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EVALUATION OF WATER PRODUCTIVITY IN THE SALINE AREAS OF LOWER KARKHEH BASIN AND DETERMINATION OF ITS CAUSES : A STUDY FROM SOUTHERN IRAN

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ABSTRACT. Karkheh River Basin (KRB) is one of the important basins in Iran regarding water resources, where both rain fed and irrigated agricultural production systems prevail. Water logging and soil salinity are the major threats to water productivity and sustainable agricultural production in the lower KRB (L-KRB). 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 water productivity (WP) of irrigated wheat, as major cultivated crop in DA and recommendation of simple and applicable management guidelines. This research was conducted in fourteen farmers'fields, typical of the farms in the region, during cropping season of two years 2005-2006 and 2006-2007. Based on the total applied water, calculated Evaporation-Transpiration (ET), and crop yield, wheat water productivity values were calculated and determined. Analysis of measured Water Productivity (WP) indicated that the range of variation in WP values is relatively high and varies between 0.1-2.1 $kg.m^{-3}$ In the southern parts of L-KRB, mainly in Dasht-e Azadegan plain (DA), available data show that the problem of soil salinity is magnified due to lack of farmers' knowledge, inadequate drainage networks, and absence of improved farming practices. In general, the main cause of soil salinity in the L-KRB is high water table, usually varying between 1.2-3.0 m below the soil surface. Evaluation of results indicates that, inefficiencies and the limiting factors affecting WP in southern part of L-KRB.

Key words: Karkheh River Basin; Water productivity; Soil salinity; Wheat.

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INTRODUCTION

Karkheh River Basin (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 (Qureshi *et al*., 2009). 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). The dry-land system prevails in the upstream and the fully irrigated areas are located in some parts of upstream and all parts of downstream of the KRB. The dry-land areas are well established and cover most of the basin agricultural lands, occupying 894125 ha, whereas irrigated lands occupy 578862 ha but expected to expand up to 340000 ha following the construction of the Karkheh reservoir Dam (Kijne *et al.,* 2003). KRB is a water shortage area and droughts are becoming a permanent feature of this region. Due to water shortage and degradation of land and water resources, livelihoods of rural communities are at stake. Considering the present pace of deterioration, the situation will become even worse in the years to come. On the other hand, there is a great potential for the improvement of land and water productivities in the KRB. The problems of KRB have a great similarity with other basins located in the similar hydrological conditions therefore; lessons learned here will be equally applicable to these basins. Other agricultural production system in the KRB is based on irrigated agriculture. It is estimated that about one million ha are irrigable in KRB, of which about 380000 ha are currently under irrigation (Anonymous, 2000). About 340000 ha of additional available arable lands will be brought under irrigation following the construction and completion of the irrigation networks under Karkheh Reservoir (Anonymous, 2007). However, in the Lower KRB (LKRB) heavy soil texture and recharge from upstream areas cause natural condition for waterlogging and is more induced by low irrigation efficiency of irrigated agriculture in the region. The available soil data indicate that the majority of arable lands in KRB possess with various degrees of limitations (either individually or in combination). Salinity, waterlogging, lack of soil organic matter, soil structural deterioration, and inadequacy of water holding capacity and low infiltration rate caused by compaction are the main factors limiting economic and sustainable crop production in the irrigated lands of lower parts of KRB (Anonymous, 2007; Wichelns and Oster, 2006).

Despite overall favorite potentials in respect to climate, soil, and water resources in the basin, agricultural water productivity in the lower and downstream areas of the KRB is very low. This is mainly due to the harsh climatic environment in the southern part and lack of sound agronomic, water and salinity management practices. The lower part of KRB region is typically hot and quite arid, and agricultural production is essentially dependent on irrigation. Waterlogging and soils salinity are the major threats to water productivity and sustainable agricultural production in the LKRB and thus guidelines based on sound and relevant research are urgently needed (Droogers *et al.,* 2001). Owing to relatively good quality of Karkheh river water (EC= 0.79-2.5 dS/m) and favorable climatic condition for agricultural activities in the LKRB, efficient use of available arable lands and good quality irrigation water will have significant effect on the economy of the region with positive national implications. The main objective of this research was to determine and evaluate water productivity (WP) of irrigated wheat, as major cultivated crop in Dasht-e Azadegan plain (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.

MATERIALS AND METHODS

The study was conducted in 14 selected farmers' fields, typical of the farms in the region, during cropping years of 2006-'07 and 2007-'08 (seven farms in 2006-'07 and seven farms in 2007-'08).

