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

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

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International Center for Agricultural Research in the Dry Areas

AREO
Agricultural Research and Education Organization

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WATER & FOOD

Improving On-farm Agricultural Water Productivity
in the Karkheh River Basin (CPWF Project no. 8)

Research Report no. 1

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T. Oweis, H. Farhani, M. Qadir, J. Anthofer, H. Siadat, F. Abbasi
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International Center for Agricultural Research in the Dry Areas (ICARDA)
P.O. Box 5466, Aleppo, Syria.
Tel: (963-21) 2213433
Fax: (963-21) 2213490
E-mail: ICARDA@cgiar.org
Website: www.icarda.org

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INTRODUCTION

The world water resources are under increasing stress as the human population and water demand per capita increases. These problems are not new, but are now becoming more widespread and their impacts more devastating. This has provided additional impetus for the search for solutions to problems arising from the mismatch between demand and supply in terms of water quantity, quality and timing. Increasing water productivity has been identified as one of the global challenges that require urgent attention.

Water in the Karkheh River Basin (KRB) is limited and becoming scarce 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 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 this CP project, 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 rain-fed systems
- Farmers' adoption of the new recommendations and technologies
- Progressive policies and suitable institutional arrangements
- Capacity building of NARS and community leaders
- 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 Research and Education Organization (AREO), and its research institutes such as the Agricultural Engineering Research Institute (AERI), Seed and Plant Improvement Institute (SPII), and Dry land Agriculture Research Institute (DARI), University of California, Davis, USA, and most importantly, the farmers and extension staff in the basin. The project is for over four years (starting in 2004), with over one third of its budget contributed by AREO. The partners' commitments of sizable matching funds and the strong presence of ICARDA and IWMI in Iran and the wider region have ensured a cost-effective and low-risk project.

This report contains five chapters, collectively providing background information and review of past research at Karkheh with some relevant information from across Iran. This is the first of a series of research reports on Karkheh, summarizing the available data and information on natural resources and livelihoods and identifying the gaps which need to be addressed in the present as well as future projects. The production of the chapters has been facilitated by ICARDA through close cooperation with NARS of Iran. The chapters stress the main challenges to improving WP and are authored by NARS scientists who have first-hand knowledge of the issues and ongoing on-farm research experiments at Karkheh.

Chapter I provides a summary background of, and justification for, the project and briefly discusses WP issues across the wider basin. Chapters II to V provide a more in-depth review of past agricultural and water research for the dominant rain-fed and irrigated systems in addition to elaborating on salinity and water-logging problems. The data presented and the opinions offered are the sole responsibility of the authors. The synthesis provided in this report should make a valuable contribution to the ongoing development of understanding of the intricacies of the efficient use of water at Karkheh River Basin.

CHAPTER I

Agricultural Water Productivity in Karkheh River Basin

Hamid Farahani[1] and Theib Oweis[2]

[1]Irrigation & Water Management Specialist, Integrated Water & Land Management Program, International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria
[2]Director, Integrated Water & Land Management Program, ICARDA, Aleppo, Syria

INTRODUCTION

The world is currently facing the challenge of producing more food with less water. Increasing water productivity (WP) is global challenge that require urgent attention. This challenge stretches across agricultural disciplines and sectors and certainly requires the concerted action of all stakeholders: farmers, water managers, hydrologists, agronomists, water resources specialists, engineers, socio-economists, and policy makers. The understanding of how effectively *water is acquired and managed and how efficiently water is used* is the key to effectively tackle the challenge of improving WP.

To improve the livelihoods of the large agricultural population in the developing world, the development and adoption of technologies and strategies that facilitate the improving of agricultural production per unit of water is becoming increasingly important. Research shows that substantial and sustainable improvements in water productivity is attainable, but can be best achieved through community-based integrated natural resource management approaches. In the past, focus on improving WP has primarily been on plant- and field-scale, while recently water productivity at higher levels such as farm-, project-, basin- and regional-scales is increasingly used.

Examining water use from a basin perspective means that not only water supply and demand for all users are looked at, but also at institutional issues involved in the provision of services. At the basin-scale, the interaction between the upstream and downstream uses and users of water becomes more evident and raising acute equity issues. Deterioration of water quality, either from agricultural or urban-industrial complexes, that reduces the value and utility of water to downstream users, is another basin-wide water issue. The basin perspective allows a greater clarity at the importance of the institutional interventions regarding how planning, policies, rights, regulations, monitoring, and water-user organizations need to be designed and implemented to enhance the effective functioning of organizations at basin and system levels as well as at the level of individual user or users. Additionally, environmental and ecological issues related to water can also be more properly looked at from a basin perspective.

In spite of the above argument, it is of utmost importance to recognize that no effective basin-wide assessment can be formulated or constructed in the absence of sound and spatially and temporally dense data from the underlying lower scales of field and farm. It is thus at this lower, but necessary level of complexity and integration, where the Karkheh River Basin (KRB, shown in Fig. 1) project initiated its research activities in the target areas of the project, with subsequent linkages and out-scaling to be made at the basin level. The challenge is how to out-scale the results to other areas in the basin and the country and how to up-scale as policy options for local, regional, and national initiatives. The use of modeling, GIS, and remote sensing technologies is promoted to simulate and estimate first-level out-scaling of the potential impact at higher scales with the goal of effective farmers' adoption and wider dissemination through outreach, enabled institutions and effective policies.

The Karkheh River Basin research project is community-based with participation of farmers, community leaders, local institutions and policy makers. The belief is that the direct interaction between the project and the beneficiaries will produce the optimum results. The hypothesis of this project is that water productivity in the KRB could be substantially increased by improving on-farm water management, introducing new

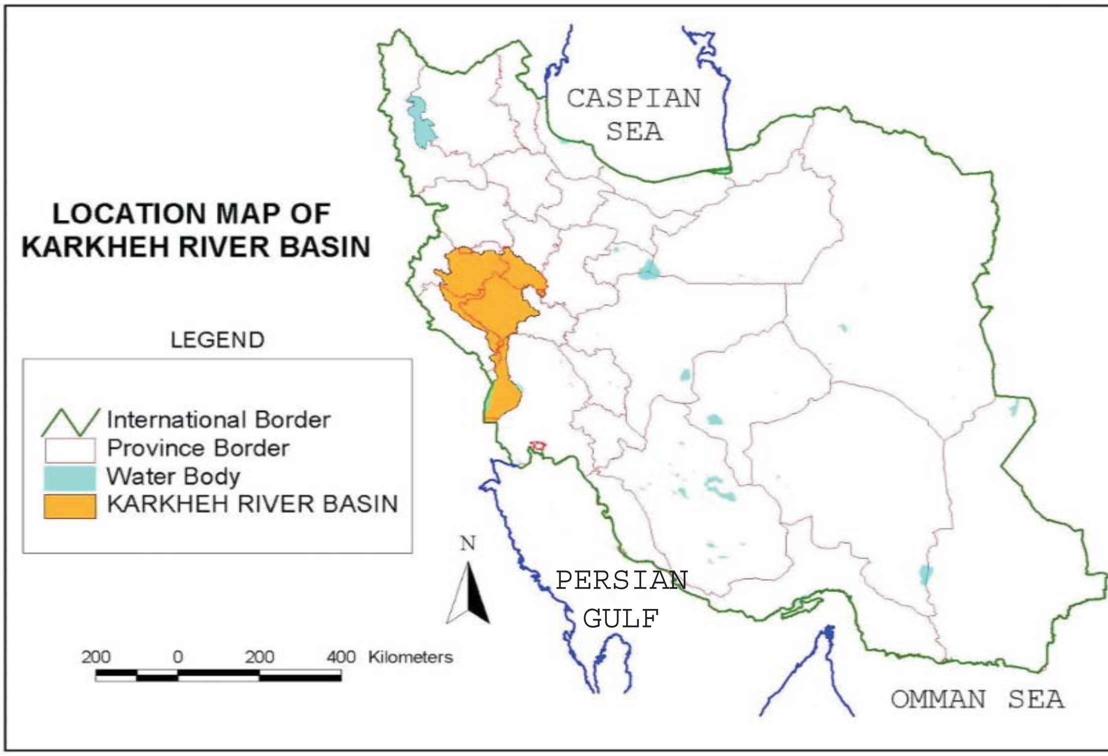

Fig. 1. Map of Iran showing the Karkheh River Basin (KRB) in the west.

crop varieties, adjusting cropping patterns, optimizing supplemental, deficit, and full irrigation and integrating appropriate agronomic practices in the crop production system with suitable institutional arrangements and policies. It is believed that the key to the realization of this hypothesis is the involvement and participation of farmers and local communities as well as the full cooperation of the official organizations and authorities responsible for water and agricultural development of the basin. Therefore, the project has made substantial efforts to provide the necessary framework and encourage participation of these target groups at all stages of the project implementation. There are also coordinated activities with other CP projects (PN24 Livelihood Resilience of ICARDA and the Basin Focal Point of IWMI) in the Karkheh basin in terms of logistics and scientific aims so as to increase the use-efficiency of the available resources.

Four benchmark sites are selected under rainfed and irrigated conditions. Experiments and demonstrations are conducted under researcher- and farmer-managed conditions to develop, test, apply, and improve the adoption of better water management, agronomic practices, and technology options. An integrated approach to developing efficient systems is used. Socioeconomics forms an integral part of the project to ensure a problem-solving approach and a higher adoption potential. Special attention is given to the role of women in agricultural water management and use. Policies and institutional structures are examined and recommendations communicated.

The consequences of the outputs at the basin level will be studied and projections made available. Existing policies and institutions will also be explored in two other relevant basins, the Euphrates and Amu

Darya, with the help of respective national experts.

The objective of this chapter is to provide an overview of the some important water productivity (WP) issues across the Karkheh river basin and at varying scales. Subsequent chapters offer more in-depth examination of WP issues at rainfed areas above the Karkheh dam and fresh and saline irrigated areas below the dam.

WATER PRODUCTIVITY IN THE KARKHEH RIVER BASIN

Background and Justification

Increasing water scarcity and frequent droughts in the region have attracted attention to the necessity of improving water productivity. While more than 90% of the water resources of Iran are used for agriculture, the overall efficiency is about 37% (Keshavarz *et al.*, 2000). Accordingly, the third National Development Plan of Iran identified increasing water productivity in agriculture as a top priority.

The Karkheh River Basin is, most notably, the eastern flank of the "cradle of civilization" (ancient Mesopotamia) and a boundary between the Arab and Persian cultures. This major river system of western Iran has unique agricultural and hydrological aspects and also has much in common with other catchments around the world such as rural poverty and land degradation, low water and agricultural productivity, a dry climate, and growing upstream-downstream competition for water.

Changes in land use patterns in recent decades, especially overgrazing and conversion of natural pastures to rainfed cropping, have taken a heavy toll. Ninety percent of the upper watershed's rangelands and 70% of its forests have been significantly degraded. The future of the KRB and its people's livelihoods clearly depends on more holistic, basin-wide management and monitoring of natural resources—water, soil, vegetation and livestock. The KRB project will contribute in two ways by: 1) Helping build a better scientific understanding of the human and biophysical dynamics of the basin, and 2) Designing practical tools, guidelines and technologies for farmers, policymakers and scientists.

The Karkheh River Basin is one of the most important agricultural zones of Iran and among the areas suffering from low water productivity. The KRB has an area of 50,764 km^2, a total of five sub-basins covering parts of 7 provinces (Figs. 2), a population of approximately 4 million, with 67% rural and a per capita income from agriculture of US$230. Annual rainfall ranges from about 150 mm in the south to 700 mm in the north, with an average of 490 mm of which an estimated 325 m (or 66%) is consumed by evapotranspiration. The climate is mainly semi-arid, interspersed with arid portions.

Total developed water resources are over 8 billion m^3 (after completion of the Karkheh dam) and irrigation water consumption is estimated.at 3.9 billion m^3/year (more than 60% is surface water). Groundwater consumption and use is about 1.65 billion m^3/year; with agriculture, drinking water and industry using up 87, 12, and 1%, respectively. The total irrigated area is 1,100 km^2, with planned expansion to 3,400 km^2. Major crops such as wheat and barley are grown over 76% of the area, pulses account for a coverage of 23% of the area, and 1% of it goes for raising forages, orchards, vegetables, and oil seeds. Area suitable for rainfed agriculture is 8,940 km^2. The main institutional arrangement for managing water is the Ministry of Power, which is responsible for water development and allocation. Detailed background on KRB characteristics can be found elsewhere (e.g., Keshavarz, 2005).

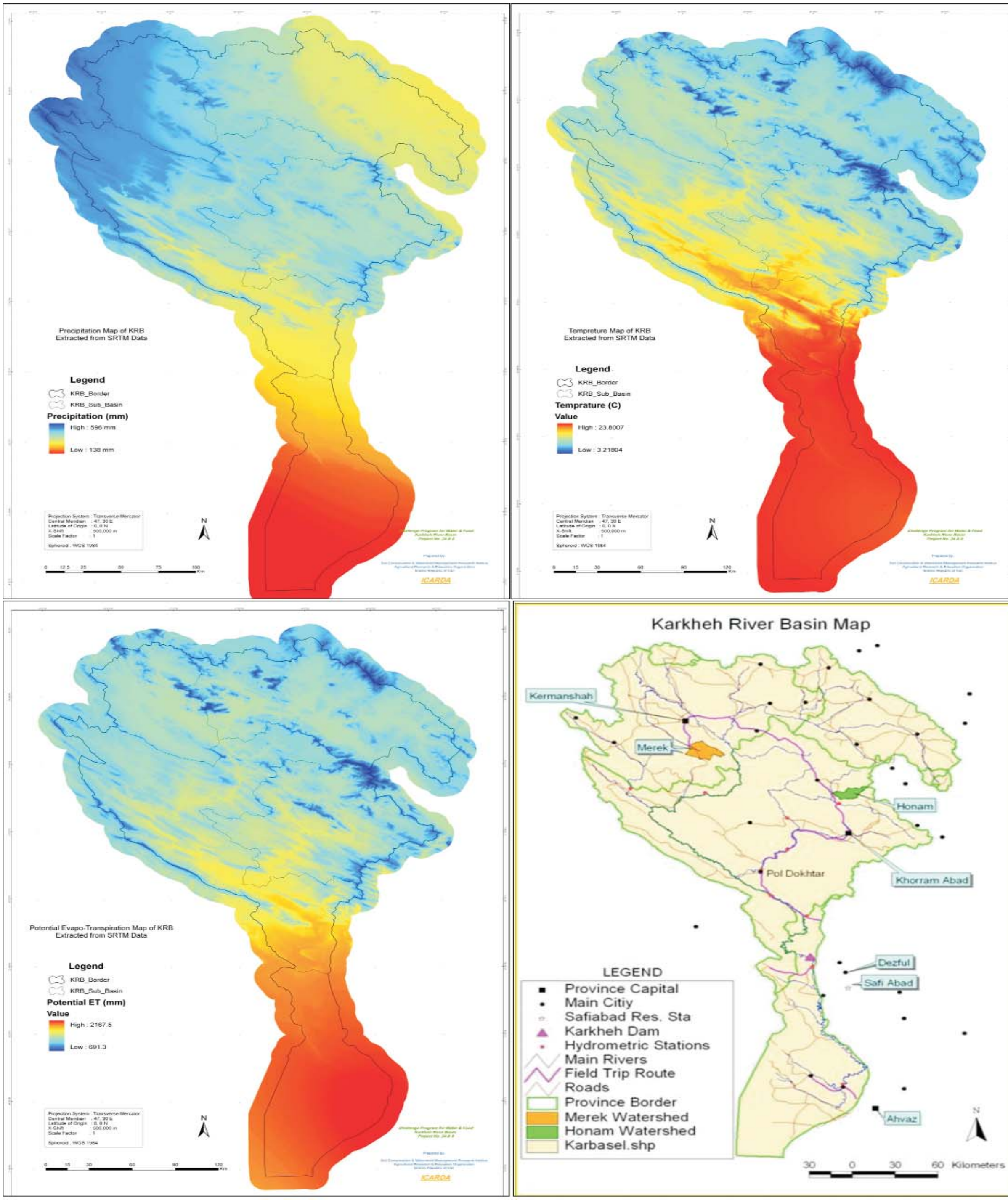

Fig. 2. Gradients of precipitation (top left), temperature (top right), and potential ET (bottom left) across Karkheh River Basin, also shown are main sub-basins and rivers (bottom right). (prepared by Soil Conservation and Watershed Management Research Institute, Tehran, Iran).

There are two major agricultural production systems in this basin. One is the rainfed production upstream of the newly built Karkheh reservoir and the other is the fully irrigated and thus intensified cropping system downstream of the dam (Fig. 3). Livestock is well integrated into most rainfed farming systems that includes cattle, sheep and goats. The rainfed areas are well established and cover most of the agricultural lands in the upper catchments, while in the lower catchments; irrigated areas were limited before the building of the Karkheh dam. However, plans for expansion are now underway.

In the upper catchments, fully irrigated summer systems cover about 250,000 hectares. Throughout the basin, there are about one million hectares of irrigable lands (JAMAB Consulting Engineers, 1991, and Moemeni, 2003). Therefore, future expansion in irrigated land is expected. In the upper sub-basins, the expansion will be in both full and supplemental irrigation, while in the lower sub-basin the increase will be in full irrigation. Water Productivity (WP) in these areas is also very low, not only compared to its potential but also considering other river basins in Iran. Overall grain WP in the basin is estimated at 0.4 kg m^{-3}.

Upper Karkheh River Basin

In the upper catchments, rainfed farming covers most of the land but limited supplemental and full irrigation systems are also present where water is available (as shown by the contrasting environments in Fig. 4). The cropping systems in the rainfed areas cover a total of nearly 894,000 ha and are predominantly cereals in rotation with legumes. Wheat, barley, and chickpea occupy 53%, 23%, and 22% of the area, respectively. The average grain production per unit area is rather low: 920 kg ha^{-1} for wheat, 950 kg ha^{-1} for barley, and about 500 kg ha^{-1} for chickpeas. Water productivity ranges from 0.3 to 0.5 kg m^{-3}; these productivity levels achieved an income of less than US $50 ha^{-1} at the beginning of the project. The upper catchments are among the most suitable rainfed zones of the country, with long-term annual precipitation of 350-500 mm. 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 well below potential.
In the upper rainfed areas the growing season is relatively short and yields of rainfed cereals are generally lower than that expected where rainfall exceeds 400 mm. One cause is the delay in the early season rainfall that results in late sowing, which exposes the crop to cold and frost damage following sowing. The result is a poor stand of the crop that cannot be compensated by rainfall later in the season, as observed in research by Dryland Agriculture Research Institute (DARI, Maragheh, Iran) and ICARDA in other rainfed areas of Iran. One potential solution is to use supplemental irrigation (SI) to assist early planting. This practice has shown impressive results in increasing crop water productivity in similar areas of Iran, Syria, Morocco, and Turkey (e.g., see DARI annual reports, 1999-02; Tavakoli *et al.*, 2005). Irrigation water availability, conveyance mechanism, and cost are the main constraints to supplemental irrigation. The KRB project has teamed up with scientists from DARI to test various supplemental and deficit irrigation strategies and improved agronomic practices on farmers' fields to enhance WP in this area (see review in Chapter II).

