkan and South Karkheh as shown in Figure 1. Basic characteristics of these 5 sub-basins are given in Table 1.

Table 1. Basic characteristics of sub-basins of the KRB.

Sub-basins	Total area (Km^2)	Irrigated area (ha)	Avg. annual rainfall (mm)	GWT depth (m)
Ghamasiab	11459	136,000	465	>15
Qarasu	5350	27,605	435	>10
Kashkan	16411	48,963	390	>10
Seymareh	8955	54,331	350	>10
South-Karkheh	8589	111,164	260	1-3

(Insert Figure 1)

Groundwater exploitation in the KRB was started as early as 1915 when first well was dug in the basin (Marjanizadeh et al., 2007). However, during the last three decades, groundwater exploitation has taken a quantum jump and currently groundwater accounts for nearly half of urban and agricultural water supply in the KRB. Total exploitation of groundwater in the KRB is about 3856 million m^3 per year. This groundwater is exploited through 17,000 wells and 2677 springs (Jamab, 2006). About 87% of groundwater is used for agriculture, 12% for drinking purposes and about 1% is consumed by industry. In the upper parts of the KRB, groundwater quality is generally good for irrigation (EC ranges between 0.7-1.5 dS/m). However, in the lower parts of the KRB (south-Karkheh), groundwater quality is bad (EC ranges between 1-5 dS/m). This quality of groundwater together with shallow water table depths poses a serious threat of water logging and secondary salinization in the irrigated areas of the lower parts of the basin. The risk of groundwater pollution through excessive leaching of nitrogen is very high in the lower KRB.

The total area of KRB is 5.1 million ha (Mha), out of which about 2.3 Mha are plain and mountainside and 2.8 Mha is mountain. According to 1994 estimates, about 894,000 ha are used for rain-fed crops and 1.06 Mha is suitable for irrigated crops. However, due to shortage of water, only 378,164 ha are currently irrigated every year. In irrigated areas, wheat, maize, rice, fodders, fruits and vegetables are common crops.

Despite the shortage of water, the overuse of water in irrigation is very common. The present irrigation practices of farmers aim at providing maximum water for maximum crop production. The amount of water applied to each crop for irrigation has little relevance to the actual crop water requirements. The depth of irrigation water mostly depends on the amount of water a farmer can capture. Therefore there is a general tendency of over-irrigation. At present, a big gap exists between water delivery from the main canals and water application in the field. Compared to the large investments for water resources development, little has been done to improve irrigation water use at farm level. Water is delivered to old traditional irrigation canals and on-farm conveyance and the use of irrigation water is generally rudimentary and wasteful. The use of earth bunds, unlined canals and poor leveling combined with low water charges have resulted in very low levels of water conveyance and use efficiencies (30% as a national average) and caused the emergence of serious drainage problems. Another reason of low irrigation efficiencies is the use of traditional irrigation methods. Surface irrigation techniques are used on 98.75 % of the area equipped for irrigation and 1.25 % benefits from a pressurized irrigation system.

Two major agricultural production systems are present in the KRB. The rain-fed system prevails mainly in the upper catchments and the fully irrigated areas are located mainly in the southern parts of the basin. The average annual rainfall in southern parts of KRB can be as low as 150 mm. The soils are alluvial in nature formed originally by the floods of the river. These alluvial areas are relatively flat with low soil permeability. Due to poor natural drainage, these areas are suffering from widespread soil salinity and water logging.

Over the past three decades, increasing access to water (mainly groundwater) has turned large rain-fed areas into irrigated areas. Farm mechanization and increased use of subsidized fertilizer has resulted in remarkable recovery in crop yields. Wheat yields in the upper KRB increased from 1500 kg/ha in 1970 to over 5000 kg/ha in 2004. Similarly wheat yields in lower KRB jumped from merely 1000 kg/ha to over 4000 kg/ha during the same period. However, these yields are still lower than the other regions of Iran. Irrigation efficiencies are as low as 35% (Keshaverz, et al., 2003). The amount of water applied to irrigate field crops is almost double than what is actually required. As a result, productivity of water is very low i.e. 0.5 kg/m^3 for most of field crops.

Data Collection and Methodology

The analysis presented in this paper is based on the 5 year (2001-05) data collected from different organizations working for the land and water development of KRB. Irrigation and yield data was collected through a comprehensive survey of KRB during 2006. During this survey, 230 farmers from all over the basin were interviewed to gather information on yields, irrigation amounts applied, fertilizer use, causes of low yields and groundwater use in the basin. In order to confirm the validity of secondary data and farmer claims, *in situ* measurements of crop yields and irrigation application rates were also done on selected farms in different parts of the basin. The analysis has been done for wheat and maize as their coverage exceeds 60% of irrigated lands in KRB.