The crop cultivated in the selected farms was wheat. For the analysis of the results of WP, the rainfall data was obtained from the closest weather stations in the studied area. In *Figs. 1 and 2* rainfall variations for the two cropping years are provided and shown.

The soil and water condition of the selected fields were typical of the DA region. The soils were mainly heavy textured with high water table. In *Table 1* specification of the selected fields and some other soil and water characteristics of them for the first and second years of experiments, are provided.

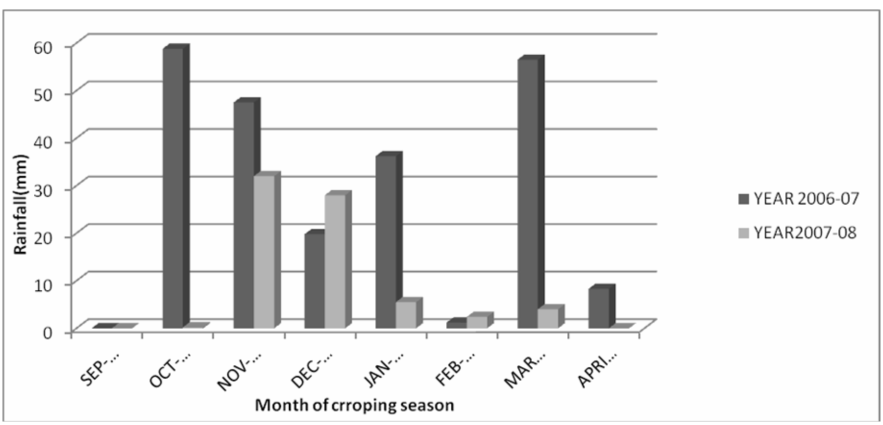

Figure 1 - Variation of monthly rainfall during cropping seasons of 2006-'07 and 2007-'08

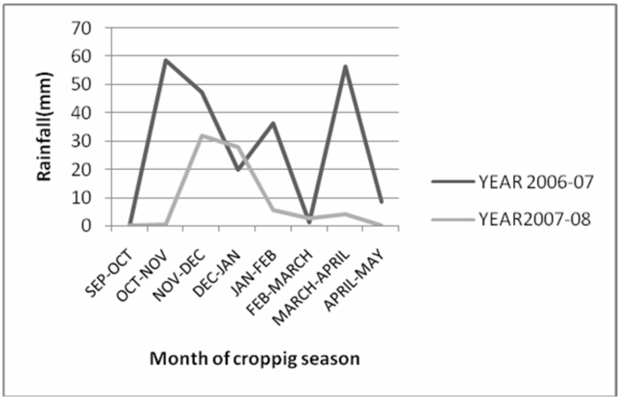

Figure 2 - A comparison of monthly rainfall during cropping seasons of 2006-'07 and 2007- '08

Table 1 - Some soil and water characteristics of the selected farms in the beginnings of cropping

Farm code	Area (ha)	Soil Texture (0-30cm)	Soil Salinity (0-30cm) (dS/m)	Depth to Water Table(cm)	Salinity of Ground Water(Ds/m)
F1	1.05	Silt loam	26.4	105	8.8
F2	1.47	Silty clay loam	10	205	39
F3	4.49	Clay loam	52.6	180	71.5
F4	3.44	C	17	195	31
F5	1.73	Clay	21.5	182	48
F6	0.46	Silty clay	21.3	173	46
F7	5.24	C	10.5	213	8.7
F8	3.79	Sil	51.4	207	34
F9	4.86	SiCL	17.8	193	48
F10	3.71	SiC	16.2	153	19
F11	6.92	SiC	15.9	205	88
F12	1.17	SiC	21.6	172	15
F13	1.93	CL	16.8	213	98
F14	23.48	C	81.3	186	24