Lower Karkheh River Basin

The downstream part of the basin stretches from the Karkheh dam in the north more than 100 km southward, where the Karkheh River discharges into the marshlands of Hoor-al- Azim. A number of sub-basins in

Fig. 3. Rainfed agriculture in upper KRB (left) and irrigated farming in lower KRB (right) are the dominant agricultural production systems.

the command area, including Dasht Abbas, Evan, Dusaif, Ardyez, and Bageh, as well as some in the lower plain, are planned for over 300,000 hectares expansion of irrigation systems including new irrigation and drainage networks (Fig. 5). In the lower KRB (especially immediately below Karkheh dam), water availability is improving due to installation of large scale irrigation and drainage networks. However, full scale delivery of irrigation water from Karkheh dam is at least a few years away due to slow pace of construction of the distribution network and in some cases, lack of funding. Agriculture in the downstream is predominantly irrigated (now about 111,000 ha), with annual rainfall ranging from 300 mm in the north to 100 mm in the south. Soils are mostly young river deposits of fine texture with little profile development and medium to low infiltration rates. Salinity of topsoil fluctuates during the season and, generally, increases towards the south. The river water quality is good, though it varies both seasonally and along the river.

The lower KRB area is suitable for a wide range of crops. Presently, wheat, maize, alfalfa, and off-season vegetable crops

Fig. 4. Contrasting wetter and dryer environments in the upper Karkheh as a result of surface water availability.

are the most popular. However, crop water productivity and irrigation and conveyance efficiencies (see example in Fig. 6) are low and land and water resources are at risk of quality degradation. Average irrigated cereal yields are still relatively low at 2300 kg/ha and water productivity values between 0.5 and 0.6 kg/m^3. Values reported for the overall irrigation efficiency of the traditional networks in Dasht Azadegan (southern areas of the lower KRB) range around 14-23% (Mir-abolghasemi, 1994). In the neighboring basin of the Dez River, in consolidated fields of the modern networks efficiencies are little better at 32-37% (Fatemi, et al, 1994). Water productivities for the annual crops such as wheat and barley are less than 0.5 kg m-^{3}. The large amount of water loss during conveyance and field application has greatly aggravated resource degradation causing, among other problems, drainage and salinity in the downstream sub-basins and lowland areas. Obviously, with the present management practices, such threats will expand in the future and their impacts will be wider. The KRB project has selected a large irrigated area (Sorkheh) just below the dam and researchers from Agricultural Engineering Research Institute (AERI, Karaj, Iran) and its research stations (Safiabad, Dezful, Iran) are leading extensive on-farm irrigation management experiments to assess and improve WP in the area (see review in Chapter III).

The salt-affected lands and wetlands are the main features of the downstream of the lower Karkheh Sub-Basin. Soil salinity is highly variable in the region with electrical conductivity (EC) ranging from about 2 dS/m to well over 100 dS/m. The major causes of salinity and water logging (Fig. 7) are high water tables (1 to 3 m below soil surface), high evaporative demand and saline soil horizons, magnified by poor irrigation distribution (Fig. 8). The construction of Karkheh dam helped in minimizing flood damage, but it has made salinity a major problem. Before the construction of the dam, seasonal floods were the biggest source of water for leaching salts. Farmers were growing wheat and barley using river water or flood water (in the past) but the yields were low (1-1.5 t/ha) and at times failures occurred. There were no significant reclamation measures practiced by farmers. As part of the KRB project, the National Salinity Research Center (NSRC, Yazd, Iran) and the provincial Agricultural Research Center are conducting on-farm salt-tolerant and water and salinity management experiments in this area (see review in Chapters IV & V).

Fig. 5. Drainage and irrigation canals in the lower KRB.

Fig. 6. Example of poor on-farm water conveyance structures and practices: An earthen irrigation ditch is shown, in which the farmer has cut through its left bank to convey water across the road to the field on the left, also causing other problems such as excess runoff (Sorkheh area, Feb 2007).

WATER PRODUCTIVITY - DEFINITION AND ANALYSIS

There are numerous publications on the concept of WP, its context-sensitivity, and scale-dependency. These are only briefly summarized below (and also in subsequent chapters) and the interested reader is referred to the recent book on comprehensive assessment of water management in agriculture (Molden, 2007) and therein.

In the most general sense, productivity is an output-input relationship, a broad concept in agriculture with water productivity encompassing biophysical as well as socio-economic aspects of the relation between beneficial outputs from the use of a unit of water input. For agricultural water use, the primary focus is placed on food production, therefore water productivity is defined as food or value output per unit of water consumed, applied, diverted, or degraded. Agricultural output resulting from water use may be: 1) agricultural or natural vegetative biomass, 2) nutritional content of various forms of food produced, and 3) economic and societal value created in different sectors such as agriculture, fisheries, livestock and agro-forestry. There is also non-agricultural uses and thus benefits of water such as in recreation and maintaining ecosystems health and wildlife habitats is of importance. In most cases water is quantified in units of volume (e.g., m^3 water) that crosses the boundary of the scale under consideration (e.g. field, farm, irrigation network, a nd basin) or changes in the volume stored within system bounds during the time period of analysis.

The basin is the highest order scale for hydrologic flows and physical water management. Agricultural water productivity at the basin scale is not simply a linear extrapolation of the individual system-level agricultural water productivities. A number of tradeoffs exist with allocating water for agriculture versus ecosystems. As a result, the water productivity definition that allows comparison across contexts needs to include multiple uses of water. These are best captured in the elusive term *value*, which reflects appreciation society holds for biodiversity, ecosystem integrity, habitat maintenance, aesthetics, cultural importance, and goods and services based on hydrologic flows. The water input denominator becomes not just the physical depletion of water but may include degradation in its quality.

The principle purpose of measuring WP is to identify opportunities to improve the gain from the use of water. For instance, in crop production, the goal of improving yield per unit water used is achieved by either increasing the productivity per unit consumption of water, reducing the consumption without decreasing production, or by reducing both, but at a lower rate for output than input water (e.g., in deficit irrigation). In all cases, water productivity quantifies how beneficial water is used in producing goods and services. Water produc-

Fig. 7. Water logged (left) and severe salt build up (right) in irrigated fields in lower KRB (Dash e Azadegan).

Fig. 8. Water logging and non-uniform distribution (left) and poor emergence (right) in saline water irrigated fields in lower KRB (Dash e Azadegan).

tivity is scale dependent. At different scales, water productivity affects different stakeholders with different sets of objectives. At the farm level, the farmer is interested in getting family food secured and income increased. At basin/regional level, national food security and health and environmental protection are also important issues to a broader group of stakeholders and policy makers.

WP of Multi-Sector Land Use Systems

Field water management is the lowest scale at which practical water management interventions may be used to increase productivity, or yield per unit water used. At the higher farm scale (i.e., multiple fields), water management and technology to improve productivity attempts to minimize irrigation deliveries, taking into account field-to-field runoff and reuse wherever practiced or appropriate. At the farm scale, water productivity can also be examined as the ratio of yield per unit of water used for each field, but a single farm level water productivity value defined as total biomass per total water used may not be meaningful if varying crops (grains vs. vegetables) are produced at different fields. Farm water productivity expressed in economic returns would be more appropriate.

At higher scales, the interest is in defining the amount of water depleted in agricultural production, which includes crop evapo-transpiration, evaporation losses from return or unused flows and losses to sinks, such as saline groundwater. In measuring depleted water, the flows not used by the crop and returned to the system must be accounted for as these are no longer quantity losses, although quality degradation may be a factor reducing value. As the scale of the systems analysis increases beyond the field, estimating the total value from water use increases in complexity. For instance, a basin includes a host of agricultural sectors and thus water-related activities, which together modify pathways of water moving in or out of any component sub-system. Differing land uses across a basin also present other complex activities which interact in ways other than water, including, food, energy, income or other social exchange. The result of the above makes the comparisons of the value of water depletion for different benefits and costs difficult.

The simplest way to compare water productivity across different enterprises is in monetary terms, although the full range of benefits from agricultural production extends far beyond the simple monetary measures and well into employment, food security, and other rural and social benefits. Another simplifying assumption for water productivity assessment at higher scales is to ignore trade-off since water consumed by one user is denied to others including the downstream users. As water becomes scarcer, the marginal cost of such loss becomes significant. Analysis of trade-off between the competing uses requires comparative production functions, most of which are non-linear and which may have poorly defined interactions over and above those connected with water use.

Since there are feed-back effects of changing water use in the hydrologic pathway like the upstream-downstream interactions, it may also be necessary to consider the impacts of different interventions and the scale of adoption in a way that internalizes hydrologic feedback in terms of water quantity and water quality. One way to do this is by integrating the production system, the hydrology, and the economics within a single modeling framework. This is much easier said than done, particularly in developing countries where limited data is available.

Methodology for Assessment/ Diagnosis of WP in Karkheh

Besides extensive field and on-farm WP research experiments, assessing agricultural water productivity across the whole Karkheh River Basin in Iran (in addition to other basins of Amu Darya in Central Asia and Euphrates in West Asia)) is also an important activity with the CP WF project. The basin-wide water productivity assessment requires a sound methodology as there is no current workable methodology for this purpose. In April, 2005, a consultation workshop was held at ICARDA, Aleppo, Syria, to develop a framework for assessment of agricultural water productivity (WP) at the river basin level and to discuss different aspects related to water productivity concept and assessment. Many prominent scientists and experts drawn from different CGIAR institutes, NARS and universities, and CP projects from Iran, Egypt, Syria, Turkey, Philippines, Brazil, Colombia, China, Kenya, Uzbekistan, Turkmenistan, Sri Lanka, USA, and Ghana attended the workshop. Using the feedbacks from the above workshop, a team of ICARDA scientists is currently formulating a framework for the assessment and diagnosis of agricultural water productivity at the river basin level. Simplicity and workability are paid due consideration in developing this framework.

The objective of the methodology (Oweis et al., 2007, draft) is to set a generic framework for assessing the water productivity at basin/sub-basin level under existing or present conditions across a basin. The methodology employs GIS, modeling, and the use of satellite imagery to delineate the larger basin into similarity zones and will be presented in subsequent reports. Briefly, the methodology considers the productivity of a unit of water used, i.e., to grow a given crop, as a complex function of many factors, including climate, soils, topography, management, and the inputs. Capturing the variability of WP as caused by these factors is also complex, but important for assessment and diagnostic purposes. Furthermore, the specific factors that directly and/or indirectly impact the productivity of water differ between similarity zones. For instance, some factors like precipitation amount and distribution have a greater impact in rainfed cropping than in the irrigated system. Identifying and mapping the spatial coverage of these factors across the watershed can help with the needed diagnostic analysis of the spatial variability of WP. The variables of interest are precipitation, temperature, soils, topography, livelihoods (including customs and cultures), and management. As a first step, spatial coverage maps of these variables are being produced, in addition to maps showing the agricultural statistics for the agriculture services administrative boundaries.

The agriculture administrative areas or districts within watersheds offer an immediate source of yearly baseline data and long-term statistics for yield, prevailing systems, water resources, and livelihoods as collected by NARS. In the case of Karkheh, national statistics are available every five years since 1950, with each census database including many attributes per village that can be aggregated to other scales of district, township, and province for spatial variability analysis of biophysical parameters that may help capture cultural, policy issues, and management characteristics of the administrative districts that may have a bearing on yield and the productivity of water. These maps will be compared with (or overlaid on) WP maps to deduce constraints and limitations to low WP values and the causes of the spatial variability in WP for a given land use and across different land uses. Any spatial correspondence or correlation between a WP map and any other climate, soil, topography (elevation and slope), yield, livelihood and poverty level, and cultural and management skills can then be documented as possible constraints or sources of variability in WP for further in-depth study. Any spatial correspondence between these maps will be valuable information in diagnostic analysis of WP variability. The usefulness of the WP mapping in conjunction with developing coverage for other factors listed above is that it identifies the communities or areas within the basin that is in need of a closer examination. That we call 'direct sampling' as opposed to the traditional 'random' or 'grid' sampling of the whole basin. Direct sampling of the communities where the above diagnostic procedure shows correlation between WP and other related factors is an efficient sampling strategy and should save time and money.

Overlaying the WP map and the other climate, topography, soils, and livelihood (or poverty) maps is suggested to help tagging low WP areas with the prevailing climatic and bio-physical and social conditions. It is generally observed that the poorer and less educated the community, the lower the productivity due to inadequate management, technical support, machinery, capital, and quality seeds and fertilizers in addition to farmers' lack of desire for improvement. The overlaying of WP and poverty maps may even prove to be an effective and simple methodology for socio-economists to map poverty using a WP map as a surrogate or proxy.

CONCLUDING REMARKS AND FUTURE WORK

The focus of the KRB water productivity project is on research and capacity building in rainfed and irrigated agriculture. An important outcome of the project will be a workable methodology to assess, map, and conduct diagnostic analysis of WP of major land uses across the basin using a systematic and logical order of: 1) downscaling across the basin to delineate major land use areas; 2) using the land use coverage to delineate major agro ecosystems as first level classification zoning of the basin; 3) selecting representative watersheds with each zone that encompasses the major land uses; 4) estimating WP across the selected watershed(s) for all land uses; and 5) out-scaling WP values from watershed(s) to zones and to across the basin. The methodology should lead to multiple outputs as discussed previously, but by far the most important are the powerful maps of WP and other variables known to cause variations in WP across the basin. These other maps include the spatial variability in precipitation, temperature, soils, topography, and livelihoods and management. Maps of WP across the basin help identify the variability over the prevailing gradient of precipitation, temperature, soils, elevation, and slope in addition to the gradient of poverty and livelihoods. Comparison of these maps should provide valuable, yet holistic, information as to the probable causes of the variations in WP.

The above discussed methodology is in its infancy and should be further perfected and polished. Future work on this methodology will concentrate on practical applications of the methodology to a range of basins, starting with KRB, to gauge its usefulness and improve data gathering and computations.

Rainfed, irrigated, and a combination of the two are major agro-ecosystems across the Karkheh River Basin. These agro-ecosystems are the natural outcome of the prevailing aridity of the climate and the state and availability of the surface and groundwater resources. For instance, the rainfall is limited to below 250 mm in the irrigated lands, mostly located in the arid environments where rainfed production is not sustainable. The rainfed zone is dictated by lack of adequate surface and ground water for irrigation but significant winter and spring precipitation (> 250 mm) for sustainable dryland farming. Within the rainfed cropping areas, there are usually pockets of irrigated summer cropping, making up the mixed zone.

The future expansion of supplemental irrigation in the upper catchments can have various impacts on downstream water flow in the river. These impacts could be positive or negative depending on many factors. Higher water use upstream of the river may decrease flood risks downstream, depending on the river hydrological characteristics and its vulnerability to flooding. On the other hand, water withdrawal upstream, may decrease water supply downstream and bring about conflict of interest between farmers. Improved management of rainfed areas (such as replacing fallow with a crop) can decrease soil erosion and the sediment load that is filling up the reservoir of the Karkheh Dam. These and other similar potential impacts of the project should be carefully studied and the negative impacts minimized by adoption of appropriate policies regarding the extent and location of application of different technological options. The upstream/downstream interactions are an important research activity within the KRB project, particularly the impact of additional water use upstream by supplemental irrigation of winter crops and its impact on water resources at the dam This activity is currently led by a team of scientists from AERI in Iran and ICARDA, requiring extensive GIS and basin-wide flow routing and modeling.

In the lower basin of KRB, over irrigation or expansion of irrigated areas could lead to increased salinity in the southern sections of the basin. The extent of such risks needs to be evaluated and ameliorative measures taken before the problems worsen. Adjusting irrigation management in such a way that drainage water is minimized will help in lowering the risks downstream.

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CHAPTER II

Supplemental Irrigation in Iran

Ali Reza Tavakoli[1], Abdolmajid Liaghat[2], Shahram Ashrafi[3] and Fariborz Abbasi[3]

[1]Irrigation and Drainage Engr., Dryland Agricultural Research Sub-Institute, Agricultural Research and Education Organization (AREO), Ministry of Jihad-e Agriculture, Kermanshah, Iran
[2] University of Tehran, Irrigation Engineering Dept, Karaj, Iran
[3]Agricultural Engineering Research Institute (AERI), Karaj, Iran

INTRODUCTION

Rainfed agriculture covers large areas of land in Iran where wheat *(Tritium aestivum* L.) and barley (*Hordum vulgare* L.) are the major crops grown. Other rainfed crops are pulses, oilseed, tea (*Camellia sinensis* L.), citrus (*Citrus spp*.), vegetables, grapes (*Vitis* spp.) and figs (*Ficus carica* L.). It is most likely that high dependency on irrigated-agriculture would not be able to meet the food and feed demands in future. Nearly 10% of the country's total agricultural products are derived from rainfed agriculture. Areas under rainfed wheat and barley were 3.95 and 1.11 million ha in 1997-98 and 4.032 and 0.87 million ha in 2003-04, respectively (Tavakoli *et al*., 2005). According to the official documents published by the Ministry of Jihad-e-Agriculture, the total production of rainfed wheat and barley were 4.69 and 0.82 million tonnes in 2003-04 seasons (Tavakoli *et al*., 2005). Low and variable rainfall, high evaporation rates, long dry periods, relatively low soil fertility, poor seed quality and inappropriate agronomic practices applied by farmers contribute to low yields in the rainfed areas. Presently, the national average yield of wheat and barley under rainfed condition are 832 and 934 kg/ha respectively (Tavakoli *et al*., 2005). Rainfed wheat yield is about a quarter of that from irrigated fields, which is 3200 kg/ha.

Rainfall variability and unreliability of rainfall events prevent the farming community from larger investments into the production system. The prevailing high risk in rainfed agriculture need to be addressed given the increasing food demand for a burgeoning population. New ways and methods of production are needed to increase and stabilize crop production in these areas. Optimized supplemental irrigation techniques have shown promising results to overcome low level and unstable yield levels. This review highlights the major research findings regarding improving water productivity in the dry rainfed areas of Iran.

SUPPLEMENTAL IRRIGATION IN WANA

In the highlands of West Asia and North Africa (WANA) region, frost occurs between December and March, placing field crops in a dormant mode during that period. In most of the years, the first rainfall, necessary for seed germination, occurs after October resulting in poor crop establishment especially since frost occurs in December and stops plant growth. Therefore, rainfed yields are much lower compared to well established crops when crop growth takes off in early spring. Ensuring a good crop stand in December can be achieved by early sowing and applying a single irrigation in October. Single irrigation applied at early sowing dramatically increases wheat yield because plants which emerge earlier in the autumn grow more vigorously and yield much more in the following spring than plants which germinate late. A four-year trial, conducted at the central Anatolia plateau of Turkey, showed that applying 50mm of SI to early sowing wheat increased grain yields by more than 60%, adding more than 2 t/ha to the average rainfed yield of 3.2 t/ha (ICARDA, 2003). Water productivity (WP) reached 5.25 kg grain/m^3 of consumed water, with an average of 4.4 kg /m^3. The study also revealed that SI applied later in the spring and early summer further increased yield, but resulted in lower water productivity. Similar results were obtained in the highlands of Iran at Maragheh (Tavakoli and Oweis, 2004).

Water scarcity in WANA is a well-known and alarming problem because water in this region is the scarcest in the world and water-related issues have become extremely acute and even critical. Today, this problem is arisen the concern of national governments and research institutions. In WANA countries, agriculture accounts for over 75% of the total consumption of water. With rapid industrialization, urbanization and high population growth (up to 3.6% per annum), water is increasingly reallocated from agriculture to other sectors though the demand for more food and fiber continues to increase.