These data were analyzed to calculate physical and economic water productivity of irrigated wheat and maize. Water productivity (WP) expresses the benefits or value derived from the use of water. Different indicators are used to describe physical water productivity. Most common are physical mass of production per unit of gross inflow, water depleted through evapotranspiration, or water available (Molden, 1997; Molden and Sakthivadival, 1999). For classical analysis, water productivity is defined as yield per unit of water depleted. These water productivity values are usually higher than the values obtained by yield per unit of applied water. Since crop evapotranspiration depends on physiological processes, it does not show large variations in water productivity values. Therefore, real challenge in water scarce environments is to improve water productivity per unit of applied water because this is directly linked to on-farm water management improvements.

For this paper, physical water productivity (WP_{AW}) is expressed in terms of crop yield per unit of applied water (effective rainfall + irrigation) (kg/m^3). Economic productivity uses valuation techniques to derive the value of water, income derived from water use or benefits derived from water (Barker et al., 2003). Therefore, economic productivity is defined as gross value of production (WP_{GVP}) and gross margins (WP_{GM}) per unit of applied water ($\$/m^3$). Gross margins are expressed in terms of GVP minus total cost of production.

Results and Discussion

Crop yields

The average wheat yields for irrigated areas of 5 sub-basins of the KRB are given in Table 2. The average basin-wise irrigated wheat yield is 3547 kg/ha with a standard deviation of 346, which is comparable to the country wide average of 3577 kg/ha (MoJA, 2005). The highest wheat yields in Gamasiab and Qarasu sub-basins are related to higher fertilizer use and availability of groundwater for irrigation. The analysis of 5-year data shows that average annual groundwater use for agriculture in Gamasiab and Qarasu sub-basins was 191 million m^3 and 161 million m^3, respectively. The groundwater use in south-Karkheh was only 52 million m^3 whereas Kashkan and Seymareh sub-basins were at the bottom with average annual use of only 30 million m^3 and 22 million m^3, respectively. The considerably lower yields in Kashkan sub-basin are related to poor soil fertility due to shallow soil depths and low fertilizer use. Relatively higher wheat yields in south-Karkheh are the result of increased access to surface water due to newly constructed Karkheh dam and irrigation network developed in the area.

Table 2: Wheat yields in irrigated areas of the 5 sub-basins of the KRB.

Sub-basins	***Wheat yields (kg/ha)***						
	2001	***2002***	***2003***	***2004***	***2005***	***average***	***SD***
Ghamasiab	3552	3757	3982	4395	4124	3962	326
Qarasu	3602	4301	4327	4926	4807	4393	523
Kashkan	2250	3097	2465	2708	2289	2562	349

Seymareh	2802	3433	3120	3728	3606	3338	377
South-Karkheh	3557	3523	3203	3582	3539	3481	157
Basin average	3153	3622	3419	3868	3673	3547	346

During the past few years, especially with the revolution in groundwater irrigation, maize production has taken lead over other crops in the KRB. Maize area has reached to 10% of the total irrigated area with yields soaring up to 9000 kg/ha. The average maize yield at the basin level is 6675 kg/ha (SD = 938), ranging from 6000 kg/ha for Kashkan sub-basin to almost 7500 kg/ha for Gamasiab sub-basin (Table 3). Like wheat, maize yields were also found higher in Gamasiab and Qarasu sub-basins. The yields in Kashkan and south-Karkheh sub-basins are also superior (6000 kg/ha) but falling short of Gamasiab and Qarasu sub-basins by 1500 kg/ha. Lower yields in south-Karkheh are related to prevailing soil salinity whereas in Kashkan, poor soil fertility is the main cause of low maize yields.

Table 3: Maize yields in irrigated areas of the 5 sub-basins of the KRB.

Sub-basins	***Maize yields (kg/ha)***						
	2001	***2002***	***2003***	***2004***	***2005***	***average***	***SD***
Ghamasiab	8221	7607	7313	7559	6672	7474	560
Qarasu	6490	6366	7757	8007	7907	7305	807
Kashkan	3934	5246	8212	7672	4876	5988	1857
Seymareh	6229	6584	6186	7332	6032	6473	521
South-Karkheh	4445	6517	6484	6657	6574	6136	947
Basin average	5864	6464	7190	7445	6412	6675	938

Applied water for irrigation

In KRB irrigation schedules vary a lot. The survey results and field measurements indicate that farmers having access to groundwater tend to apply more water for irrigation than those who are fully dependent on surface water. Farmers usually do not plan their irrigations in advance. Their decision mainly depends upon the visual plant stress and accessibility to surface water and groundwater resources. There are large differences in the amounts of water applied for irrigation to wheat and maize in different sub-basins of KRB (Table 4).