The research was conducted in 14 selected farmers' fields, typical of the farms in the region, during cropping years 2006-'07 and 2007-'08. The measured parameters were inflow and outflow of the irrigation; salinity of the inflow and outflow waters; soil texture; soil salinity; pH; soil organic matter; the P, K, Fe, Mn, Zn, Cu of the soil prior to planting and during cropping season; depth and quality of ground water during cropping year; and crop yield. In order to have some information on the soil and water salinity status of the fields, soil, irrigation water, groundwater, and drainage water samples were taken and were analyzed for determination of the EC and other relevant ions values. For the assessment of waterlogging situation of the selected field water table depth were measured and monitored during cropping seasons. For measurement of crop yield 20 field samples were taken in an area of 1 by 1 meter in the field. The fields were harvested at roughly 14% moisture. The amount of applied irrigation water was measured by WSC (Washington State College) flumes (FAO, 1993). For determining the WP (in kilogram per cubic meter of water applied, kg/m^3) total yields of the selected fields was measured through sampling method. Then yield per unit area (hectare) was calculated. The irrigation intervals were the same as practiced by the farmers. The WP calculated by dividing total applied irrigation water to the total harvested grain yield per hectare.

RESULTS AND DISCUSSION

In *Table 2*, results of the measured yield for the two years of the study are provided. In these tables the Grain yield per hectare values are calculated from total grain yield divided by the farm total area (in hectare).

As it can be seen from *Table 2*, the grain yield of the selected fields are low and varies largely between almost 0.5-4.8 Tons per hectare. However the average yield is almost 2.0 Tons per ha, this value is almost half of the country's average yield of the irrigated wheat (Slabbers and Dunin, 1981).

The amount of water applied to the fields (by farmer) was measured using WSC (Washington state College) flumes. The measurements for each field and for the every irrigation event, during cropping season were done. In *Tables 3 and 4* the volume of water applied with each irrigation and the total water applied to the each field for the two years of the study are provided.

Table 2 - Selected farms and their yields

Farm code	Total Grain Yield (kg)	Grain Yield (kg/ha)*
F1	2500	2392
F2	1500	1021
F3	6000	1336
F4	5000	1453
F5	5250	3032
F6	2250	4851
F7	7500	1431
F8	9750	2573
F9	6400	1317
F10	6000	1617
F11	11760	1699
F12	2450	2094
F13	2100	1088
F14	11000	468

* Total grain yield (kg)/Farm area (ha)

Table 3 - Amount of irrigation water consumed in different farms (years 2006-2007)

Field	Applied water (m^3/ha)					Total water Applied (m^3/ha)
	Irrigation event	1^{st}	2^{nd}	3^{rd}	4^{th}	
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	-	

Based on the total applied water, and measured crop yield at 14% moisture, wheat water productivity values were calculated. In *Table 5*, values of water productivity of different fields are provided.

Based on the obtained results, there was a wide range in irrigation amount, yield and irrigation WP. Based on the latest agricultural statistics, the Iran produced 67 million tons of agricultural products from 84 BCM of water consumed (Alizadeh, 2005). Therefore, currently the country's average WP is almost 0.8 kg/m^3 which seems quite low compared with the world's average value (around 1.5 kg/m^3) (Heydari *et al*., 2006). Previous results of field studies conducted in three provinces in Iran, namely, Kerman, Golestan and Khuzestan, indicated that the 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 and the range of WP is generally wide and, for wheat, is varied between 0.6-1.7 kg/m^3.

In this research, the amount of irrigation water applied per unit area tended to increase with field size (R^2=0.35) (*Tables 1 and Fig. 3c*). This is an indicator of the problems associated with irrigation management in larger field sizes. The lack of equipment, facilities and farmers skills in proper water management has led to higher application rates.

As it can be seen from *Table 4*, although the range of variation in WP is large (from 0.1 to 2.1 kg/m^3), but most of the WP values fall within 0.6-0.9 kg/m^3.

Evaluation of the relationships between WP and initial soil salinity, ground water depth, groundwater salinity, farm size, and the number of irrigation events, indicated that there is no clear correlation between WP and each of these factors (*Figs. 3, 4 a, b, c, d)*. However, there are some fairly relationships between WP and indicated parameters for a certain groups of the farms. For instance, there is not clear relationship between WP and the groundwater depth and farm size, but in some farms with increase in groundwater depth and reducing the farm sizes; WP has improved *(Figs. 3, 4 a, b, c, d).*

Table 4 - **Amount of irrigation water consumed in different farms (years 2007-'08)**