Two distinct environments may be identified along a transect within the dry areas of WANA. The first is the relatively wet zone, where winter rainfall is enough to support purely dry farming systems. Since rainfall amounts and its distribution in this zone are usually suboptimal, moisture stress periods often occur once or twice during crop growth causing very low crop yields.

Variation in rainfall amounts and distribution from one year to the other causes substantial fluctuations in production that can range from 0.3 to over 2.0 t/ha in the case of wheat. This situation creates instability which negatively affects household incomes. Small and scattered rainstorms in these regions fall on lands that are generally degraded with poor vegetative cover. These areas have been affected by overgrazing, and by removal of bushes for fuel wood, leading to desertification. Although rainfall is low when expressed in annual average, it constitutes a huge volume of ephemeral water over the entire season. While it forms a major water resource, it is lost almost completely through direct evaporation or through uncontrolled runoff. Therefore, agricultural productivity of rainwater in these areas is extremely low.

Most of the agricultural area of WANA is rainfed and a large proportion of the region's agricultural livelihood is based on Dryland farming systems. While irrigated areas may produce far higher yields and marketable surpluses, the overall value of Dryland production is much greater than its market value due to social and other indirect benefits associated with these systems. In the dry areas, water, not land, is the most limiting resource for improved agricultural production. Therefore, maximizing yield per unit of used water (water productivity), and not yield per unit of land is the suitable criterion to compare production systems or technologies. Agricultural productions and livelihoods in dry areas can be sustained, only if priority is given to improving water productivity and enhancing the efficiency of water procurement. In other words, more food, feed and fiber must be produced using less water.

Many technologies to improve water productivity and the management of scarce water resources are available. Among the most promising and efficient-proven technologies are: (i) supplemental irrigation (SI) for optimizing the use of the limited water available from renewable resources in rainfed areas, and (ii) water harvesting (WH) for improved farmer income in drier environment (Oweis and Hachum, 2003, 2004). Improving crop water productivity, however, refers not only to a more efficient use of water resources but also includes all other inputs such as improved germplasm, fertility and cultural practices.

The goal of supplementary irrigation is to provide enough water during critical growth stages to produce optimal yield per unit of water, not to provide stress-free conditions throughout the growing season with the aim of producing maximum yield (Oweis *et al*., 1999).

The foremost concern in arid and semiarid areas is availability and efficient use of water. In drylands in North America (Winhold *et al*., 1995; Campbell *et al*., 1993b; Music *et al*., 1994), the major constraint to wheat is low rainfall. Though crop yields under dryland conditions are related to seasonal rainfall, water use efficiency can be substantially improved by crop management practices (Cooper and Gregory, 1987; Keatinge *et al*., 1986; Haris *et al*., 1991) and fertilizer use (Harmsen, 1984; Keating *et al*., 1985; Ryan and Matar, 1992). Wheat production and water use efficiency under rainfed conditions are low and subject to substantial yearly fluctuation due to erratic rainfall and poor distribution (Simane, 1993).

Northern Iraq is a typical rainfed area in the West Asia region where most of the grains of the country are produced. In a rainfall zone (from 300 mm to 500 mm with non-uniform temporal and spatial distribution), huge investments in SI systems were put to overcome rainfall shortages. The results of studies conducted by ICARDA and Iraq showed that substantial improvement can be made in yield and WP by using SI in conjunction with proper production inputs and system management (Adary *et a*l., 2002). In the growing season of 1997-98 (annual rainfall 236 mm), rainfed wheat yield increased from 2.2 t/ha to 4.6 t/ha by applying 68 mm of irrigation water at the critical time. Applying 100 to 150 mm of SI in April and May achieved near maximum results. Early sowing (November) is the optimal sowing date for wheat in northern Iraq. Every week of delay in sowing may result in a grain yield loss of up to 0.5t/ha of wheat. Yield, increased significantly with increased levels of nitrogen fertilizer rates. Hence farmers were strongly advised to monitor the soil N content for economical and environmental reasons. As fertilizer N responses are directly related to rainfall under Dryland conditions (Ryan *et al*., 1991; Campbell *et al*., 1993a; Pala *et al*., 1996), N use should be correspondingly greater, when SI is also applied (Tavakkoli and Oweis, 2004, Tavakoli *et al*., 2005; Feiziasl, 1997; Belson, 1999; Oweis, 1997; Oweis et al., 1999; Ramig and Rhoades, 1963). However, the response of wheat to irrigation water is dependent on the cultivar (Fischer and Maurer, 1978; Sojka *et al*., 1981; Nachit *et al*., 1992). Thus, the potential yield in any environment depends not only on water and N (Aggarwal and Kalra, 1994), but also on the cultivars as well (Anderson, 1985; Guy *et al*., 1995). Another yield determining factor in drylands is the sowing date. Research in Australia's Mediterranean climate showed that delayed sowing after the optimum time, which coincides with the onset of seasonal rains, consistently reduced yields (O'Leary *et al*., 1985; French and Schultz, 1984; Batten and Khan, 1987). In Cyprus, agronomic research showed the importance of early sowing (i.e., in November) resulted in higher wheat production per unit area (Photiades and adjichristodoulou, 1984). In Iraq, during the 1997/98 season which was very dry, for every week delayed in sowing, there was a resultant grain yield reduction of 220 kg/ha for rainfed crops, and 520 kg/ha for crops under SI (Adary *et al*., 2002). One of the practical problems of SI is that all the fields may need irrigation at the same time in the spring. The result is a very high water supply and large irrigation system is required. A multi-sowing date strategy reduced the peak farm water demand rate by more than 20%, thus potentially allowing a reduction in the irrigation system size and cost (Oweis and Hachum, 2001).

At ICARDA several barley genotypes were supplemental irrigated to replenish 33, 66, and 100% of the deficit soil moisture in an area with total rainfall of 186 mm. The mean grain yield was 0.26 t/ha (rainfed); 1.89 t/ha (33% SI); 4.25 t/ha (66% SI); and 5.17 t/ha (100% SI). Among the genotypes, Rihane-3 produced the highest yield which was 0.22, 2.7, 4.75, and 6.72 t/ha respectively for the four SI treatments. These dramatic results under SI were obtained partly because of the drought during this season (ICARDA, 1989).

SI and single irrigation are the major methods used in low rainfall areas to ensure that crops receive enough water to produce an economic yield. While water harvesting is generally used in areas that receive between 100-300 mm of rainfall annually, SI is used in areas with a slightly greater annual rainfall of approximately 300-600mm (Oweis *et al*., 1999). Supplemental irrigation and single irrigation have been described as techniques used on crops that can be grown using rainfall alone, which applies a limited quantity of water during times of low rainfall to ensure that enough water is received to support crop growth and stabilize yields (Oweis *et al*., 1999; Perrier and Salinki 1987; Tavakoli and Oweis, 2004; Caliandro and Boari, 1992).

In contrast to conventional irrigation, the quantity of water applied by SI alone is not sufficient to ensure full crop growth under non-stressed conditions. Conversely, conventional irrigation supplies the entire water needs to the crop because rainwater may not provide sufficient water for plant growth for all or part of the season (Perrier and Salinki 1987). Conventional irrigation is used in regions where water is plentiful, while SI and single irrigation is often used in places where water is often scarce.

Timing of water application is one of the most important factors to be determined when using SI. Supplemental water applications are especially important when water is scarce during critical growth periods.

The water used for SI can be obtained from different sources. Groundwater, surface water, industrial wastewater, and water obtained through water harvesting methods are all used for SI. The water harvesting methods are often used in conjunction with SI since SI is often undertaken in low-rainfall areas. Important factors to be considered while designing a water harvesting system for SI include the storage capacity, the type of storage and storage location. Specific methods of irrigation used depend upon the resources available to the farmers in an area as well as any economic or labor costs that may be involved with setting up the SI system.

Potential benefits that can be achieved through the use of SI include increased yields, stabilization of yields across years, and creating conducive conditions for the use of high yielding varieties, herbicides and fertilizers (Oweis *et al*., 1999). Research at the ICARDA research station in northern Syria has shown that water use efficiency can be greater under SI than under rainfed agriculture. Under controlled conditions on-station, it was found that the application of one cubic meter of water at a time of water stress, combined with good management, increased water use efficiency more than twice over that of rainfed production (Oweis *et al*., 1999).

In the dry areas, water, not land, is the most limiting resource for improved agricultural production. Increasing water productivity, instead of yield per unit of land, is therefore a better strategy for dry farming systems. Under such conditions, more efficient water management techniques must be adopted. Supplemental irrigation and single irrigation are highly efficient practices with great potential for increasing agricultural production and improving livelihoods in the dry rainfed areas (Tavakoli and Oweis, 2004, 2006). 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.

In the drier environments, most of the rainwater is lost by evaporation; therefore the rainwater productivity is extremely low. Water harvesting can improve agriculture by directing and concentrating rainwater to the plants. It was found that over 50% of lost water can be recovered at very little costs.

Among agronomic practices, application of nitrogen, SI and early sowing of appropriate cultivars are widely recognized as a means of increasing wheat yield in the dry areas (Cooper *et al*., 1987; Siddique *et al*., 1990; Anderson and Smith, 1990; Oweis *et al*., 1998). The introduction of SI to winter cereals can potentially stabilize and increase yields, as well as increase the use efficiency of water received both from rainfall and from irrigation (Oweis *et al*., 1992; Tavakoli and Oweis, 2004; Tavakoli *et al*., 2005). In the rainfed regions of Iran, application of single irrigation at planting time and heading-flowering growth stage for winter cereals (wheat and barley) can increase yield from 500 to 2500 kg/ha and from 500 to 1000 kg/ha, respectively (Tavakoli, 2001; Tavakoli *et al*., 2000). Nitrogen deficiency, after drought, is the major constraint in dryland cereal farming (Campbell *et al*., 1993a; Tavakoli and Oweis, 2004). Within the Mediterranean areas, N deficiency is ubiquitous, being extensively reported from Morocco (Mossedaq and Smith, 1994; Ryan *et al*., 1992; Shroyer *et al*., 1990) to Syria (Anderson, 1985; Harmsen, 1984) and prevalent in many countries of the region (Ryan and Matar, 1992).

Water resource management strategies have become more integrated and current policies look at the whole set of technical, institutional, managerial, legal, social, and operational aspects required for development at all scales. Sustainability is a major objective of national policies. A sound strategy of an integrated approach for natural resources management in the drylands deals with water as the central issue and using it efficiently is accorded highest priority.

SUPPLEMENTAL IRRIGATION IN IRAN

Climate in Iran

Iran is bounded by the Caspian Sea, the Republic of Azarbaijan, the Republic of Armenia, and Turkmenistan in the north, the Persian Gulf in the south, Afghanistan in the east and Iraq in the west, and a few rivers along the northern, western and eastern borders. Iran is located between 25° to 45° Northern Latitude and between 44° to 64° Eastern Longitude. The country is situated in the arid to semi-arid belt of the world. It has an area of about 1.65 millions square kilometers within the West Asia region and has a population of about 69 millions (UNDP, 2004). The country's food production largely depends on irrigated agriculture particularly in the central plateau where the annual rainfall is usually below 150 mm. Due to sufficient rainfall the northern and western parts of the country produce rainfed cereals, orchard and other annual crops.

Generally, the dry climate of Iran is affected by various geological features. Most of the rivers in low precipitation areas (100-200 mm annual rainfall) receive water from snowfall on high mountains during winter. According to the National Water Plan (NWP), Iran is divided into eight climatic zones as follows:

- ***Very Arid***: This zone covers an area of 57.4 million ha (35.4% of the total area). It has very hot and dry climate with mean annual precipitation of 150 mm and annual potential evapotranspiration (ETO) between 2700 and 3000 mm prevail.
- ***Arid***: This zone covers an area of about 47 million ha (29% of the total area). It has a hot and dry summer climate, and warm (south) or cool (north) winter climate. Mean annual precipitation and annual ETO is estimated to be between 150-250 mm and between 2400-2700 mm, respectively.
- ***Semi-arid***: This zone covers an area of about 33 million ha (20% of the total area). It is hot in summer and cool in winter. Mean annual precipitation ranges between 250 and 350 mm and annual ETO varies between 2000 and 2400 mm.

- ***Mediterranean***: About 8 million ha (5% of the total area) falls in this zone. The climate of the zone is characterized as warm in summer and cool in winter with mean annual precipitation of 350-450 mm and annual ETo between 1700 and 2000 mm
- ***Semi-humid***: While warm in summer and cold in winter, this zone covers an area of about 5.5 million ha (3% of the total area). Mean annual precipitation and annual ETO for this zone varies from 450 to 550 mm and1400 to 1700 mm, respectively.
- ***Humid***: This zone is warm in summer and cool to cold in winter. Mean annual precipitation ranges from 550 to 700 mm and annual ETO ranges between 1200 and 1400 mm. It covers an area of about 6 million ha (4%)
- ***Very humid*** (type A): The climate of this zone is warm in summer and cool to cold in winter. Mean annual precipitation ranges from 700 to1000 mm and annual ETO varies between1000 and 1200 mm. It covers an area of about 5 million ha (3%)
- ***Very humid*** (type B): Warm climate in summer and very cold in winter at high altitudes. This zone receives mean annual precipitation of 1000-2000 mm and annual ETO occurs between 800 and 1000 mm. It covers an area of about 1 million ha (0.5% of the total area).

According to this classification, the main rainfed areas of Iran are located in the Semi-arid and the Mediterranean zones, with some relatively smaller areas in the Semi-humid parts.

Water Resources

The annual per capita share of renewable water resources in Iran is estimated to be 2015 m^3. Due to the geographical distribution of the water, many parts of the country experience different levels of water scarcity.

Rivers are the main sources of fresh water in Iran, in addition to hundreds of perennial and ephemeral streams. The main rivers include the Karun (890 km), Sefidrood (765 km) in the north, Karkheh (755 km) in southwest, Mond (685 km) in southeast, Qara-Chay (540 km) in north central, Atrak (535 km) in northeast, Dez (515 km) and Hendijan (488 km) in southwest, Jarahi (438 km) in southwest, and Zayandehrood (405 km) in the central.

The renewable water resources of the country, both surface and groundwater, were estimated to be about 130 km^3/year. The annual surface and groundwater flows were estimated to be at about 97 and 33 km^3/years, respectively. Drainage of aquifer contributes to about 5.4 km^3/year to the total annual surface runoff. These water resources depend on countrywide average annual rainfall of 25 2 mm; about the two-third of the country receives less than this amount in a normal year. More than 60 dams store a large part of the surface runoff. Recently constructed, Karkheh Dam with a reservoir capacity of about 7 km^3 is the largest among all these dams. Based on a policy of better utilization of surface water resources, another 70 or more dams are needed with a total capacity to store 19.6 km^3 of surface water resources. (Ghodratnama, 1998; Jamab Consulting Engineers, 1991).

Long-term average data show a groundwater recharge of about 50 km^3/year. An annual overdraft of about 5 km^3 has been reported for the entire country during last decade. Groundwater overuse in 150 plains of the country amounts to a total volume of about 4 km^3. This figure rose to 6.9 km^3 during 1998-2000 and about 11 km^3 during 2000-01, mostly due to drought.

However, not all of the renewable water resources are used. Presently, the total annual water uses are estimated to be about 88.5 km^3. Water use by different sectors varies from year to year, particularly due to annual variations in the available water. The agricultural sector demands more than 90%, while domestic (rural and urban areas) and industrial sectors utilize about 5.5% and 1%, respectively. Nearly 0.5% is used for fish ponds and for the control of the downstream water depth. It is important to note that the percentages indicated for the different sectors, particularly for agriculture, includes the water "used" for power generation and flood control. Domestic and industrial sector shares are expected to rise in the future due to population growth and economic development.

WATER PRODUCTIVITY (WP) CONCEPT

The productivity of applied water is defined as crop yield per unit volume of water use. Volume of water use refers to irrigation, rainfall or the summation of the two amounts. Rain water productivity (RWP) is the ratio of rainfed yield to total rainwater, irrigation water productivity (IWP) is the ratio of total yield to irrigation water use, gross irrigation water productivity (GIWP) is the ratio of increased yield to the gross depth of applied water and total water productivity (TWP) is the ratio of irrigated yield to total water supply (rain + irrigation), or simply:

$$RWP = \frac{Yield}{rain} \quad \text{.........(1)}$$

$$TWP = \frac{Yield}{irr. + rain} \quad \text{.........(2)}$$

$$IWP = \frac{Yield}{irr.water\ use} \quad \text{.........(3)}$$

$$GIWP = \frac{Yield_{irr} - Yield_{rainfed}}{irr} \quad \text{.........(4)}$$

PREVIOUS SUPPLEMENTAL IRRIGATION RESEARCH

A literature review of past research efforts indicates that the relation between rainfall amount and crop yield in dry-farmed zones of Iran has been a subject of interest since last decades. Mirnezami (1972) concluded that the rainfall is the most important factor limiting the yield of rainfed wheat in Iran. He stated that a threshold value of 295 mm of rain is necessary to achieve a satisfying yield level. In the same study, the correlation coefficient of the linear relationship between wheat yield and six different moisture indices were in the range of 0.928-0.981. Hashemi (1973) found a positive correlation coefficient of 0.78 between dryland wheat yield and the total annual rainfall in different parts of Iran, excluding the Caspian Coast and area with annual rainfalls greater than 600 mm. His analysis showed a lower and more variable yield response as rainfall approaches 400 mm. Bookers et al. (1975) prepared a country map showing the suitable areas for supplementary irrigation. However, they did not give the criteria used for such planning. ICARDA's initiative to identify the potential for SI in Iran and in the Near East including a workshop held in Rabat, Morocco, was a major milestone in presenting a concrete scientific output on this topic in the region (Perrier and Salkini, 1987).

Siadat (1987) carried out a countrywide survey and prepared a report on the potential of SI in Iran. The report cites several locations where farmers practice SI during years of below-normal precipitation. Only one irrigation to wheat and barley in almost all of such cases increased the grain yield by 50 to 100%. There are indications that this single irrigation increased the yield to a level higher than the average yield obtained in normal years. This may be due to the effect of timely irrigation in contrast to the precipitation in a normal year that may not fall in the right time. Another important finding of this survey was the fact that almost everywhere water for SI was taken from wells. This is noteworthy since SI is practiced in dry years, when the surface streams are limited or non-existent and the only reliable source of water would be the groundwater.

In the 1990's, interest in the research on SI started to grow and a series of experiments were designed and conducted in various regions of Iran by the staff of the Soil and Water Research Institute (SWRI) and, later, by the newly established Dry-land Agricultural Research Institute (DARI) (Moradmand, 1991; Naseri, 1993; Kalantari, 1993; Moradmand *et al*., 1994; Niazi and Javaheri, 1996; Sayadyan, 1997). Results of some earlier experiments in this series were mixed. In some years SI had little or no impact, and in other years the effects were significant. Also, some findings indicated that the location of a particular experiment was not suitable for rainfed production since the yields were very low without irrigation.