Table 4: Irrigation amounts applied to wheat and maize (m^3/ha) in 5 sub-basins of KRB.

Sub-basins	Wheat			Maize		
	Max	Min	Avg.	Max	Min	Avg.
Gamasiab	7776	1980	4628	13230	6800	9752
Qarasu	5400	2550	3485	21600	5400	10684
Seymareh	5950	1620	3172	8500	4320	6239
Kashkan	8820	1512	3606	16520	4630	5950
South-Karkheh	5184	1512	2680	17010	5184	8796
Basin	8820	1512	3514	21600	4320	8284

The average amount of water applied to wheat and maize is 3514 and 8284 m^3/ha, respectively. The large gap between maximum and minimum values shows that farmers do not plan their irrigations according to crop water requirements. These findings are in agreement with the observations of Keshaverz et al. (2003). They have reported irrigation water applications of over 6000 m^3/ha for wheat and 10,000-13,000 m^3/ha for maize. These water application rates are also higher than the net irrigation requirements recommended by the Ministry of Agriculture. They have recommended 2600 m^3/ha for wheat and 5900 m^3/ha for maize, respectively (National Database, 1998). This is a clear demonstration of the fact that farmers tend to maximize their crop yields through excessive irrigation. However, in most cases, irrigation water is applied at less water sensitive stages of the growth cycle causing significant losses through evaporation thereby reducing the efficiency of water use.

The survey data was also used to develop relationship between irrigation water applied and yields for wheat and maize and the results are presented in Figure 2. The correlation between crop yields and irrigation water applied is not straightforward as it is often assumed by the farmers that crop yield increases with increase in irrigation water applied. The *r-squared* values for the relation between yield and irrigation water applied are low for both crops. The difference is more pronounced for maize than wheat. This shows that there is a strong need for farmers to shift their thinking from maximizing crop production through excessive water use to optimize crop production with minimum irrigation supplies.

(Insert Figure 2)

Water productivity

Table 5 gives physical and economical water productivity for wheat and maize in KRB. The basin level water productivity of wheat is found to be 0.66 kg/m^3 ranging between 0.45 kg/m^3 in Kashkan to 0.85 kg/m^3 for south-Karkheh. The highest WP_{AW} in south-Karkheh can be ascribed to higher yields with limited water supply conditions. Lower WP_{AW} values for Kashkan are mainly due to higher water application and relatively lower wheat yields. The calculated WP_{AW} values for wheat in KRB are lower than those observed in other regions of Iran. Afshar (2004) has reported WP_{AW} values up to 1.32 kg/m^3 for irrigated wheat in Mashad region of Iran. For similar conditions in Syria, Oweis and Hachum (2001) have also reported WP_{AW} of 0.93 kg/m^3 with average yields going up to 5800 kg/ha. This clearly shows that there is a good scope for improvements in water management to increase land and water productivity in KRB.

The average WP_{AW} for maize (0.79 kg/m^3) is found to be higher than wheat although it remains lower than other similar regions of Iran. Afshar (2004) has also reported WP_{AW} values of up to 1.0 kg/m^3 for irrigated maize in Mashad region of Iran. Despite excessive water use, higher WP_{AW} of maize is the result of superior yields. The average maize yields in upper and lower KRB are 6700 tons/ha whereas individual farmers in Gamasiab are getting as high as 8000 kg/ha. These higher yields are mainly due to excessive use of fertilizer for maize crop. The average fertilizer application rate for maize in the upper KRB is 300 kg-N/ha whereas for lower KRB it is 170 kg-N/ha. These substantially higher nitrogen application rates are the result of government subsidy provided on fertilizers. Farmers apply these higher nitrogen rates to get substantive yields to make agriculture profitable. The

WP_{AW} for maize is also lower than WP_{AW} values in Syria (1.2-1.5 kg/m^3) under similar environmental conditions (Zhang and Oweis, 1999). The major reason for lower WP_{AW} in KRB is the higher amount of irrigation water applied as the average crop yields are comparable to other regions of Iran.