Field	Applied water (m^3/ha)					Total water Applied (m^3/ha)
	Irrigation event	1st	2nd	3rd	4th	
F8	Volume	1279	1184	1242	-	3705
	Date	Nov. 21, 2007	Jan. 8, 2008	Feb. 24, 2008	-	
F9	Volume	900	1288	-	-	2188
	Date	Dec. 3, 2007	Feb. 29, 2008	-	-	
F10	Volume	1025	1257	-	-	2282
	Date	Dec. 2, 2007	March. 16, 2008	-	-	
F11	Volume	1245	1273	-	-	2518
	Date	Nov. 21, 2007	March. 13, 2008	-	-	
F12	Volume	1366	946	1184	-	3496
	Date	Nov. 16, 2007	Dec. 29, 2007	Feb. 20, 2008	-	
F13	Volume	1142	977	1023	-	3142
	Date	Jan. 1, 2008	Feb. 27, 2008	Feb. 20, 2008	-	
F14	Volume	1222	1138	1092	1184	4636
	Date	Nov. 8, 2007	Dec. 5, 2007	Jan. 9, 2008	March. 4, 2008	

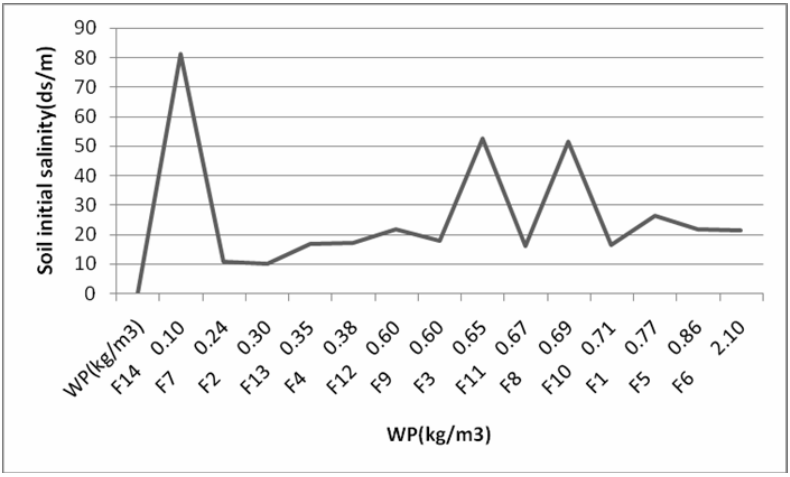

Figure 3 - **The relationship between WP and the initial soil salinity**

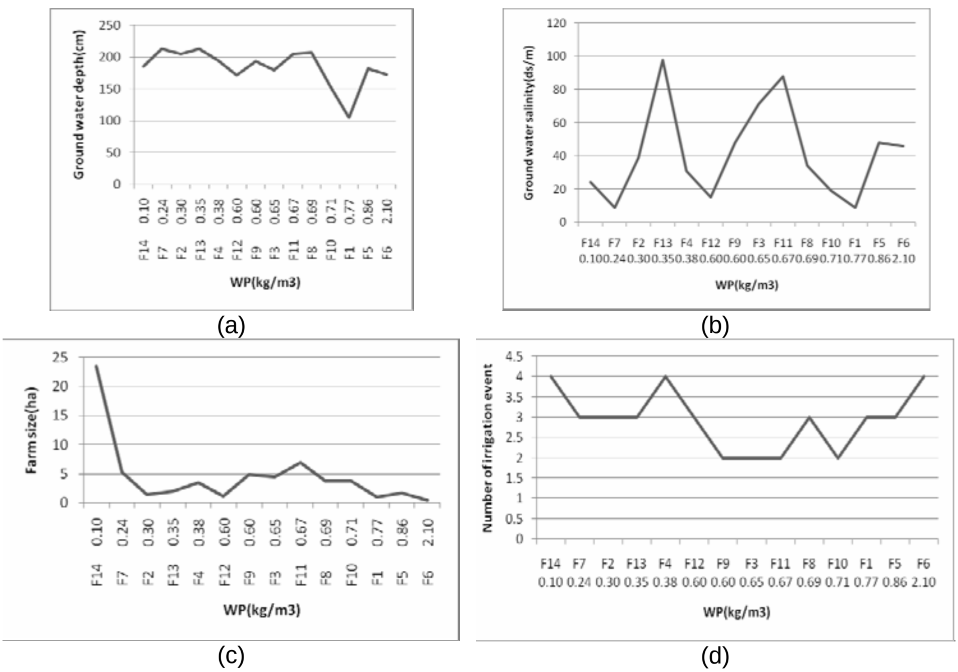

Figure 4 - The relationship between WP and some of the important affecting factors (a: groundwater depth; b: ground water salinity; c: farm size; d: number of irrigation)