The relationship between the amount of precipitation (evapotranspiration and/or soil moisture status) and the yield of dryland wheat was studied. A final point to be discussed is the relation between ETa and crop yield. For the data obtained in Maragheh the relationship (R^2=0.74) was (Tavakoli *et al*., 2005):

$$Y = 0.0093ETa - 1.384 \quad (5)$$

The data points are those of the three study seasons averaged over five nitrogen rates. The coefficient of determination i.e. R^2, is reasonably high and it indicates that about three quarters of the variations in yield are associated with changes in ETa.

The relationship improves by omitting the result obtained for the rainfed treatment in 2001-02 season. This omission is justified because of the very long delay in rainfall after planting and its inadequacy during the first month after planting. According to the improved relationship, 84% of the variations in the yield can be described by the changes in ETa values. This is a rather strong relation that supports the application of SI in order to maintain crop transpiration when rainfall is inadequate.

Hashemi (1973) found a correlation coefficient of 0.78 for the positive linear of relationship between wheat yield and amount of precipitation in various parts of Iran except when rainfall exceeds 600 mm. In a study by Mirnezami (1972), the author concluded that precipitation was the most important limiting factor affecting yield of rainfed wheat. The linear relationship between wheat yield in these areas and six moisture levels considered in Mirnezami's study gave a correlation coefficient of 0.928-0.981.

An experiment carried out during 1983-87 at Tikmeh-Dash Research Station located in the northwest of Iran showed that SI of rainfed wheat at heading and grain formation stages results in an average yield of 1748 kg per ha of wheat. In the same experiment, one irrigation (single irrigation) applied at either of these stages resulted in a yield of 1500 kg/ha. Comparing these data with the average yield of dryland crops, which is below 1000 kg/ha, shows the potential for increasing yields with SI and single irrigation in same regions (Siadat, 1987).

Also, an experiment carried out during 1982-85 at Mahidash Research Station (near Mereck site, Karkhe River Basin Project) located in the west, showed that 2 irrigations applied at the heading and milk growth stages resulted in a 3 year average of about 2800 kg/ha, where average yield of rainfed crops in the area were 1200 kg/ha.

Results of such studies can be interpreted as showing the potential of increasing yields and the benefits that could be expected if single irrigation or SI are applied. Table 1 shows the results of SI in four districts including Miandorood, Agh-Ghola, Bala-Darband and Mahidasht (Siadat, 1987).

Table 1: Yield of wheat and barley under rainfed and supplemental irrigation (Siadat, 1987).

District	Grain yield (kg/ha)			
	Wheat		Barley	
	Rainfed	SI	Rainfed	SI
Miandorood	2500	3500	2750	3500
Agh-Ghola	1500	2500	1100	2000
Bala-Darband	1800	4000	2000	4000
Mahidasht	1200	1700	1800	2500

Miandorood district is located in the Mazandaran Province in the coastal area of the Caspian Sea. Agh-Ghola district is situated in the Golestan Province along the coast of the Caspian Sea and the east of Mazandaran. Bala-Darband district is northwest of Kermanshah situated in the west. Mahidasht district is located 10 km to the southwest of Kermanshah

Since mid 1990's, DARI has expanded its research activities on this topic. Experiments on SI and single irrigation became part of research activities of a number of research stations run by DARI in different parts of the rainfed zones of Iran. These experiments were designed based on climate data of DARI's stations at different parts of Iran (Mahmoodi, 1997-2005). Later, with the help of ICARDA's expertise, additional periments were conducted in some of the stations supervised by DARI.

Corresponding research activities investigating other crops under rainfed conditions have also shown significant results. Experimental data on tea production from 4-years water and fertilizer trials conducted by SWRI showed appreciable yield increases with SI. In 1970 and 1971, yields increased on average by 2179 kg/ha and 1593 kg/ha, respectively, as a result of four SI. Recent investigations of the effect of SI on rainfed cotton and soybean on the Caspian Coast also revealed significant yield responses. For soybeans, three SI applications, totally 95 mm of water use, resulted in an 80% increase in bean production when compared to yields received under rainfed conditions. In the case of cotton, a 145% increase in yield was obtained upon application of 212 mm of water applied in 5 supplemental irrigations (Siadat, 1987).

In Kermanshah province, the best treatment for rainfed wheat (Sardari cultivar) was found to be one single irrigation at heading to flowering stage (Sayadyan and Tallie, 2000). The increase of barley grain and straw yield by single irrigation was highly significance.

Results of an experiment at Ghachsaran Research Station in Kohkiloyeh & Boyerahmad province (southern Iran) showed that single irrigation applied to rainfed sunflower cultivars and just before flowering stage increased grain yields from 1.88 t/ha under rainfed conditions to 2.94 t/ha by single irrigation before flowering stage (Absalan, 2005).

Poordad (1996) reported from Kermanshah region significant grain yield increases due to the application of one single irrigation for different sunflower cultivars.

Flowering growth stage and early filling pod was the most critical time for rapeseed (canola) and single irrigation at these periods increased yield (Richards and Thurling, 1978; Rao and Mendham, 1991; Pasban-Eslam *et al*., 2000, Tavakoli, 2004b; Dehshiri *et al*., 2001) and the number of pod per square meter and the number of seed per pod (Clarke and Simpson, 1978; Mendham *et al*., 1984, Tavakoli, 2004b).

Food legumes are important crops in WANA, particularly for providing low- cost protein for people with low incomes. Rainfed yields are low for the same reasons outlined earlier for cereals. For chickpea, the final growth stages (pod initiation and seed development stage) is the most critical time and single irrigation at these periods increase grain yields as well (Tallie and Sayadyan, 2000; Kochaki and Banayan-Avval, 1993; MajnonHoseini, 1993). For Kermanshah condition, it has been reported that single irrigation at seed development stage had the highest effect on increasing grain yield (Tallie and Sayadyan, 2000) and irrigation water productivity was 5.9 kg/mm.

In a long term experiment from 1989 to 1996, carried out at Sharekord station located in the Charmahal & Bakhtiyari province (central of Iran), average grain yield of rainfed wheat with single irrigation at flowering stage, with double irrigations at flowering stage and filling stage and grown under rainfed condition was 1896, 2400 and 314 kg/ha, respectively (Moradmand, 1998).

An experiment carried out by Haghighati-Maleki (1998) at Maragheh Research Station located in the northwest of Iran showed that 50 mm single irrigation of rainfed barley at planting time increased to 500 kg/ha grain yield as compared with rainfed condition. This increase of barley grain yield by SI was highly significance.

An on-farm experiment carried out by Tallie (2005) at farmer's field of Kermanshah province, showed that single irrigation of rainfed improved barley variety (Sararood1) at early May (during heading to flowering stage) increased grain yield by 1204 kg/ha compared with rainfed condition. Irrigation water productivity was between 12 and 50 kg/mm.

An experiment carried out by Najib Mamendo (1993) at Sararood research station located in the Kermanshah province reported that a single irrigation at filling stage of rainfed wheat increase grain yield by 2460 kg/ha compared to rainfed condition. The same results were reported by Sayadyan and Sadjadi (1997).
Niazi and Javaheri (1996) carried out an experiment at two cold and warm climates of Fars Province and showed that the best treatment for rainfed wheat at cold region was one time irrigation (single irrigation) at heading stage and at warm region is SI at during stem elongation, heading and flowering stages. Fars province is located in the south of Iran.

An experiment carried out by Taoshih (2002) during 1995-98 at Ghamloo station located in the Kordestan province (west of Iran), reported that the single irrigation strategy in mid October improved the yield of rainfed wheat cultivar (Sabalan). In spite of variation in climatic conditions for every season, considerable increases of grain yield and thousand kernel weight of single irrigation at planting time showed preference relative to other treatments (rainfed and single irrigation at spring time). Single irrigation at planting time increased grain yield by 154% compared to rainfed condition.

In wet years, with sufficient rainfall (amount and distribution), SI at spring time (heading, flowering or filling stages) for wheat and barley did not have significant effects on increasing yield (Kalantary, 1993; Feiziasl, 1997; Feiziasl and Valizadeh, 2001). But Feiziasl (2003) reported substantial increase in wheat yield by one time irrigation at early sowing time.

Radaei and Hajiloei (1994) based on an experiment carried out at Hamedan Province showed that the increase grain yield of two wheat varieties (Sabalan and Sxl-Glenson) by one time irrigation at planting time (autumn) was significant. Hamedan province is located in central Iran.

An experiment carried out by Fardad and Golkar (2002) at Tehran University located in central Iran reported that the SI strategy allowed one to apply 35% less irrigation water and to increase 300% cropping areas.

Amount and distribution of precipitation can alter the effect of single irrigation and SI on the crop yield. Some reports showed that SI did not have significant effects on increasing grain yield, especially when rainfall came immediately after irrigation (Azari *et al*., 1994; Sayadyan, and Sadjadi, 1997; Kalantari, 1993; Moradmand, 1996; Najib Mamendo, 1993; Perrier and Salkini, 1987).

An experiment was carried out during two cropping seasons from 2002 to 2004 at DARI Maragheh research station to determine the response of rainfed wheat varieties to single irrigation and sowing date for Maragheh condition (DARI annual Reports of 2002-2003; Tavakoli, 2005). The experiment consisted of three sowing dates (early, normal and late), three SI treatments (I_0 = rainfed, I_1 = one irrigation of 50 mm and I_2 = one irrigation of 100 mm) and five advanced lines and cultivars of wheat. Irrigation water was measured and delivered by a polyethylene pipe to each plot, where it was applied through a perforated pipe held at the top of the canopy and moved along the basin. This method was adopted to increase uniformity of application. The timing of irrigation was based on the soil moisture content of 3 treatment. That is, whenever the available soil moisture content in the effective root zone in I3 dropped to 50%, all plots were irrigated. In Maragheh, soil moisture was measured several times during the season, using TRIME (TDR group). The rainwater productivity was between 3.08 to 4.32 kg/mm. Irrigation water productivity were between 7.18 and 23.94 kg/mm and total water productivity was between 3.63 and 8.52 kg/mm. The average wheat grain yield of two seasons under single irrigation (100 mm, early sowing), single irrigation (100 mm, normal sowing), single irrigation (50 mm, late sowing), and rainfed condition for Azar2 wheat variety were 3017, 3232, 2050 and 1404 kg/ha, respectively (Table 2).

A similar experiment was designed at the same location to determine the response of rainfed barley varieties to the single irrigation and sowing date for Maragheh condition. The study was carried out during 2004-05 season at Maragheh research stations (DARI annual Reports of 2004-05). The rainwater productivity (RWP) ranged between 2.77 and 3.04 kg/mm. Irrigation water productivity ranged between 16.56-31 kg/mm and total water productivity was between 5.2-8.1 kg/mm. The average grain yield of rainfed barley under different treatments (single irrigation 100 mm at planting time, early sowing), (100 mm, normal), (50 mm, late), (100% spring = 75 mm, normal), (50% spring =38 mm, normal) and rainfed condition for Yesevi-93 barley advanced line were 3268, 3614, 2139, 2348, 2197 and 1019 kg/ha, respectively (Table 3).

An experiment consisted of three SI treatments (I_0 = rainfed, I_1 = one irrigation of 50 mm at planting time and I_2 = one irrigation of 50 mm during heading - flowering stage) and five advanced lines and cultivars of wheat (V). The study was carried out during 1997-99 season at three research stations, namely, Maragheh, Sararood, and Haydarloo (Tavakoli *et al*., 2000; Tavakoli, 2001).The statistical design was randomized blocks with strip plots.

Table 2. Rainwater Productivity (RWP), total water productivity (TWP), irrigation water productivity and GIWP of two new rainfed varieties of bread wheat grains in northwest of Iran.

Year	Rain mm	Rainfed grain yield (kg/ha)	RWPa (kg/mm)	SI (mm)	Rain+SI (mm)	Irrigated yield (kg/ha)	TWPb (kg/mm)	GIWPc (kg/mm)
			V3 wheat variety (Turkey 13//F9.10/Maya"S")					
2003/04	416	1368	3.29	I1 (100mm)	516	3157	6012	17.89
				I2 (100mm)	516	3580	6.94	22.12
				I3 (50mm)	466	1727	3.71	7.18
2004/05	368	1591	4.32	I1 (100mm)	468	3381	7.24	17.9
				I2 (100mm)	468	3985	8.52	23.94
				I3 (50mm)	418	2308	5.52	14.34
			Azar2 wheat variety					
2003/04	416	1280	3.08	I1 (100mm)	516	2995	5.8	17.15
				I2 (100mm)	516	3031	5.87	17.51
				I3 (50mm)	466	1692	3.63	8.24
2004/05	368	1528	4.15	I1 (100mm)	468	3040	6.5	15.12
				I2 (100mm)	468	3433	7.34	19.05
				I3 (50mm)	418	2407	5.76	17.58

I1: Early sowing date + 100mm single irrigation at planting time
I2: Normal sowing date + 100mm single irrigation at planting time
I3: Late sowing date + 50mm single irrigation at planting timea RWP is the ratio of rainfed yield to rainwater
b TWP is the ratio of irrigated yield to total water supply (rain + SI)
c GIWP is taken as the ratio of increased yield to the gross depth of SI water

Table 3. Rainwater Productivity (RWP), total water productivity (TWP), irrigation water productivity and GIWP of two new rainfed varieties of barley grains in northwest of Iran

Barley variety	Rain mm	Rainfed grain yield (kg/mm)	RWPa (kg/mm)	SI (mm)	Rain+SI (mm)	Irrigated yield (kg/ha)	TWPb (kg/ha)	GIWPcb (kg/mm)
Yesevi-93	368	1019	2.77	I1 (100mm)	468	3268	6.98	22.49
				I2 (100mm)	468	3614	7.72	25.95
				I3 (50mm)	418	2139	5.12	22.4
				I4 (75mm)	443	2348	5.30	17.72
				I5 (38mm)	406	2197	5.41	31.0
Dayton		1117	3.04	I1 (100mm)	468	3249	6.94	21.32
				I2 (100mm)	468	3803	8.13	26.90
				I3 (50mm)	418	2158	5.16	20.82
				I4 (75mm)	443	2359	5.33	16.56
				I5 (38mm)	406	2226	5.48	29.18

I1: Early sowing date + 100mm single irrigation at planting time
I2: Normal sowing date + 100mm single irrigation at planting time
I3: Late sowing date + 50mm single irrigation at planting time
I4: Normal sowing date + 75 mm single irrigation at during heading - flowering stage
I5: Normal sowing date + 38 mm single irrigation at during heading - flowering stage
a RWP is the ratio of rainfed yield to rainwater
b TWP is the ratio of irrigated yield to total water supply (rain + SI)
c GIWP is the ratio of increased yield to the gross depth of SI water.

Irrigation water was applied through a sprinkler system with adjustable angle. One sprinkler was installed at each corner of the irrigated plots. The 50 mm irrigation was applied after planting (I_1) and 50 mm irrigation at flowering stage (I_2). Results of the experiment are summarized in table 4. A general reduction in the yield of all treatments is evident during the second season. This is mainly a consequence of the drought situation in that year, which inflicted a lot of damages to crop production in many parts of the country, particularly in the rainfed areas. According to the table, at least one of the two supplemental irrigations led to appreciable yield increase in all cases. Average yield increases due to SI during these two seasons in different locations were as follows: in Maragheh, 53-63%, in Sararood, 8-66%, and in Heydarloo, 13-46%.

Timing of a single SI is also important and it seems to be site specific. Supplemental irrigation, single irrigation and their timing are effective on water use efficiency (WUE) and water productivity (WP). In Maragheh, WUE in both years was significantly higher for irrigation at planting than at flowering or the rainfed treatment. At the other two stations, however, the best results were obtained with irrigation at flowering time.

An experiment was designed at Maragheh, Sararood, and Haydarloo research stations in 1999-2000 to determine the response of wheat cultivars to various levels of SI and nitrogen application (Tavakoli *et al*., 2003). Levelled and suitable land for basin construction to cultivate locally popular cultivars of wheat at each station was used. The SI treatments included control (I_0, no irrigation), I_1 (1/3 of full irrigation), I_2 (2/3 of full irrigation) and I_3 (full irrigation). Five nitrogen application levels were exercised for each trial, which included N_0 (no nitrogen application), N_{30} (Nitrogen application of 30 kg/ha), N_{60} (Nitrogen application of 60 kg/ha) N_{90} (Nitrogen application of 90 kg/ha), and N_{120} (Nitrogen application of 120 kg/ha). The source of nitrogen was urea which was added to all treatments two times: half at planting time and the rest in spring. The experimental design was RCBD with split-plots and three replications. The number of irrigations varied between two to four in different seasons. In the first irrigation in fall, an equal amount of water (between 30 to 40 mm in different cases) was applied to all irrigated plots. For the rest of the growing seasons, the amounts of water applied in each irrigation to the I_1 and I_2 treatments were 33% and 66%, respectively of that applied to the fully irrigated treatment of I_3. Observations such as grain, straw and biological yields, harvest index, productivity degree, plant height, kernel number per spike, spike number per square meter and thousand kernel weights were measured. Yields of rainfed conditions varied with seasonal rainfall and its distribution, with all main factors having significant effects.

Table 4: Average grain yield of some advanced wheat lines under different single irrigation treatments (kg.ha-1), during 1997-99.

Station	Season	Average of all varieties			Average of all irrigation treatments				
		I_0	I_1	I_2	V_1	V_2	V_3	V_4	V_5
Maragheh	1997-98	1491	2428	1670	1859	1811	2053	-	1729
	1998-99	992	1515	1217	1258	1188	1427	-	1092
Sararood	1997-98	2511	2589	2716	2697	2577	2517	2714	2523
	1998-99	882	1071	1463	1011	1216	1497	1101	869
Haydarloo	1997-98	2133	2613	3112	2150	2578	2795	2741	2832
	1998-99	1205	1348	1357	1201	1432	1241	1490	1151

I_0 = No irrigation; I_1 = One irrigation of 50 mm at planting; I_2 = One irrigation of 50 mm at flowering

Results of path analysis for rainfed wheat showed that increase in grain yield was due to increased seed numbers per spike, height and straw yield, respectively. Optimum level of SI for Sabalan was 1/3 of full SI 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, a maximum net benefit was obtained along with probability of 180% cropping area increase, which led to 74% increase in total grain yield. Limit of benefit ability for optimum level of SI was determined as 2857 Rial/m^3 water. Results of path analysis for irrigated wheat showed that increase in grain yield was resulted from increase of spike/m^2, seed number per spike and straw yield, respectively (Tavakoli, 2003, 2004a).

Positive impacts of SI on the yield of rainfed wheat are generally evident in the data, although the results of first year experiment at Sararood were not statistically different. The highest yield increases due to SI in different seasons/stations were mostly in the range of 1 to 3 tons per hectare. In all cases, full irrigation treatment (I_3) resulted maximum yield. In the first year at Maragheh, I_2 followed that treatment in the same statistical group with I_1, but, it was in a higher group than I_1 in the second year. Probably, the lower rainfall of the second season in that station led to a more clear distinction between the treatments. Such results indicated that yield response to SI was dynamic and dependent on a number of environmental factors including rainfall.