In water limiting environments such as KRB, the main objective of irrigated agriculture is to maximize the returns per unit of water and not per unit of land. In these environments, higher water productivity is usually linked with higher crop yields. However, this parallel relationship is not valid under all conditions (Zwart and Bastiaanssen, 2004). After attaining certain higher level of yields, incremental yield increases requires much more water resulting in significant reduction in efficiency of water use.

Figure 3 shows the relationship between yield and water productivity for wheat and maize in KRB. It is obvious that maximum water productivities for wheat are achieved at the yield levels of about 5000 kg/ha. After this yield level, water productivity started reducing mainly because the amount of water needed to produce yields higher than 5000 kg/ha is much more than the amount of water required at lower yield levels. It is clear that under the given circumstances, it is more economical to produce only 5000 kg/ha and then use the saved water to irrigate other lands than to maximize yields with excessive amount of water.

For maize, maximum water productivity is achieved at yield of 7000 kg/ha. An attempt to get higher yields than these values will reduce the water productivity drastically. This curvilinear relationship is stronger for maize than wheat. This means that maize growing farmers have to be much more careful in using scarce water resources of KRB.

Figure 3 also reveals that higher water productivity values are usually obtained at less than maximum yields per unit land. Therefore these concepts make more sense in situations where water, and not the land, is a limiting factor or where water shortages restrict irrigation of available lands. If the saved water resources are allocated to other cropped areas, the total production and productivity of applied water will be increased. However, in such conditions, farmers need to be guided on when and how much water should be applied in order to avoid unwanted water stress on plants.

Afshar (2004) found, for different locations in Iran, water productivity values of 1.5 kg/m^3 and 1.3 kg/m^3 against water applications of 3000 m^3/ha and 6000 m^3/ha for wheat and maize, respectively. He also noted that water productivity was considerably decreased when applied water exceeds 3000 m^3/ha and 6000 m^3/ha for wheat and maize, respectively. Hussain et al. (2003) has also reported a wheat yield of 4500 Kg/ha and 4200 Kg/ha against irrigation water application of 3050 m^3/ha and 3700 m^3/ha for Bhakra (India) and Punjab (Pakistan), respectively. Sarwar and Perry (2002) have also reported increased water productivity under deficit irrigation conditions of Punjab, Pakistan. The corresponding water productivity values were 1.47 kg/m^3 and 1.13 kg/m^3, respectively. Even though production depends on conditions of the environment, the market, and the soil and water conditions are not equal across sites, there appears to be a considerable scope for improving productivity of water.

(Insert Figure 3)

Economic productivity

For the calculations of economic productivity, gross value of production (GVP) and net gross margins (GM) in US $ per hectare were calculated using crop yields and prices of wheat and maize. Productivity of land shows the same pattern as of yields. The GVP for irrigated wheat is US$ 788 ranging from US$ 570 for Kashkan to US$ 976 for Qarasu sub-basin. These differences are mainly related to yield differences in different sub-basins as the prices of wheat[5] are fixed in the whole basin. The basin level GVP for maize stands at US$ 1120, ranging from US$ 1018 for Kashkan to US$ 1270 for Gamasiab. The average basin level GVP for maize is about 40% higher than average GVP for wheat. Higher GVP for maize corresponds to higher yields as per unit price for wheat is higher than maize. The variations in GVP values within sub-basins are relatively lower as compared to wheat.

The average production cost for wheat in Gamasiab is US$ 245/ha. The main contributions to this total comes from planting costs (US$ 60/ha), followed by fertilizer and water charges (US$ 125/ha) and harvesting costs (US$ 60/ha). The higher production costs for maize are due to increased planting costs, water (mainly groundwater) charges and harvesting costs[6].

The gross margins (GM) are higher for maize than wheat. This is probably the reason that maize cultivated area is increasing over time. The basin level GM for maize is US$ 790 as compared to US$ 597 for wheat. Although average maize yields in Gamasiab are higher than Qarasu, gross margins are 12% higher for Qarasu. It is due to higher production costs in Gamasiab. The major contributors are groundwater pumping and fertilizer costs. It is evident from table 5 that salinity has pronounced effect on the productivity of land. In non-saline areas of upper KRB, wheat yields are almost double than the saline parts of the basin (south-KRB).