Table 5 - **Values of water productivity of different farms**

Year 2006-07		Year 2007-08	
Farm	WP (kg/m^3)	Farm	WP (kg/m^3)
F1	0.77	F8	0.69
F2	0.30	F9	0.60
F3	0.65	F10	0.71
F4	0.38	F11	0.67
F5	0.86	F12	0.60
F6	2.10	F13	0.35
F7	0.24	F14	0.10

The relationship between WP and the initial salinity of the soil profile indicate that although in one case (F 14 in year 2007-‘08) the lowest value of WP obtained with the most saline soil, but in most of the farms there is not such a clear relationship and in some cases WP increase with increase in soil initial salinity *(Fig. 3)*. We may relate this to the nature of salinity in this region. The soil salinity in the southern parts of LKRB is dynamic. The salinity values changes greatly with fluctuation of water table and irrigation with almost good quality of Karkheh river water. Because of low and variable depth of impermeable layer with percolation of irrigation water watertable rises rapidly and hence contribute to the soil surface salinity changes. The highest values of soil salinity normally are seen in the beginning of cropping season following fallow period. But following the first irrigation most of the salts are washed to the deeper layer. In addition to the highly temporal variability of soil salinity, it spatial variability is in the field is also high. Due to poor land leveling and distribution of water in the field surface we can see great changes of salinity values even in the same field. Cheraghi (2008) monitored the soil salinity and depth of shallow water table November 2003 to April 2004 in the Dasht-e-Azadegan region. They also concluded that there was a large variation in salinity of groundwater ranging between 4 to 100 dS/m leading to high variation in surface soil salinity. As already mentioned, variation in depth of impermeable layer and high fluctuation of saline groundwater considerably causes very complex and dynamic situation of soil salinity in the region. Karma (2002) also noted that alluvial plains in Iran and especially those in Khuzestan Province, including LKRB are considerably stratified and recognition of impermeable layer in these soils is very difficult. Therefore, it is difficult to find out very simple and direct relation between soil salinity and WP values in the Dasht-e-Azadegan region (Anonymous, 1989). However, it is clear that salinity and waterlogging conditions are as major sources of low WP in this region.

Overall, based on findings obtained during the field works with the farmers, the sources of inefficiencies and several factors causing low values of agricultural WP in the southern part of LKRB like:

- Limitations that are out of farmer's management control and authority, e.g., irrigation intervals and rationing, and shortage of agricultural inputs (fertilizers, other agrochemicals, machinery etc.).

- Technical and infrastructure limitations and problems. (e.g., inadequate drainage and reclamation, and incomplete irrigation and drainage networks).

- Farmer management problems and limitations whose solution is simple and do not need much investment and can be accomplished easily e.g., flow control, irrigation and land preparation methods, improvements in water intake structures, growing improved variety, fertilizer and weed control management etc.

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

- Traditional common irrigation in the area is a mixture of border-basin irrigation method. The long borders (up to 400 m, 12-15 m wide) are divided into small basins (30-60 m Length). Every basin receives its water from the previous (upstream) basin. Water is pounded for a long time in the upper basins in the sequence until the bottom basin has been irrigated, damaging the seed in the upper basins due to prolonged waterlogging. The high inflow rate at the top also results in erosion and exposure of the seeds. As there is not enough control on cutoff time,a large amounts of water accumulate in the lower parts and creates surface waterlogging. It is recommended to irrigate via a farm ditch alongside the border and a proper intake into each basin.

- Problems in water intake and conduct of water into the irrigation plots due to lack of proper constructed intake structures. This problem leads to waste of a lot of time and efforts to be done by the farmers to control irrigation flow (start and terminate the flow to the plot). This directly leads to extra runoff, deep percolation losses, and poor water management in the field. Construction of temporary and low-cost intake structures (gates etc.) to facilitate water intake and improve water management are recommended.

- Improper leveling and slope of the fields causes non-uniform distribution of water in the plots.

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

CONCLUSIONS

The main objective of this research was to find out cost effective and short-term solutions for solving these problems and to improve WP of wheat in the salt-prone areas of lower

KRB. It was attempted to assess and evaluate WPs under farmer's field. Waterlogging and soil salinity are major threats to the productivity and sustainability of agriculture in the LKRB. Soil salinity is the major cause of low yields and water productivity (WP) in this region (Bybordi, 2002). In general, the main cause of soil salinity is the high water table, varying between 1.2-3.0 m below the soil surface.

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

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