The main effects of nitrogen were significant in all cases, except in the 2001-02 season in Sararood. The data obtained in Maragheh suggested that the application of 60 to 90 kg.N/ha was the best recommendation when higher amounts of water were applied. Application of N_{60} resulted in the maximum yield or its yield was in the same statistical group with the treatment yielding the highest. It is noteworthy that higher rates of nitrogen, particularly N_{120}, decreased yield or produced similar result as the lower rates. In Maragheh, application of all nitrogen rates in the non-irrigated (I_0) treatment decreased yield to the levels below the control. On the other hand, at higher water application rates, wheat yields increased in response to nitrogen use. Similar trend in the response of wheat to N-fertilizer and SI are reported for Syria (Oweis, 1997). In Sararood, however, lower rates of nitrogen application may be favored since N_{30} treatment in combination with I_3 or I_2 resulted in the maximum yield in two of the three experimental seasons. This is probably due to higher organic carbon content of the soils in Sararood compared with Maragheh. Generally, these results are site-specific, but they clearly emphasize the need for adjusting nitrogen application rates to the seasonal availability of water in the root zone.

The interactions of N x SI were highly significant at Maragheh in the three years of study. Here, the full irrigation (I_3) in combination with N_{90} gave the maximum yield of 3233, 4537, and 5204 kg/ha, respectively for the first to the third study season. Similar results were obtained for I_3 at Sararood, though not statistically significant result was found in the first two seasons.

However, in the first season I_3 yielded a maximum of 3861 kg/ha in combination with N_{30}, which was nearly 1 tonne higher than the corresponding rainfed treatment i.e. I_0N_{30}. Results for the third year at Sararood were highly significant, with I_2N_{30} giving the maximum grain yield of 4446 kg/ha. At both stations, the minimum yield was always obtained for the non-irrigated (I_0) treatment mostly in combination with N_{120}, and once with each of N_0 and N_{60} treatments. Thus, it becomes apparent that when precipitation falls short of the average and a relatively dry season prevails in these areas, use of N-fertilizer is not advisable.

In order to investigate the effects of single irrigation amounts at different stages of rapeseed on yield increase and its stabilization, a field experiment was conducted at Maragheh agricultural research station of DARI, during 2002-03 on rainfed spring rapeseed variety (PF.7015.91). This experiment was conducted as split plot arranged in a randomized complete block design (RCBD) with three replications. The treatments included four levels of single irrigation amounts (Rainfed, 30, 60 and 90 mm of water use) at growth stages (stem elongation, flowering and filling stage). The observations included parameters such as WUE, WP, grain, straw and biological yield, harvest index, plant height, and thousand kernel weight. The analysis of variance indicated that, there were significant effects due to the single irrigation amounts, growth stages and their interactions. There were positive significant correlations due to grain yield with all variables.
Spring rapeseed grain yields increased under single irrigation amounts in northwest of Iran, with application of limited amounts of SI (90, 60, and 30 mm) at different growth stages (stem elongation, flowering and filling stage), when compared with rainfed condition. Rainfall is the major water source for rainfed crop growth and production, thus the amount of water added by SI can by itself support economical crop production. Results showed that optimum level of single irrigation for rapeseed was 60 mm water use at flowering stage which produced 1071 kg grain per hectare.

The WP_{I+P} (I stand for irrigation and p for precipitation) and WPI for this treatment were 4.79 and 8.09 kg/mm respectively. The water use efficiency increased from 2.0 (rainfed) to 2.46 kg/mm-ETa (60mm single irrigation). Scenario analysis of total productivity of applied water under single irrigation amounts at different growth stages of spring rapeseed showed that, 60 mm single irrigation at flowering stage had maximum amount of water productivity (4.28 kg/mm). In addition to yield increases, SI also stabilized wheat production. The coefficient of variation was reduced from 100% to 20% in rainfed fields that adopted SI.

Strategically, SI can be exercised in one of the following methods:

- Applying one or more irrigations at the specific stages of crop growth during soil-moisture stressed period.
- Application of deficit irrigation at the time when soil-moisture stress occurs.

Considering the limited availability of water resources in the dry areas, application of a small amount of water as deficit irrigation could provide a chance for crop to survive and maintain modest growth until it receives rainfall or irrigation.

The potential areas of single irrigation in Iran include western parts (Central Zagros Valleys), northwestern provinces (West and East Azarbaijan Provinces), and the Caspian Coast in the north. Besides these areas that constitute the main zones of rainfed agriculture, some other relatively smaller areas and sub-zones, such as rainfed areas in Fars and Khorasan provinces that have similar agro-climatic conditions, are also suitable for SI.

In addition to wheat and barley as main rainfed crops, pulses, oilseed, tea, citrus, vegetables, grapes and figs are also grown under rainfed conditions in various parts of the country. Single irrigation and SI in Iran can be beneficial for raising diversified crops of high market values.

It can be concluded that the supplemental and single irrigation increased yields, water productivity indices, water use efficiency and stability of crop production during different climatic conditions, but these increases depend on factors such as seasonal precipitation, rainfall distribution (especially at two critical stages; sowing date and heading-flowering stage), type of crop, type of soil, agronomic practices including seed rate, fertilizer (amount, source and timing use), machinery, weed, pest and disease control and environmental conditions of the specific area.

Optimization of Supplemental Irrigation

Optimal SI in rainfed areas is based on the following three basic aspects (Oweis, 1997):

- Water is applied to a rainfed crop that would normally produce some yield without irrigation.
- Since rainfall is the principal source of water for rainfed crops, SI is only applied when rainfall fails to provide essential moisture for improved and stable production.
- The amount and timing of SI are scheduled not to provide moisture-stress-free conditions throughout the growing season, but to ensure a minimum amount of water available during the critical stages of crop growth that would permit optimal instead of maximum yield.

Increase in crop production per unit land or per unit water doesn't necessarily increase farm profit because of the non-linearity of crop yield with production inputs, particularly with water and its interactions with other input factors. Following English et al. (1990) and English and Raja (1996) analysis, ten years of SI data (1985 to 1996) on bread and durum wheat were analyzed to evaluate water-yield relations and to develop optimal irrigation schedules for various rainfall conditions (Zhang and Oweis, 1999). Quadratic crop production functions with the total applied water (rain+SI) were developed and used to estimate the levels of SI water for maximizing yield, net profit and levels to which the crops could be under-irrigated without reducing income below that which would be earned for full SI under limited water resources. The study concluded that SI scenarios maximizing the profit under limited water resources conditions or for a targeted grain yield of 4 to 5 t/ha should be recommended for sustainable utilization of water resources and higher WP.

ICARDA has developed methodologies to help farmers determine the right SI management. Determining rainfed and SI production functions is the basis for optimal economical WP. SI production functions for wheat are developed for each rainfall zone by subtracting the rainwater production function from the total water (SI + rain) production function. Since rainfall amount cannot be controlled, the objective is to determine the optimal amount of SI that results in maximum net benefit to the farmers. Knowing the cost of irrigation water and the expected price for a unit of the product, maximum profit occurs when the marginal product for water equals the price ratio of water to the product.

One of the practical problems of SI is that all the fields may need irrigation at the same time in spring. As a result, a very high water supply and large irrigation system is required. A multi-sowing date strategy reduced the peak farm water demand rate by more than 20%, thus potentially allowing a reduction in the irrigation system size and cost (Oweis and Hachum, 2001). Also, the water demand of a larger area can be met with the same water supply. However, optimal sowing dates that minimize farm water demand do not always maximize total farm production and/or water productivity. The outcome depends on the crop water requirements and yield for each sowing date. Furthermore, selection of the optimal strategy is greatly influenced by the level of water scarcity.

CONCLUSIONS

Literature review revealed that the following points could be helpful in assessing the potentials of using SI and single irrigation in Iran:

- Supplemental irrigation and single irrigation aims at stabilizing yield and preventing (and or) minimizing risks due to temporal variability of rainfall. It is a compensatory action practiced when rainfall was less than the long-term average for a period of time long enough to threaten economical reduction in rainfed crop production.
- More than 90% of the country's average annual rain falls during October to April. About one-third of the time during 32 years, the rainfalls below the average value of the record. It is generally believed that the country is prone to a drought once in 5 to 7 years. Supplemental irrigation could help to save great losses of the yield at this time particularly, and to improve the yield during average rainfall years.

- Iran has many microclimates. This means that the countrywide average rainfall may not necessarily reflect the local conditions in a particular rainfed area. As such, even in a year judged as "normal" on the basis of countrywide average, certain rainfed regions may be suffering from inadequate precipitation. Therefore, the situations suitable for application of SI are more frequent than what the countrywide average rainfalls may indicate.

Rainfall in WANA rainfed areas, especially in the dominant Mediterranean-type climate, is characterized by low annual amount, unfavorable distribution over the growing season and large year-to-year fluctuations.

In Maragheh, a major Dryland farming area in North West of Iran, the annual rainfall ranges from 202 mm to 504 mm with an overall average of 343 mm. Rainfall occurs mainly during the winter months (December- February) and early spring (March, April and part of May), so that crops must often rely on stored soil moisture when they are growing most rapidly during May and June. In the wet months, stored water is ample, plants sown at the beginning of the season (October) are in their early growth stages, and water extraction rate from the root zone is limited. Usually little or no moisture stress occurs during this period. However, during spring, plants grow faster with high evapo-transpiration rate and rapid soil moisture depletion due to higher evaporative demand conditions. Thus, a stage of increasing moisture stress starts in the spring and continues until the end of the season.

Shortage of soil moisture in the dry rainfed areas occurs during the most sensitive growth stages (flowering and grain filling) of cereal and legume crops. As a result, rainfed crop growth is poor and yield is consequently low. The mean grain yield of rainfed wheat in WANA is about one tonne per hectare, but ranges from 0.5 to 2.0 tonnes ha^{-1} depending on the precipitation amount and distribution, and on agronomic factors such as soil fertility and crop variety. These yield levels are far below the yield potential of wheat (over 4 to 5 tonnes/ha). Supplemental irrigation using a limited amount of water, if applied during critical crop growth stages, result in substantial improvement in yield and water productivity.

Research results from the Dryland Agricultural Research Institute (DARI) and others, as well as harvest from research stations and farmer's fields, showed substantial increases in crop yield in response to the application of relatively small amounts of single and SI water. This increase covers areas with low as well as high annual rainfall.
Furthermore, using irrigation water conjunctively with rain was found to produce more wheat per unit of water than if used alone in fully irrigated areas, where rainfall is neg-

ligible. In fully irrigated areas water productivity in producing wheat ranges from 0.5 to about 0.75 kg/m^3, one third of that achieved with SI. This difference suggests that allocation of limited water resources should be shifted to the more efficient practice (Oweis, 1997).

In water-scarce areas, water, not land, is the primary limiting factor to improved agricultural production. Accordingly, maximizing yield per unit of water, not per unit area, is a more viable objective for on-farm water management in the dry farming systems. Improving water productivity in water-scarce areas requires a change in the way agriculture is practiced. Conventional guidelines designed to maximize yield per unit area need to be revised with a view to achieving maximum water productivity. Appropriate policies related to farmer participation and water cost recovery are needed to prompt the adoption of improved management options.

Supplemental irrigation and single irrigation are options with great potential for increasing water productivity in rainfed areas. Scarce water presently used for complete irrigation could be reallocated to supplement rainfed crops for improved water productivity. However, to maximize the benefits of SI, other inputs and cultural practices should also be optimized.

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CHAPTER III

Overview of Crop Water Productivity in Irrigated Agriculture in Lower Karkheh River Basin

Hossein Dehghanisanij[1] and Mansour Moayeri[2]

[1]Assistant Professor, Irrigation and Drainage Department, Agricultural Engineering Research Institute (AERI), Karaj, Iran

[2]Irrigation and Drainage Department, AREI, Safi Abad Research Station, Dezful, Iran

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, 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 use of water in agriculture.

Since in many parts of the world water, not land or other factors, is the most limiting resources 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 rather through increased crop yields due to better varieties and the use of mineral fertilizers. Iran is situated in one of the most arid regions of the world with an average annual precipitation of about 250 mm, which is less than a 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). Agricultural sector is the main water user in the country. The irrigated agricultural area in Iran comprises about 8.4 million ha and presently is using 85.2 billion m^3 (92%) of total water use (92.5 billion m^3). Since the possibility to increase the water resources for the agricultural sector in arid and semi-arid regions like Iran is limited, improvement of the agricultural water productivity might be a more realistic strategy. Karkheh river basin (KRB) is one of the most important agricultural zones of Iran located in the south west of Iran. The objectives of this paper are to provide information on the current use of water resources and its productivity in irrigated areas of lower KRB, and to assess past research efforts and research needs related to the WP in lower KRB.

Crop water productivity (WP) is defined as the crop yield/production (Y) per unit of water consumption, comprising both 'green' water (effective rainfall) for rain-fed areas and both 'green' water and 'blue' water (diverted water from water systems) for irrigated areas. De Wit (1958) was among the first to do this and he expressed the water use efficiency in kilogram crop production per cubic-meter of water transpired. The definition of WP is scale- and user-dependent. Molden (1997) introduced the broader term water productivity, for analysis of water use at different aggregation levels. Molden *et al*. (2003) refer to this problem as "which crop and which drop". As the numerator, total dry or fresh biomass or harvested product can be used, expressed in physical (kg) or economic terms ($). As the denominator, there are numerous options such as WC which refer to diversion or consumption of irrigation water, such as deficit water applied (DI), ETc, water diverted (WD), beneficial water consumption (BWC) and/or non-beneficial water consumption (NBWC). Accordingly;

$$WP_1 = Y / DI \quad (1)$$

$$WP_2 = Y / ETc \quad (2)$$

$$WP_3 = Y / BWC \quad (3)$$

$$WP_4 = Y / (BWC + NBWC) \quad (4)$$

$$WP_5 = Y / WD \quad (5)$$

The values of the water productivity change based on the hydrological domain at the denominator. Herein, the WP value decreases in the sequence WP_1 to WP_5, which could be explained through different forms of technical efficiency. Under deficit irrigation (WP_1) it has been assumed that all applied water (irrigation and/or rainfall) is used as evapo-transpiration (Hexem and Heady, 1978). The WP_2 is related to farm irrigation efficiency (FIE), which is based on the hydrological domain and could be related to the water conveyance efficiency (Burman *et al*., 1981) and to the unit irrigation efficiency (Burman *et al*., 1981). Farm irrigation efficiency (FIE) is water diversion divided by irrigation requirements or crop evapo-transpiration (ETc) minus effective rainfall (Molden *et al*., 1998 ; Burman *et al*., 1981).

$$FIE = WD / (ETc - Rn) \quad (6)$$

then;

$$WP_2 = Y / [(WD / FIE) - Rn] \quad (7)$$

The WP_3 is related to the irrigation efficiency (IE), the volume of irrigation water beneficially used divided by the volume of irrigation water applied (Burt *et al*., 1997);

$$IE = BWC / WD \quad (8)$$

then;

$$WP_3 = Y / (IE \times WD) \quad (9)$$

and WP_4 is related to the irrigation consumptive use coefficient (Burt *et al*., 1997). The irrigation consumptive use coefficient (ICUC) is the volume of irrigation water consumed divided by the volume of irrigation water applied.

$$ICUC = (BWC + NBWC) / WD \quad (10)$$

then;

$$WP_4 = Y / (ICUC \times WD) \quad (11)$$

The pertinence of one or another concept of WP depends on the hydrological domain such as crop, field, irrigation unit, basin (Playan and Mateos, 2005). The WP_1, WP_2 and WP_3 could be applied at any scale. However, they are more meaningful at the field or crop level since they are related mainly to agronomic aspects of the crops related to transpiration. If the water that is used is not completely consumed within an irrigation unit and the remaining amount cannot be reused within the domain (e.g. evaporation, flow leaving the domain), then WP_5 is pertinent. However, if water is not consumed upstream but reused downstream in the same domain, then WP_4 is more appropriate. Several strategies could be applied for enhancement of crop WP by integrating improved crop varieties and better resources management at different hydrological domains.

WATER AND LAND RESOURCE AND PRODUCTIVITY

In Karkheh river basin (KRB), two major agricultural production systems prevail: rainfed agriculture in the upper basin of the newly built Karkheh reservoir, and fully irrigated systems in the lower parts of the basin. The rainfed areas are well established and cover most of the agricultural land in the upper basin, while in the lower basin, where irrigated areas were limited before

Table 5: Cultivated area, cropping pattern, and average yield for the main crops in irrigated agriculture of KRB (Keshavarz *et al.*, 2005).

Crops	Cultivated area (ha)	% of total cultivated area	yield (kg ha^{-1})	Total Yield (ton)
Cereals (wheat, barely and maize)	236700	63.8	2308	546304
Rice	3900	1.1	2686	10475
Forage crops	37500	10.1	9136	342600
Pulses	16000	4.3	1151	18416
Oil seeds	3700	1.0	1229	4547
Vegetables	39100	10.5	18019	704543
Potato	1100	0.3	15755	17331
Orchards	26100	7.0	6674	174191
Sugar beet	2600	0.7	30065	78169
Industrial crops	300	0.1	1703	511
Others	4100	1.1	1088	4461
Total	371100	100	-	1901548

the building of the Karkheh dam, there are now many irrigated fields and plans for their expansion are underway. Out of the total area of KRB (5.2 million ha), only 1.07 million ha are suitable for irrigation and 0.9 million ha are used for dry farming.

The most important crops in the irrigated area of lower KRB are cereals, forage crops, rice, vegetables, and sugar beet (Table 5). Vegetables are grown as off-season crops and it includes onion, melon, tomato, and cucumber.

The downstream part of the basin stretches from the Karkheh dam in the north more than 100 km southward, where the Karkheh River discharges into the marshlands of Hoor-al-Azim. A number of sub-basins in the command area, including Dasht Abbas, Evan, Dusaif, Ardyez, and Bageh, as well as some on the lower plain, are planned for over 300,000 hectares expansion of irrigation systems including a new irrigation and drainage network. Agriculture in the downstream is dominantly irrigated (now about 111,000 ha), with annual rainfall ranging from 300 mm in the north to 100 mm in the south. Soils are mostly young river deposits of fine texture with little profile development and medium to low infiltration rates. Salinity of topsoil fluctuates during the season and generally increases towards the south. The river water quality is suitable for irrigation, though it varies both seasonally and along the river, reaching an EC of about 3 dS m^{-1} near the outlet. The area is suitable for growing a wide range of crops. Presently, wheat, maize, alfalfa, and off-season vegetables are the most popular crops.

The agricultural water resources in KRB consist of both surface and ground water. Out of the total 24.9 billion m^3 annual rainfall in KRB, about 16.4 billion m^3 (65.8%) directly evaporate, 5.1 billion m^3 (20.5%) is surface water and 3.4 billion m^3 (13.7%) infiltrate to aquifers. On the average, the total volume of water used by irrigated agriculture from available water resources is more than 3.915 billion m^3 of which 36.68% originate from underground and 63.54% from surface water resources. Karkheh River Basin (KRB) is a relatively water scarce area and droughts are becoming a frequent feature of this region. The irrigation efficiency in KRB is low and the land and water resources are at the risk of quality degradation. Irrigation efficiency of traditional networks (southern KRB) ranges between 14-23%

(Mirabolghasemi, 1994) in Dasht Azadegan. The neighboring basin of the Dez River has higher efficiency rates of 32-37% with consolidated fields of modern networks (Fatemi *et al*., 1994). Irrigation efficiency is different between the plains and the sub-basins of KRB. It is usually higher where water is taken from underground resources. The large amount of water losses during conveyance and field application has greatly aggravated resource degradation causing salinity in the downstream sub-basins and lowland areas. Obviously, with the present management practices, such threats will expand in the future with more severe impacts.