The maximum crop water productivity often does not coincide with the farmers' interest as their objective is to maximize land productivity or economic profitability. Therefore attaining higher yields with increased water productivity is only economical when the increased gains in crop yields are not offset by increased input costs (Oweis et al., 1998). Figure 4 shows the comparison of WP_{GM} for wheat and maize in different sub-basins. WP_{GM} values for wheat are general higher in all sub-basins. However, at the basin level, WP_{GM} values for wheat and maize are comparable. This is because of lower GVP and GM values for maize as a result of higher cost of production. This stressed the need that farmers should optimize their maize yields through economical use of fertilizer and scarce water resources. This will not only increase their profitability but will also reduce the groundwater pollution caused by heavy nitrogen leaching as a result of excessive fertilizer use. Presently, these problems are not very evident in the upper parts of the KRB due to deeper water tables but continuation of these

[5] Wheat price in KRB is taken as 2000 Rials per kg (US$ 0.22) whereas maize price is 1500 Rials per kg (US$0.16). These are the prices at which government buy wheat and barley from farmers at the farm-gate. Government sells the wheat flour back to people at the subsidized rate of about 1500 Rials (US$ 0.17) per kg.

[6] The harvesting costs in Gamasiab are US$ 60/ha as compared to US$ 40/ha for other parts of KRB. In south-Karkheh harvesting charges by combines are based on hourly basis whereas in Gamasiab harvesting charges are based on a percentage of total yields obtained per ha. This is due to higher yields in Gamasiab.

practices will have serious consequences in the future. Such measures are indispensable to ensure long-term sustainability of irrigated agriculture in this basin.

Conclusions and Recommendations

The analysis presented in this paper clearly shows that there are large differences in the crop yields and productivity of water for irrigated areas of the 5 sub-basins of the KRB. The results also suggest that in addition to water availability, location-specific factors such as soil fertility, fertilizer use and access to modern technologies are major contributing factors in crop yields and water productivity differences across the basin.

The most dominant factor for higher land productivity has been the increasing use of fertilizer and irrigation water. Individual farmers are more interested in increasing their land productivity and farm incomes and are less bothered by the decreasing water productivity. This is probably due to low cost of surface water in KRB. The subsidized electricity for agriculture has also made groundwater use very economical. Therefore, increasing surface water charges and limiting groundwater pumping by removing subsidies on electricity could be potential options for restricting excessive water use for agriculture.

Farmers of KRB are found to be ignorant of actual crop water requirements and tend to over-irrigate their lands. As plants are constrained in their capacity to extract more water than the atmospheric demand, extra water is lost as deep percolation to groundwater and recycled again through pumping causing inefficiency in water use. Therefore, farmers need to be educated about the actual irrigation requirements for different crops. By practicing improved irrigation techniques, farmers can save a considerable amount of water. This is especially needed in south-Karkheh where groundwater is shallow and saline therefore any water lost through deep percolation can not be re-used.

Since water productivity enhances as a consequence of increases in land productivity, agronomic practices such as introduction of improved crop varieties, adjusting crop calendars according to water availability, application of appropriate rates of fertilizers and reducing non-beneficial losses of water can help a great deal in improving crop yields, water productivity and gross margins.

Irrigation dominates water use in KRB and is expected to continue as major user of both surface water and groundwater resources. Therefore, in order to increase sustainability of irrigated agriculture, the overall strategy should be to make better use of existing water resources. The irrigation water requirements for different crops under different agro-climatic zones of KRB need to be calculated and disseminated. This will not only help in saving precious water resources but will also increase profitability of farmers.

Table 5: Physical and economical productivity of water for irrigated areas of the KRB.

Indicators	Gamasiab		Qarasu		Seymareh		Kashkan		South-Karkheh		Basin average	
	wheat	maize	wheat	maize	wheat	maize	wheat	maize	wheat	maize	wheat	maize
Yields (kg/ha)	3962	7474	4393	7305	3338	6473	2562	5988	3481	6136	3547	6675
AW (m^3/ha)	6088	9952	5445	10944	5012	6509	5656	6240	4094	8806	5379	8490
Cost of production (US$/ha)	252	434	174	301	173	297	178	313	176	315	191	331
GVP (US$/ha)	880	1270	976	1241	742	1100	570	1018	744	1043	788	1121
GM (US$/ha)	628	836	802	940	569	803	392	705	568	728	597	790
WP_{AW} (kg/m^3)	0.65	0.75	0.81	0.67	0.67	0.99	0.45	0.96	0.85	0.70	0.66	0.79
WP_{GVP} (US$/$m^3$)	0.14	0.13	0.18	0.11	0.15	0.17	0.10	0.16	0.18	0.12	0.15	0.13
WP_{GM} (US$/$m^3$)	0.10	0.08	0.15	0.09	0.11	0.12	0.07	0.11	0.14	0.08	0.11	0.09

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