Water productivity in KRB is also very low with 0.54 kg m^{-3} (based on the total irrigation water annually used for irrigated agriculture, 3.915 billion m^{-3}, and production of 2.1 million tonnes,), not only compared to potential WP but also to that of other river basins in Iran.

Safi Abad Research Station

Safi Abad Experimental Station near Dezful is close to the KRB and is the only research station suitable for conducting studies related to the irrigated agriculture in lower KRB. Safi Abad research station is located at 32° 16' N and 48° 26' E. It spreads over 500 ha and was established in 1963. In 1985, this station was equipped with a meteorological station to measure climatic data.

Dezful region has a semiarid climate (Nazemosadat, 1998). The temperature in this region range between 6.7 and 45.6°C and humidity from 27.4 to 74.5%. The rainy season usually starts in October and continues until the middle of May. The average annual rainfall is about 330 mm. The annual potential evaporation (Keshavarz and Ashrafi, 2004) is about 2400 mm, ranging between 50 mm $month^{-1}$ during December and January and 400 mm $month^{-1}$ during June and July. Water used at this station originates from the Dez irrigation network that has a very suitable quality for irrigation, with EC of about 0.4 dS m^{-1} and and pH 7.6. The Dezful research station has a uniform soil type with clay-loam texture at 0-60 cm and silty-clay-loam at 60 120 cm depth. The pH of the soil ranges between 7.5 and 7.9 from the soil surface to 80 cm depth, where EC varies between 0.57 and 1.1 dS m^{-1}.

Research at Safi Abad Station

Research activities related to soil and water issues in the Dezful region started in Safi Abad station in 1962, when the station was established. Besides its mandate for agricultural research for irrigated areas in lower KRB, the Dezful search station synthesized research outputs from other research stations with similar climatic conditions and transferred it to the farmers through local extension organizations. During the last decade, research activities related to improvement of water productivity have been mainly on the following topics:

- Evaluation of irrigation efficiency,
- Improvement of different surface irrigation management,
- Adaptation and evaluation of modernized irrigation systems,
- Improvement of land preparation,
- Applying deficit irrigation under different irrigation systems.

In the following sections, the research activities directly or indirectly related to assessment and improvement of wheat, maize and sugar beet water productivity are reviewed and discussed.

Wheat, Maize and Sugar Beet Water Productivity in Dezful

In northern parts of lower KRB, wheat and barley are usually sown around the middle of November. Wheat is harvested during the middle of May, while barley comes to harvest 2 to 3 weeks earlier than wheat.

Based on the Penman-Monteith model (Allen, 1998), the wheat and barley irrigation water requirement in Dezful region is about 592 mm. Based on climatic data of twenty years, the effective rainfall for wheat and barely growing season is about 283 mm. Therefore, 48% of the wheat and barely net water requirement is provided by rainfall, while the rest must be supplied by irrigation. Furrow and border irrigation systems are two conventional surface irrigation systems in Dezful region. Moayeri and Lotfian (2004) showed that wheat yields under these two irrigation systems were not significantly different. However, wheat water productivity under furrow irrigation (0.75 kg m^{-3}) was 22% higher than that under border irrigation (0.61 kg m^{-3}). In addition, the yield was significantly lower when seeds broadcasted compared to seeds broadcasting plus corrugating (Moayeri and Lotfian, 2004). There was no significant yield difference between seeding rate of 300, 400 and 500 kg ha^{-1}.

However, wheat yield was significantly lower when seeding rate was 200 kg ha^{-1}. There are two growing seasons for maize in Dezful. For the first season, sowing is in early July and harvesting is in early November. The net maize water requirement is about 705 mm during this season and the effective rainfall is about 40 mm (Keshavarz *et al*., 2000). For the second season, the planting date is mid January and the crop is harvested in early April. During this season, total net maize water requirement is about 461 mm, of which about 116 mm is supplied by effective rainfall.

For maize cultivated in second season showed that there was no significant difference between maize water productivity when irrigation water was applied at different dates based on the accumulated evaporation of 70, 90, and 110 mm from class A pan (Moayri and Barzegadri, 2000). However, the possible deep percolation was higher, and the economical efficiency was lower, when irrigation water was applied at 70 mm evaporation from the pan, might be due to the shorter irrigation interval.

Based on the research by Moayeri and Barzegari, (2002) the main cause of low water productivity in maize fields in Dezful region is the high amount of runoff resulting from poor irrigation management, long lengths of runs, and improper water allocation. The impact of different management systems of furrow irrigation on maize production and water productivity was studied in Dezful research station during 1999-2001 (Moayeri and Barzegari, 2002). Full furrow irrigation (T1) was compared with single furrow irrigation under two different irrigation management of non-alternate irrigated strips (T2) and alternate irrigated strips (T3). The total irrigation water applied in T1, T2 and T3 treatments were 16819, 11642 and 11208 m^3 ha^{-1}, respectively, during the 1999-2000 and 28411, 18564, and 17533 m^3 ha^{-1} during 2000-2001. The average grain yield of the T1 treatment was 7.0 tonnes ha-1, significantly higher than that of the T2 (5.0 tonnes ha^{-1}) and the T3 treatments (5.0 tonnes ha^{-1}). However, the average maize water productivity was almost the same with 0.31, 0.34 and 0.33 kg m^{-3} for T1, T2 and T3, respectively. The average runoff was high in all three treatments comprising about 50% of the irrigation water applied.

With pressurized irrigation systems, runoff was found to be very low. Azari (2005) studied the impact of drip irrigation system on maize production and water productivity in comparison with furrow irrigation. He applied three levels of irrigation water based on 80, 100 and 120% of the maize water requirement (ETc) estimated using the Penman-Monteith model (Allen, *et al*., 1998). The irrigation water applied under drip irrigation was significantly less than that under furrow irrigation (Table 6). The yield of maize was higher under drip irriga-

Table 6: Grain yield, irrigation water applied and water productivity of maize under furrow and drip irrigation system.

Irrigation treatments	Irrigation water applied (m^3 ha^{-1})	Yield (kg ha^{-1})	Water productivity (kg m^{-3})
Drip irrigation			
80%Etc	5775	9098	1.57
100%ETc	7017	10147	1.45
120%ETc	8264	10536	1.28
Furrow irrigation	7934	21609	0.38

tion compared to that under furrow irrigation, where irrigation water was almost 3-4 times higher. Accordingly, the maize/water productivity under drip irrigation was 1.43 kg m^{-3} on average, which was almost four times more than that under furrow irrigation system (0.37 kg m^{-3}). The drip irrigation with irrigation levels being 80% of the ETc requirement showed the highest water productivity with 1.57 kg m^{-3}. Similar results were reported by Morid (2003), where maize/water productivity under drip irrigation increased to 1.22 kg m^{-3} compared to furrow irrigation (0.50 kg m^{-3}). He reported 30% runoff under furrow irrigation.
According to these results, runoff under surface irrigation might be one of the main factors of the low WP in the Dezful region. Improving the surface irrigation management to decrease runoff will lead to higher WP.

The WP data of wheat and maize from different locations in Iran were evaluated. The database comprised 10 field experiments conducted by the Iranian Agricultural Engineering Research Institute during 1998-2001 in Karaj, Mashhad, Orumieh, Dezful, and Esfahan (Dehghanisanij *et al*., 2006). Five maize experiments were conducted each in a given location and five wheat experiments were conducted in three locations; three in Mashhad and one each in Karaj and Orumieh.

Maximum values of wheat WP was measured in the Mashhad region, where deficit irrigation was applied during the growing season, while the maximum yield was recorded in Karaj where full irrigation was applied. Therefore, it can be concluded that the maximum WP occurs where deficit irrigation is applied.

Wheat WP in Dezful was low in comparison with that in other main wheat producing regions of Iran. In Orumieh, Mashhad, and Karaj, wheat WP ranges between 0.5 and 1.8 kg m^{-3} (Figure 9).
The measured maize WP from research conducted in Karaj, Mashhad, Orumieh, Dezful, and Esfahan ranged between 0.33 and 2.33 kg m^{-3}. The maximum value was measured in Orumieh (2.33 kg m^{-3}) where yield and irrigation water applied were 9366 kg ha^{-1} and 4025 m^3 ha^{-1}, respectively. The maximum irrigation water was measured at Dezful (32558 m^3 ha^{-1}) where the minimum WP was observed.
Maximum values of measured maize WP was in the order Orumieh > Mashhad> Esfahan > Karaj > Dezful. The broad range of crop WP might be related to the factors that influence the soil-plant-water relationship. For first order explanations of wide ranges in crop WP, irrigation water management, climate, and soil management are the most effective factors.

With the same data, it could be demonstrated that crop WP can be increased while saving water by reducing the quantity of irrigation water (Figure 10).

According to these results, maize WP in Orumieh was higher when compared to the other regions for any amount of irrigation water. The quantity of irrigation water applied to maize in Dezful was almost 60-200% higher than that in other experimental

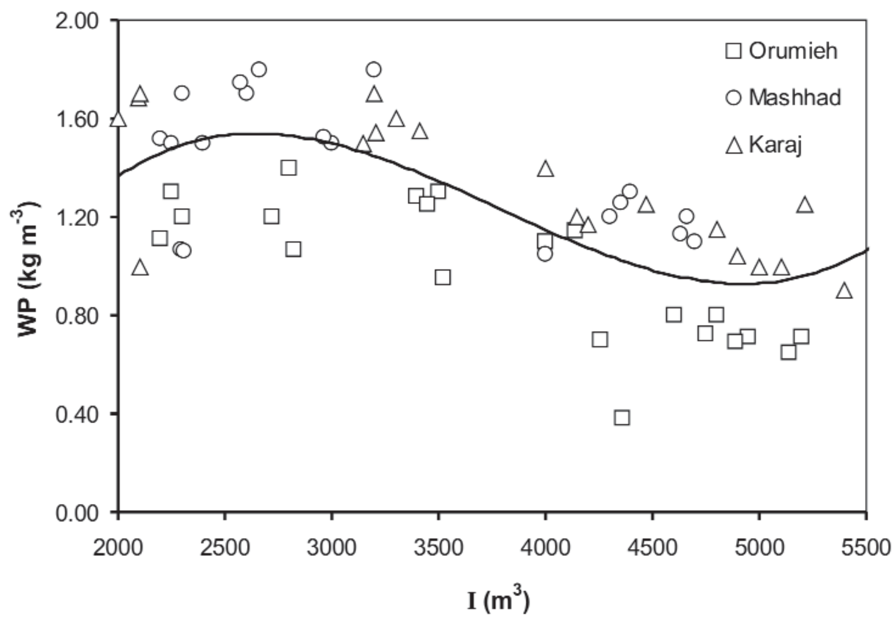

Fig. 9. The relationship between measured wheat water productivity (WP) and amount of irrigation water applied (I).

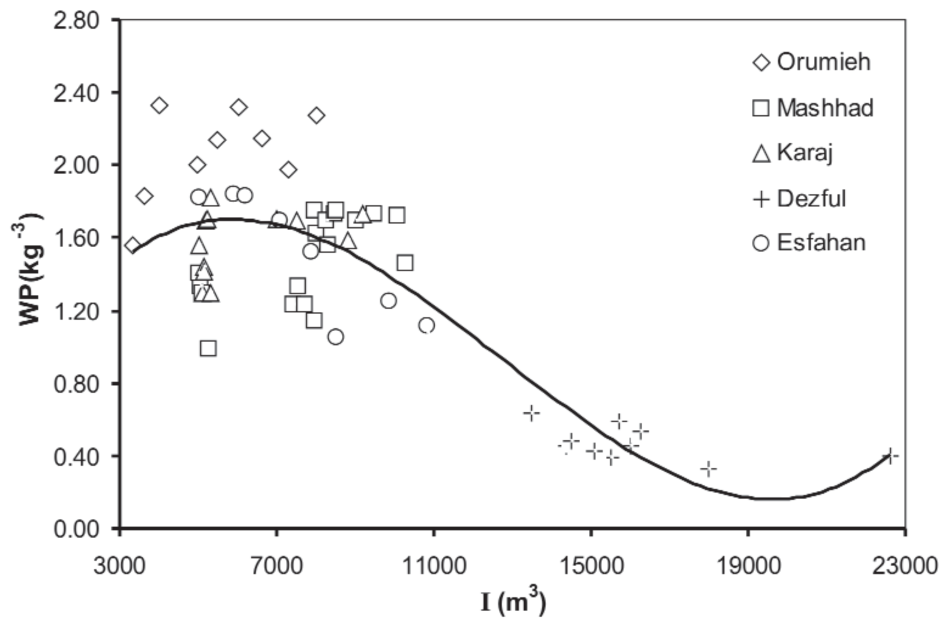

Fig. 10. The relationship between measured maize water productivity (WP) and amount of irrigation water applied (I).

sites. Water productivity of maize decreased when applied irrigation water increased to more than 5900 m^3. The maize WP was 1.70 kg m^{-3} with 5900 m^3 irrigation water. We concluded that this value of WP as optimum level for maize production. This should be considered for inclusion in the recommendations of cropping system at the national level. A maximum crop WP will often not coincide with farmers' interests, whose aim is to maximize land productivity or economic profitability. It calls for a shift in irrigation science, irrigation water management and basin water allocation to move away from 'maximum irrigation-maximum yield' strategies to 'less irrigation-maximum crop WP' policies.

Sugar beet is another major crop in the irrigated area of northern parts of lower KRB, which is usually planted in early September and harvested by the end of April. The net water requirement of sugar beet is 459 mm out of which 122 mm is provided by effective rainfall (Keshavarz *et al*., 2000).

Malekzadeh et al. (1999) studied the WP of sugar beet under three irrigation systems of furrow, sprinkler and center-pivot irrigation systems in Dezful. The irrigation efficiency of furrow, sprinkler and center-pivot irrigation system ranged between 10-20%, 71-74% and 57-64% respectively. Irrigation efficiency under center-pivot irrigation was lower than that under sprinkler system maybe because of higher evaporation during the irrigation. In sugar beet field under furrow irrigation, runoff losses were 30-35% of the water applied. In addition, deep percolation expected additional losses. Accordingly, sugar beet WP was 5.89, 12.20 and 10.24 kg m^{-3} for furrow, sprinkler and center-pivot irrigation system respectively. Sugar beet water productivity was also higher under drip irrigation compared to that under furrow irrigation. Sugar beet WP was 17.2, 15.2, and 13.1 kg m^{-3} when 50, 75, and 100% of the crop water requirement was applied through drip irrigation while it was 6.9 kg m^{-3} under fully irrigated furrow irrigation (100% of the crop water requirement). Therefore, deficit irrigated sugar beet under drip irrigation had a higher WP compared to that under full irrigation. Total irrigation water applied for 100% crop water requirement under drip irrigation was 6898 m^3 ha while that under furrow irrigation was 13237 m^3 where 21% of irrigation water was lost as runoff. Accordingly, in the case of sugar beet cultivation as well as that of maize, the main reason for the low WP is poor irrigation system management.

CHALLENGES AND OPPORTUNITIES FOR IMPROVING WP

As already discussed, low WP in irrigated area of KRB is mostly due to poor irrigation management. In other words, water productivity in the KRB could be substantially increased by improving on-farm irrigation management, introducing precision irrigation, decreasing deep percolation and runoff in traditional irrigation systems, allocation of irrigation water, based on actual crop water requirement, introduction of new varieties, adjusting cropping patterns and integrating appropriate agronomic practices in the crop production system together with suitable institutional setups and policies. Besides, drought-resistant varieties play an important role in increasing WP. Hence, genetic improvement of irrigated crops could be a part of the effort. Another important area of interventions is the study of the interactions between soil fertility and water management at the plant-, plot-, field- and basin-level. It is believed that the key to the realization of this hypothesis is the involvement and participation of farmers, local communities as well as government organizations and institutions responsible for water and agricultural development in the basin.

The followings approaches are suggested to improve the water use in agriculture and to enhance WP, which needed to be con-

sidered in research and extension activities:
1. Optimization of irrigation efficiency, agricultural inputs and planting system

- Modifications in cropping pattern to optimize water use.
- Genetic improvements of agricultural crops with higher WP and selection of high yielding varieties and their release to the farmers.
- Comparative studies on irrigation efficiency in consolidated and non- consolidated agricultural lands.
- Integrated management of irrigation water and fertilizer application.
- Optimized water consumption through modified planting dates in some irrigation areas to avoid drought effects during ripening.
- Introduce and application of early-maturing crop varieties with high initial growth rate.
- Reduction of evaporation losses from the soil surface using different mulches, sub-irrigation, subsurface irrigation, absorbents and agronomic methods.
- Reducing non-beneficial percolation and runoff.

2. Improving surface irrigation systems

- Development of land leveling and land consolidation plans and estimation of appropriate farm sizes.
- Dissemination of raised-bed furrow and alternate furrow irrigation methods to farmers.
- Reuse of return flows in furrows and borders.
- Dissemination of methods leading to faster water flow in furrow and border irrigation to reduce deep percolation and direct evaporation losses.
- Dissemination of modern techniques in surface irrigation (e. g. surge irrigation).
- Use of controlled drainage sub-irrigation methods especially in the areas with subsurface drains.
- Study and expansion of subsurface irrigation methods.

3. Use of pressurized irrigation systems for optimized water consumption

- Determination of the potential area for expansion of pressurized irrigation systems.
- Extension of pressurized irrigation systems in potential areas to replace surface irrigation methods.
- Expansion of micro-irrigation systems due to its better water conservation and other advantages.
- Advanced management of pressurized irrigation systems in order to prevent salinization and degradation of irrigation land.
- Study and convert traditional surface irrigation methods in orchards to different micro-irrigation systems.
- Production of vegetables and summer crops in greenhouses with micro-irrigation systems to increase yields and reduce water consumption.
- Studying the best irrigation schedule for different pressurized irrigation systems based on cropping pattern and crop water requirement.

4. Use of optimized deficit irrigation technique to increase WP in irrigated lands.

Although parts of the objectives and approaches discussed above have been addressed by previous research efforts conducted on-stations, there are big gaps between these findings and their practical application by the farmers. Little is known as to why farmers have hardly adopted technically viable and improved technologies. This is believed to be primarily due to inadequate interaction between scientists, extension staff, and farmers so far. There is a need to integrate biophysical and socio-economic research to better understand why farming communities have adopted or disregarded technologies to optimize water use efficiency and WP.

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CHAPTER IV

Overview of Soil and Water Resources and Salinity in Lower Karkheh River Basin

Nader Heydari[1] and Seyed Ali Mohammad Cheraghi[2]

[1]Assistant Prof. & CPWF Karkheh River Basin Coordinator, Irr. and Drain. Dept., Iranian Agr. Eng. Res. Ins. (AERI), Agr. Res. and Edu. Org. (AREO), Ministry of Jihad-e Agriculture, Karaj, Iran

[2]National Salinity Research Center (NSRC), Yazd, Iran

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-petroleum exports, and 90% of raw materials used in various industries (Keshavarz *et al*., 2003). The climate of Iran is one of great extremes due to its geographic location and varied topography. Approximately, 90% of the country is arid and semi-arid. The summer is 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 agricultural production is very limited. Currently more than 93% of water consumption (84 billion m^3) is used for irrigation of 8.1 million ha. Agriculture, in general and irrigated agriculture in particular, is the greatest consumer of water among the country's economical sectors; also the major losses of water occur in this sector.

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

Based on the latest agricultural statistics, the country produced 67 million tonnes agricultural products from 84 billion m^3 of water consumed. Therefore, currently the country's average WUE is almost 0.8 kg/m^3 which seem quite low in comparison to the world's value. Based on farmer's field studies were conducted in five regions in the country namely Kerman, Hamedan, Moghan, Golestan, and Khuzestan (Heydari et al., 2006a), the crop Water Use Efficiency (WUE) for the irrigated wheat, sugarbeet, 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*., 2006b).

However, there is no literature on measurement and assessment of WUE in the LKRB. Based on rough estimates concluded from farmers field visits and questionnaires 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.

Karkheh River Basin (KRB) is one of the important basins in Iran regarding water resources both in dryland and irrigated agricultural production systems. Water in KRB is limited and becoming scarce as population and demand are increasing. The productivity of rainfed agriculture is very low; conventional irrigation management is poor; cropping systems are suboptimal; and policies and institutions are weak (Anonymous, 2007a). 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, mainly due to resource degradation and unpredictable droughts (Anonymous, 2007b). 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 in the country with a very high out migration rate (Anonymous, 2007c).

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 Iranian 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 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 Services (NARS) of Iran.

This review paper provides an overview of the soil and water potential of the Lower KRB (LKRB) and the salinity and water logging constraints to agricultural production and agricultural water productivity (WP) in this part of the basin. It also addresses the soil and water potentials and agricultural production issues in the Khuzestan Province of Iran because LKRB is administratively governed by this province. Therefore, WP in the LKRB will be affected by the physical, socio-economic, administrative organizations, and policy issues in this province.

THE KHUZESTAN ENVIRONMENT

The Khuzestan Province is located in the South West of Iran at latitudes 29° 56°, 33° 5° South and Longitudes 47°, 42°, 50° 22°. It encompasses an area of approximately 67130 km^2. The Zagros mountain range is located in the South and East of the province dividing it into two sections. The five major rivers of Iran – Karun, Dez, Karkheh, Jarrahi, and Zohreh (Hendijan) – flow through this fertile plain. Along these rivers are the remnants of ancient civilizations showing how important this province had been throughout the history of agricultural development in Iran. The existence of ancient renowned structures such as Cheghozanbil water purifier, water wills at Shushtar, shipping along the lower Karun River and many other heritages have made this province an attractive place for the tourists.

It has been estimated that approximately 4.1 million hectares of arable land exists within the borders of Khuzestan Province, of which roughly 2.2 million ha have the potential for irrigation. A study on 1.78 million ha of land in the Khuzestan province shows that with due regards to the proposed crop patterns, a potential of developing 1.2 million ha of irrigated crops out of 1.78 million ha exists. In Table 7 some information on the Khuzestan province is provided.

The vast Khuzestan plain is mostly composed of alluvial deposits and small aggregate sediments of the main rivers and numerous tributaries. The fertility of the soil gradually decreases from the North to the South of the plain, in as such that the soil in the South of the province is heavy with large contents of saline and sodic minerals and very difficult to drain.

Climate and Soils

The Khuzestan Province is influenced by the low pressure Mediterranean Front, the Siberian high pressure Centre, and the low pressure hot Arabian and North African desert winds, thus making it one of the hottest and most arid regions in the world. Elevations vary from zero to 4000 meters above sea level. The average annual rainfall is approximately 265 mm and the average annual amount of evaporation is 2500 mm. The average temperature in the region is 25° Centigrade. Total agricultural areas of the Khuzestan province is 3.3 million ha. The area of surveyed lands, non

Table 7: Some information on Khuzestan province, Iran

Khuzestan province area	6.7 M ha
Ratio of province to total country area	4%
Number of plains	50
Area of plains	3.7 M ha
Area of mountainous areas	2.9 M ha
Maximum altitude in the northern plains	150 m asl
Minimum altitude in the Persian Gulf areas	2 m asl
Province population	4.5 million
Ratio of urban residence	64.8%
Ratio of rural residence	35.2%
Percent of population working in Agriculture sector	17%

surveyed lands, and the wetlands in the province are 2, 1.3, and 0.64 million ha, respectively (Public Relation Office, 2006a)

Surface Water Resources

The average inflow of the five major rivers in the Khuzestan province is approximately 31.3 billion m^3, which is equivalent to a third of the total surface water in Iran. The average flow rate is approximately 950 m^3/s.

In the province more than 8.9 billion m^3 of water is used by the irrigation sector, of which 93% is abstracted from surface flows and the rest from ground water sources.

The average amount of water consumption per hectares is approximately 17,200 m^3 and the average efficiency rate is less than 30%. In Table 8 and (Figure 11) information on basin area and flow discharge of the major rivers in Khuzestan plain are provided respectively. A comparison of the water resources and sedimentation in the Khuzestan province to the whole country is also provided in Table 9.
As can be seen from Table 8, out of the eight rivers/gauging station in the Khuzestan Province Karkheh river stands in fifth, fourth, and fourth ranking position in regard to basin area, average annual discharge, and average annual flow parameters respectively.

Ground Water Resources

Ground water resources are often found in the form of springs or wells in the region. An exact study carried out on the alluvial lakes in the Karkheh, Andimeshk, Dezful, Shushtar, Gotvand, Ramhormoz, Iezeh and Behbahan plains showed that the existing hydro potential among the stratum is approximately 2 billion m^3. Currently 831.3 million m^3 is being abstracted by 3039 wells of which 739.6 million m^3 is being utilized in the agricultural sector; 64.9 million m^3 is being used for drinking purposes; and 27.1 million m^3 is being used by the Industrial sector.

The Khuzestan Water & Power Authority (KWPA)

The existence of vast water and soil resources in the Khuzestan province and the exigency of utilizing these resources necessitated vast and thorough studies to be carried out in the region. On May 29, 1960, the National Parliament and Senate passed a bill by which the Khuzestan Water and Power Authority (KWPA) was officially established in order to carry out the projects in the Khuzestan region. The Khuzestan Water and Power Authority is the sole custodian of water resources in the province and therefore responsible for the allocation, operations and protection of this natural resource with the ultimate goal of optimal development and operation.

Table 8: Information on basin area and flow discharge of the major rivers in Khuzestan plain

River	*Station*	*Basin Area (km²)*	*Year of establishment of station*	*Annual discharge*				*Annual flow (MCM)*			
				Avg.	Prob. 80%	Max	Min	Avg.	Prob. 80%	Max	Min
Karoon	Gotvand	34425	1953	390.0	257.2	828.0	187.0	12301	8111	26112	5897
Dez	Dezful	17813	1956	249.0	158.1	554.9	120.0	7851	4985	17499	3784
Great Karoon	Ahvaz	60737	1970	634.4	428.6	1443	269.0	20006	13516	45506	8483
Karkheh	Paypol	43183	1961	180.3	104.6	397.9	56.9	5687	3299	12548	1795
Allah	Jokank	2260	1956	20.0	10.9	54.6	4.7	629	344	1723	149
Maroon	Behbahan	3740	1953	50.1	26.2	120.2	11.9	1581	825	3790	374
Zohreh	Dehmolla	11703	1955	80.8	37.4	213.3	21.2	2549	1180	6727	669
Shavoor	Shavoor	-	1959	16.6	11.7	24.1	10.0	523	369	760	315
Total				986.8	658.6	1986	455.4	31121	20768	62624	14361

Table 9: A comparison of the water resources and sedimentation in the Khuzestan province to the whole country (Public Relation Office 2006b)

Item	Total dams of the Country	Dams in the Khuzestan *province*
Total area of river basins of the Dams in the country	240,000 km²	91,000 km²
The total capacity of the country's reservoirs	25.6 BCM	15.5 BCM (60% of the total)
Annual sedimentation in the reservoirs	180 MCM/yr	92 MCM/yr (51% of the total)

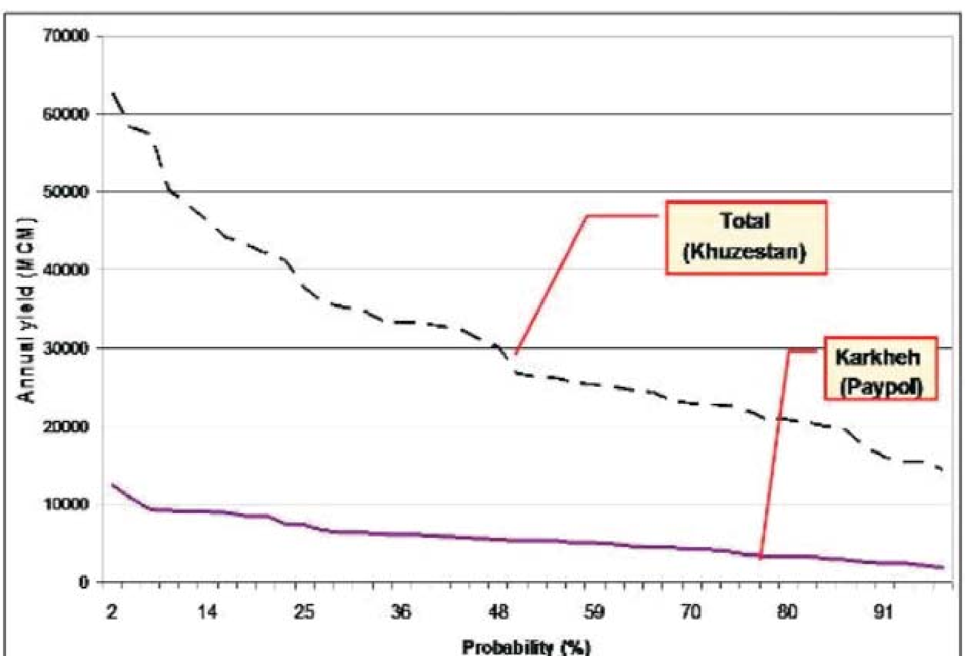

Fig. 11. Annual water yield of total rivers in the Khuzestan plain and the Karkheh River.

Large rivers such as the Karun, Dez, Karkheh, Jarrahi, and Zohreh and the numerous tributaries, springs, and streams along these rivers flow downstream from the Zagross mountain, through the fertile Khuzestan plain and down into the Persian Gulf. In Table 10 information on irrigation and drainage networks development projects of the KWPA in the entire Khuzestan province is given and in Tables 11 and 12 information on total numbers of irrigation networks in the Khuzestan province and the irrigation and drainage networks in the lower KRB are provided.

Challenges in the Soil & Water Development of Khuzestan Province

The followings are identified as key challenges in the province:

- Shortage of investments, especially investment from private sector
- Lack of a proper comprehensive agricultural plan in the province
- Problems with exports
- Unemployment
- Water withdrawal in upstream areas of the basin
- Socio-cultural factors limiting agricultural productions
- Lack of emphasis on the fisheries sector.

The large dam reservoirs, large rivers and lakes located in the Khuzestan province offer a good opportunity for fisheries development, but unfortunately not much attention is paid to this activity in this province.

With regard to shortage of investments, the following areas of investments can be recommended:
- Investments required for the execution and completion of irrigation networks
- Delay in execution of the irrigation networks construction and increase of the estimated costs

SOIL AND WATER SALINITY IN IRAN

Salinity stress poses 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. This Plateau is surrounded by two main ranges of high mountains running northwest to northeast (Labors) and northwest to southern parts and southeast (Zagrous Mountains).

Average yields of common crops vary according to locations and climatic condition. However, they are generally lower than the potential yields expected. There are a number of natural, technological, and man-made reasons for the relatively low yields obtained under farmers' conditions. Natural problems are quite varied in different parts of the country, but they are mostly due to climatic conditions (such as low precipitation rates and high evaporative demand), water availability and its quality, and soil conditions. Among the major natural obstacles which prevent the achievement of high yields in Iran is the salinity of soil and water. It is estimated that in areas where salinity is present, average yields losses may be as high as 50% (Siadat, 1997a)

Extent and Types of Saline Soils in Iran

Even though most of the salt-affected soils in Iran are found in the Central Plateau, the problems of salinity and sodicity are present in other parts of the country also. It is estimated that some 10% of the total area the country suffers from salt accumulation. However, considering that man-made salinization has been occurring and intensified in the last decades, due to the expansion of irrigated farming, an increase in the total area of salt-affected soils is to be expected. In fact, more recent estimates put this area at around 18 million ha, including the salt marshes of the Central Plateau (Siadat, 1997b)

Table 10: KWPA irrigation and drainage networks development division projects (Public Relation Office, 2006c)

Watershed	*Area (ha)*	*Under Study*		*Ready for construction*	*Under construction*		*Operations*
		Phase I	Phase II		Supply and conveyance	Main networks	
Karkheh	328434	13900	115995	94076	258474	48403	56060
Karoon	251503	62400	11000	72657	93492	30381	75065
Dez&Shavoor	236400	56700	7500			18000	154200
Marun & Allah	84323			27569	27569		56754
Zohreh&Boneh Basht	90300	22000		46852	52000	9200	12248
Total	990960	155000	134495	241154		105984	354327

Table 11: Total irrigation networks in the Khuzestan province based on the river basins (Public Relational Office 2006d)

Basin	*Area (ha)*	*Study*		*Ready to execute*	*Under Execute*		*Operation*
		Phase I	Phase II		Supply and Conveyance	Main Networks	
Karkheh	314534		115995	94076	258474	48403	56060
Karoon	197103	35000		64192	93492	43611	54300
Dez&Shavoor	185000	55000					130000
Marun&Allah	80823			27569	49594	22025	31229
Zohreh&Boneh Basht	75300	10000		45852	52000	7200	12248
Sugarcane project	130000			40000			78000
Fishery	35000			17000			18000
Total	1117760	100000	115995	288689	453560	133239	379837

Table 12: Irrigation and drainage networks in the lower KRB (Public Relational Office 2006e)

Networks	*Area (ha)*	*Study*		*Ready to construct*	*Under Execute*		*Operation*
		Phase I	Phase II		Supply and Conveyance	Main Networks	
Hamidieh&Ghods	15700						15700
Zamzam	2500						2500
Avan	13000						13000
Koot&Hamooddy	7800						7800
Arayez, Dosalegh, Bagheh	51575			35427	51575	16148	
Azadegan plain (East)	22334			4229	22334	18105	
Chamran	76553		63300	13253	76553		
Koosar	14150				14150	14150	
Azadegan Plain (West)	36826			36826	36826		
Azadegan Plain (development)	52695		52695		52695		
Hamidieh (development)	4341			4341	4341		
North of Hamidieh	17060					17060	
Sum	314534		115995	94076	258474	48403	56060

Since extensive parts of the country have arid to semi-arid climate, soils belonging to arid lands such as Aridisols are widespread. Saline soils of this order in Iran belong to both Hapiosalids and Aquisalids great groups. The latter soils are mostly bordering the playas and have a groundwater level within one metre from the soil surface. Haplosalids, however, are located away from these playas where groundwater depth is below one metre depth (Siadat, 1997c).For both of these great groups, Typic, Gypsic, and Calcic sub-groups are found in different areas. In all, a Salic horizon is present with varying thickness depending on parent material and use.

There are other types of saline soils in Iran, which present problems of high salt content but lack a Salic horizon according to the definition of USDA Soil Survey Staff (Siadat, 1997d). Such soils are either Alfisols or Inceptisols having a Natric horizon with high concentration of sodium. These saline soils belong to two soil sub-groups, namely Natrixeralfs and Natric camorthids with SAR >13 or ESP >15. Geographic distribution of these soils follows the same pattern as the groundwater containing sodium carbonate and sodium bicarbonate in low terraces of the river valleys and flat slopes of the rivers fans. Kovda in 1970 reported the presence of these saline soils in the northern and eastern parts of Iran as well as in the Central Plateau (Siadat, 1997e).

Causes of Soil Salinization in Iran

The existence of large areas of saline/sodic soils in various parts of Iran reflects the fact that there are many factors affecting this phenomenon. Indeed, the causes of soil salinity can be divided in two categories, namely, natural or primary causes and secondary or man-made causes.

The natural causes includes geological and physiographic conditions, Climatic conditions and Salt transport by water.

The man-made causes are mainly due to poor irrigation management and waterlogging problems mostly occurring in the irrigation networks developed under regulated waters like dams. Increased application of marginal waters for irrigation without required management has also increased this problem in recent years. Overall, the man-made causes include the poor water management, over-exploitation of groundwater poor land preparation, fallowing and overgrazing and sea-water intrusion.

Salinity Research and Management in Iran

For the last forty years, major efforts have focused on the solutions to salinity problems in Iranian agriculture. Much of such research was initiated in early 1960's by the Soil Institute (Presently called Soil and Water Research Institute, SWRI, Tehran, Iran) in cooperation with the Soil Fertility Project of the FAO.

During the last two decades, most of the studies on saline soils and water resources used in agriculture have been carried out by the SWRI and Agricultural Engineering Research Institute (AERI), Karaj, Iran. Other governmental organizations such as the Ministry of Energy, the Ministry of Jihad and some faculties of agriculture have also been engaged in certain studies.
In recent years, salinity research has got more attention by the policy makers. This led to the establishment of National Salinity Research Center (NSRC). NSRC is the youngest, but very closely linked, institute to the work relating to salt-prone land and water resources degradation and their management. The center started working in 2000 in the Yazd Province, which is most seriously affected by salinity relate problems. The mandate of the center has four major aspects (Cheraghi, S.A.M. 2004):

- Research on the causes and manner of development of saline and sodic soils
- Determination of the effects of saline

and brackish water on soil and crop production
- Implementation of research to determine the most suitable methods of crop production under saline, saline-alkali, and sodic soil conditions
- Cooperation in research to determine the varieties and plant genetic resources resistant to salinity and flooded conditions

Besides its main campus and research facilities in Yazd, NSRC has several regional networks addressing the unique problems of salt-prone land and water resources in specific agro-ecological areas. These networks are in Khuzestan (through Ahwaz Agricultural Research Center stations, e.g. Shavoor research station), Khurasan, Fars, Esfahan, Golestan, Boshehr, and Qazvin. In addition, the NSRC has several linkages and collaborative work with national and international organizations.

The Shavoor Agricultural Research Station is one of the major agricultural research stations of Ahwaz Agricultural Research Center in Khuzestan province. This station was established in 1936 and is located near Ahwaz city, the center of Khuzestan Province. This station was initially named as Soil Reclamation Research Station. The typical research in the beginning was confined to soil leaching and reclamation, and effects of drain spacing on groundwater level, and application of amendments (e.g. Gypsum, Sulfure, Organic matters, Bio amendments, etc.)

The following areas of research are prominent in this research station
- Use of marginal waters in drained lands.
- Use of organic matters and its effect on reclamation of saline- sodic soils.
- Research on application of macro and micro fertilizers under soil and water salinity conditions.

At present, following the installation of drainage system in the centers, salinity and sodicity are alleviated from soil profile through leaching. Therefore, common agricultural research practices required for the region are being conducted in that station and there is not much space for salinity research in that area.

Based on a summary list of the research topics conducted in the country on salinity management by individual research institutes[1] , till year 2004 almost 115 research projects are conducted specifically on salinity issues. These research projects cover some provinces or regions in the country facing with soil and water salinity hazard e.g., Yazd, Golestan, Fars, Khurasan, Khuzestan, Markazi, Hormozgan (Boshehr), Moghan, Azarbaijan, Esfahan, and Qom. However, very limited salinity research projects have been conducted in LKRB and on salinity-WP related issues in this basin or even in whole country nothing much is done. Out of 115 research topics, almost half are crop-based and the other half are confined specifically to soil and water subjects. So there is a balance in this regard.

In the field of soil leaching and reclamation, so far, most of the research findings have been about leaching requirements and, to a lesser degree, the type of suitable amendments materials such as sulfur, gypsum, and sulfuric acid. Accordingly, the most extensive remedial action which has been actually applied in certain limited areas is salt leaching by irrigation water. This has been carried out in Khuzestan and Fars provinces in governmental projects.

Farmers and private sector involved with agriculture, however, are not known to have any planned programs for leaching or used any of amendments. Some traditional practices, though, may be interpreted as salinity control measures. For example, in many areas, farmers apply a heavy irrigation at the time of planting. This contributes both to the storage of water in the

[1]The list was collected from the relevant institutes (AERI, SWRI, and NSRC) by the first author

lower soil layers and the removal of some salts from the top layer. Besides, the common observation that in many salt-affected agricultural fields irrigation water is applied in excess of plant water requirement may be interpreted as a traditional intermittent leaching practice. Therefore, it is reasonable to state that intermittent leaching is commonly used by the farmers.

Till now salinity research has covered the followings areas:

- Extent of salt affected soils
- Characteristics of salt affected soils in Iran
- Methods used to ameliorate salt affected soils
- Crop productivity potentials of salt affected soils
- Productivity of saline water used in different parts of Iran
- Values of saline water in Iran as drainage water and groundwater
- Quality of saline water with respect to salts and other contaminants in drainage water and ground water

It is also fair to say that little has been done in the following areas and thus more work is needed:

- Environmental aspects of salt-affected soils
- Crop productivity potentials of salt-affected soils
- Economic evaluation of the management options for the salt-affected soils
- Response of communities to salt affected soils
- State of knowledge on above aspects in KRB
- Different approaches used to irrigate with saline water
- Response of communities to irrigate with saline water
- Economic aspects/evaluation of irrigation with saline water
- State of knowledge on above aspects in KRB

SALINITY IN KARKHEH RIVER BASIN (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 KRB are mostly in the eastern and central parts. The plains are mostly in the Northern and Southern parts covering almost 45% of the basin area. Based on hypsometric studies, 75% of the basin is located in altitudes of 1000-2000 and 0.6% of the basin is above 2500 m altitude.

The Karkheh River arises from the confluence of numerous large and small tributaries including the three large rivers, namely Gamasiyab, Ghareh so, and Kashkan. The Karkheh River has various names along its route and is locally best known as the Saymareh river at the point where the Gamasiyab and Ghareh rivers combine and later at the point were the Kashkan River flows into the main waterway, it is known as the Karkheh River. The river ultimately flows into the Hawr-al-Azim (HAA) wetland that borders Iran and Iraq.

After Pay Pole hypsometric and slope of the basin decreases and gently passes HAA wetland. In Table 13 physiographic characteristics of KRB are provided. Based on general hydrological classification of basins in Iran, the KRB is considered as one of the Sub-basins of the Persian Gulf Great Basin. From the North, the basin is limited to Sirvan, Ghezel Ozan, and Gharachai rivers, from the west to the basins of Iran-Iraq Border Rivers, from the East to the Dez river basin and from the South to part of western border of Iran. Among the important cities in this basin, Malyer, Nahvand, Toyserkan, Kangavar, Songhor, Kamyaran, Kermanshah, Kerend, Khoramabad, and Sosangerd are most notable.

The pattern of precipitation in KRB is affected by Mediterranean regime. It means that the dry season is coinciding with summer and rainy season match with cold months. The rainfall in the basin is classified as winter rains and then autumn and spring rains. The annual precipitation of the basin is 219 mm in Hamidieh (Southern part of KRB) to 765 mm in the northern part.

Based on climatic maps, the hottest areas of the basin are located in its southern parts and are surrounded by the 25°C Isotemperature (Isohyets) contour. The coldest areas of the basin are located in altitude higher than 3000 m, and are mostly located in the North and North-east of the basin and are surrounded by the 50°C Isohyets contour map.

Evaporation in KRB varies between 1800 and 3600 mm depending on altitude. For example it is around 3560 mm in Abdol - Khan Station in an altitude of 40 m in LKRB. Almost 79% of annual evaporation occurs from almost May to September.

Water resources of KRB are both surface and ground water. In 1994, the share of agricultural water consumption from these resources was 3.915 billion m^3. The agricultural water consumption untill the completion of the on-going water works can be increased to 7.433 billion m^3 (90% increase). The water resources of the basin in general have a good quality. However, the quality of ground water in the Southern plains deteriorates to some extent. Potential of surface water resources of KRB is 7.374 billion m^3. In wet years it can be doubled and in dry years it can be as low as half. Agricultural water withdrawn in KRB is 3.956 billion m^3 (in year 1994). Out of which 37% is supplied from ground water and 63% from surface water resources.

The rate of surface to ground water resources consumption in sub-basins of KRB is different. The Gharasou sub-basin in the North has the greatest rank (75.2%) in

Table 13: Physiographical characteristic of KRB (Mahab-e Ghods, 1996)

Basin	Area (km^2)	Mean elevation (m)	Slope (%)	Gross slope of rive (%)	Average slope of river (%)	Length of river (km)	Gravelliest coefficient	Perimeter (km)	Equivalent rectangle Length (km)	Equivalent rectangle Wide (km)
KR -Hamidieh Station	45654.8	1439.2	4.66	0.36	0.19	630	2.11	16.5	246.32	61.18
KR - Pay PoleStation	42239.3	1548.06	5.21	0.49	0.33	437	1.8	1324.5	590.25	21.5
The inner area (from Hamidieh to HAA*)	5150	17.31	0.102	0.02	0.004	25	1.17	300	96.79	53.21

* HAA: Hawr al Azim wetland

ground water consumption. The Kashkan sub-basin (also in the North) has the highest rank (93.9%) of surface water consumption. From the point of view of the quantities the most of ground water is withdrawn in Gamasiab, followed by Gharasou sub-basin, in the Northen part of KRB. In the whole KRB the highest consumption of surface water resources is in the Southern (Lower) KRB. Based on the 1994 statistics, out of different plains of KRB, Azadegan plain (Dasht e Azadegan, DA) with 662 million m^3 water consumption is the greatest consumer of water in the basin. This plain is also the greatest consumer (660.2 million m^3) of surface water in the basin. The Nahavand plain in the northern (Upper) KRB is the greatest (215 million m^3) consumer of ground water resources in the basin.

Based on 1994 statistics, out of 4157.4 million m^3 consumed water, 2504.6 million m^3 (60%) was from surface water and 1653 million m^3 (40%) from ground water resources. Out of total consumption, share of rural, urban, industry and mining, and fishery consumption were 1.23, 3.93, 0.32, and 0.35% respectively. The share of agricultural water consumption in this year was 94.17. Therefore, from aspects of water resources consumption, the KRB is completely an agricultural basin and the industrial and mining consumptions were just 0.32% of total water consumptions. From urban water consumption point of view, Kermanshah plain with 58.5 million m^3 water consumption and from the viewpoint of industrial water use this plain with 7.73 million m^3 has the greatest consumption. From agricultural point of view, Azadegan plain (DA) with 642.6 million m^3 water consumption is the higher consumer of water in the KRB.

KRB encompasses one of the poorest regions of Iran because it has very low infrastructure and is severely affected by the 1980-'88 war with Iraq. Low food production under both dry farming and irrigated conditions are issues of crucial importance to increase per capita income of farmers in the basin.

Two major agricultural production systems prevail in the KRB. The dry-land system prevails in the upstream and the fully irrigated areas are located in some part of upstream and all parts of downstream of the KRB. The dryland areas are well established and cover most of the basin agricultural lands, occupying 894,125 ha, whereas irrigated lands occupy 578,862 ha but expected to expand by additional 340,000 ha following the construction of the Karkheh reservoir Dam (Anonymous, 2007d)

KRB is one of the main basins in the country's rank. 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. 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. Therefore KRB is well suited to be a major area for development-oriented research activities to be implemented under the Challenge Program on Water and Food (CPWF). KRB provides a unique opportunity for the CPWF to make an impact through improvements in land and water management, which in turn will improve the livelihoods of millions of rural poor living in this basin. 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.

However, in the lower Karkheh river basin (KRB) heavy soil texture and recharge from upstream areas cause natural condition for water logging and is more induced by low irrigation efficiency of irrigated agriculture in the region. The available soil data indicates that the majority of arable lands in KRB possess various degrees of limitations (either individually or in combination). Salinity, water-logging, lack of soil organic matter, soil structural deterioration, 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, 2007e)

The Karkheh Dam was completed in 1999 and became operable in 2001. The main objectives of the dam are to produce Hydro-electric power (1000 GW/h/year), flood control, and supply of regulated flow for irrigation of more than 340,000 ha of lands on down stream side of the dam. These arable lands are located in different plains situated in the lower parts of KRB (Mahab-e Ghods, 2005)

At present there are no modern irrigation and drainage networks under operation within the dam coverage area and agriculture is not yet fully developed. However, the government started to study and construct irrigation and drainage networks, or modify the traditional irrigation systems. The drainage outlet of the area, which also is a basin outlet, is the HAA Wetland in Iran-Iraq common border. Irrigation efficiency and water productivity in the lower parts of KRB,like in the upper parts, are low. In this area, despite the availability of irrigation water, agricultural water management is poor and because of high water table and high potential evaporation rate, land and water salinity are major problems. This area is planned for further development following the model of adjacent Dez irrigation district.

Waterlogging and soil 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. In addition to the national food security objective, improving the well-being of the agricultural communities in the lower region are exceptionally important to minimize socio-economic problems regarding local migration of farmers and security issues along the Iran-Iraq border communities.

Owing to the relatively good quality of Karkheh river water (EC= 0.79-2.5 dS/m) and favorable climatic condition for agricultural activities in the lower KRB, 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.

In the LKRB, because of the differences in factors affecting agricultural water productivity in the northern and southern parts, two distinct regions can be identified. They are the areas in the northern part and the southern parts of LKRB.

In the northern part, there are not much limiting factors regarding soil and water quality. In this area improving farmer's skills and application of appropriate farming systems can improve water productivity greatly. Limitations in water supply and excess irrigation water losses (mainly in earthen canals) also causes lower water productivity of crops. Therefore, demonstration of new farming systems e.g., pressurized irrigation, land preparation methods (raised bed, double row cropping, etc.), could be useful for improving water productivity. In this part successful introduction and implementation of new farming systems and technologies in accordance with agricultural service center could be an effective way for improving water productivity. Two major problems in this area are the large farm size and low population density.

In the southern parts of LKRB, mainly Dasht-e Azadegan (DA) plain, available data and surveys showed that the problem of soil salinity is magnified due to lack of farmers' knowledge, skills and unavailability of new and improved farming practices. In general, the main cause of soil salinity in the LKRB is high water table, often less than 2.0 m, usually 1.2-3.0 m below the soil surface, If left alone, the problem is likely to worsen, especially with the current plans for expansion of irrigation networks.

In the southern parts, it seems that in addition to the factors limiting water productivity (e.g., farmers skill, new farming system, etc.) the major limiting factors are water logging and soil and water salinity. This problem will worsen in future with expansion of irrigation networks. At present, despite construction and operation of main drains in the area, the situation has not improved. This is mainly due to some technical problems (e.g., slope of drain) and also the problems concerning the outlet. Gravity drainage to outlet is not possible and it needs pumping. Environmental concerns regarding drainage to Hawr Al Azim wetlands are also another problem. It is claimed that the government is studying a plan to construct a main drain and carry drained water to the Persian Gulf by gravity (Anonymous, 2007f). However, research topics (both on-farm and experimental) related to water table management and salinity control will help much to improve in productivity of agriculture in this area.

Dasht-e Azadegan Plain

This region stretches from Karkheh Sofla sub-basin to Hawr-Al-Azim wetland and is generally divided into southern and northern parts. The northern district, which is called Pay-e Pole, ends up to Karkheh Diversion Dam in Hamidieh area; hence the Southern district mainly accommodates the municipal facilities. Karkheh River diverts towards northwest of the region near the city of Hamidieh and eventually joins Hawr Al-Azim wetland. Dasht-e Azadegan (DA) region is located at the furthest southern part across the delta of Karkheh River 20 km west the city of Ahwaz. Total area under study in this research was almost 200,000 hectares, of which 95000 hectares spread over the current civil projects of Dasht-e Azadegan region. This plain is located between 47' 55'' to 48' 30'' E and 31' 15'' to 31'45'' N and its height above sea level varies between 3 to 12 m.

DA is covered with fine sediments carried by Karkheh River and with an almost even surface and mild slope expanding towards the West and the East flanks. The general slope of the plain is also towards southwest. The area of study included the lands between Karkheh river and Karkheh Noor river i.e, main DA plain, eastern district of DA, western district of Dasht-e Azadegan, northern part of Karkheh river, falls on the left bank of Karkheh river and other farmlands along this river.

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

Based on the existing statistics, the total number of the villages in DA and Hamidieh is 219 of which 96 have been abandoned now. These villages are located in 7 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 existing statistics indicate that the weather is hot in summer with mild and short winter. Annual mean temperature of the region is 23.1 °C. The maximum daily temperature in the warmest months of the year (Tir and Amordad according to solar calendar corresponding to June, July and August) is 43 °C and the minimum daily temperature in the coldest month of the year (Dey according to solar calendar corresponding to January) is 5 °C. The average precipitation in the area is 175 mm over the past decade. The wettest month of the year is Azar (corresponding to October) with 44.1 mm and the driest months are Khordad, Tir, Mordad and Shahriver (corresponding to the period from March to late September) when there is almost no precipitation. Annual mean evaporation in this area is 2005 mm. The maximum evaporation 304 mm is in Tir (corresponding to July) and the minimum of 43 mm occurs in Dey (corresponding to January). Based on the climatological data of past ten years at Sosangerd and Howeyzeh stations also based on the bioclimatic map of Mediterranean region (by FAO and UNESCO), and despite the existent 260 dry days in a year, Dasht-e Azadegan has not been classified as Accentuated Sub-Desertic Area. The total rainfall in Sosangerd and Bostan is 180 mm and 200 mm respectively. There is a weather station in Bostan. The agricultural service centers also are equipped with rain gauges. Table 14 presents some of the influential factors in climate and evaporation state of Dasht-e Azadegan region.

Current crops in Dashte-Azadegan include cereals such as wheat, barely, rice, and ground cereals; vegetables such as melon, watermelon, tomato, cucumber, eggplant, okra, lettuce, cabbage, carrot, radish, and onion; legumes such as beans; fodder for livestock such as alfalfa, barely, corn and Sudan grass. More than 78% of agricultural production in Dasht-e Azadegan region is

Table 14: Some metrological parameters and Evapotranspiration values for different months in Dasht-e Azadegan Plain (Hamidieh station), (Mahab-e Ghods 1993 a).

Month*	**Temperature (C)**			**Precipitation**	****ET**
	Average Min	Average Max	Average	(mm)	(mm)
Day	5	16.4	10.7	41.3	42.7
Bahman	6.9	19.7	13.3	24.1	62.5
Esfand	11	24.8	17.9	23.3	105
Farvardin	15.2	30	22.6	17.7	150
Ordibehesht	19.6	36.6	28.1	6.5	234
Khordad	22	41.8	31.9	0.0	299.2
Tir	23.7	43.2	33.5	0.2	303.6
Mordad	22.8	43.2	33	0.0	279.8
Shahrivar	19.2	41.2	30.2	0.7	235
Mehr	14.8	35.1	25	4.2	155.5
Aban	10.1	26.6	18.3	11.5	88.1
Azar	6.7	19.1	12.9	45.5	49.5
Average	**14.8**	**31.5**	**23.1**	**175**	**2004.9**

* Based on Iranian Calendar ("Day" coincides almost with January)
**ET is calculated from the Blaney- Cridlle or adjusted Pruit equation

dominated by grains-mainly wheat and barely (Anonymous, 2007 G.), (Mahab-e Ghods, 1992). 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 productions almost impossible.

The reasons why farmers prefer wheat cultivation currently are that there is limited water supply, the assured returns from it (guaranteed purchase of the produce by the Government), and security problems in the region (wheat needs less labor, less irrigation, and less maintenance).

The source of irrigation is mainly the water pumped from the 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 (Main irrigation and drainage canals in Koot and Hamoodi in Construction units of 1 &2 are under construction). But, there is hardly any secondary or tertiary canals or drain lateral.

The main problem of agriculture in this region are water logging and salinity. Water logging followed by soil salinity occurs in a certain period. For example, in wheat cultivation in DA, planting is taken up in early November. In late November, the first irrigation for land preparation is given. The harvest is in late May. Deep percolation losses of irrigation during this period causes the water table to rise. The peak of water table rise is in February. The salinity (EC) of ground water and irrigation water in this area is 6-9 dS/m and 3 dS/m respectively. Water table depth is between 0-1.2 m. Operation of Main Drains is started recently (in 2003) and their outlet is Hor-al Azim Wetland (Anonymous, 2007 H).

At present despite of the construction and operation of main drains in the area, in some areas the system is not properly functioning. This is mainly due to some technical and excavation problems (i.e., improper slope of drain lines) and also the problems concerning the outlet (Based on Regional Agricultural Organization experts and authorities and information from local visits in 2004). Gravity drainage to outlet is not practically possible and pumping is required. Environmental impacts regarding drainage flow directly into the mentioned wetland is also another concern that should be considered.

Salinity in the Dasht-e Azadegan

Land classification studies for Dasht-e Azadegan region showed that approximately 33,334 ha of this region belong to land classes I and III. Tables 15 and 16 present different land classes and sub-classes along with irrigation potentials for Dasht-e Azadegan region. The main constraints on these lands and the classified lands include: salinity and alkalinity of the soil, high levels of saline groundwater, soil permeability and drainage restrictions in the area. In fact, almost all of the farmlands in this region have salinity and alkalinity problems.
The results of semi-detailed studies indicate that approximately 80% of farmlands of Dasht-e Azadegan region are lands with both low or high salinity and alkalinity. Table 17 displays the extent of the problem.

Overall, out of 91,470 ha of Dasht-e Azadegan region
- 1% or 70 ha have no salinity and sodicity limits;
- 16% or 14599 ha have moderate salinity and sodicity;
- 27.4% or 25040 ha have high salinity and sodicity.
- 2.2% or 2040 ha are lands with varying rates of salinity and sodicity.

Table 15: Classes and Sub-classes of land classification in the Dasht-e-Azadegan Plain (Mahab-e Ghods 1992a).

Class and Sub-class	Class		Sub-class	
	Area (ha)	(%)	Area (ha)	(%)
II	64.98	6.84	-	-
IIA			2670	2.81
IIAS			2674	2.81
IIAW			267	0.30
IIASW			878	0.92
III	26836	28.26	-	-
IIIS			2042	2.15
IIIA			13752	14.48
IIIW			1046	1.10
IIIAS			4902	5.16
IIISW			170	0.18
IIIAW			2513	2.65
IIIASW			2411	2.54
IV	1534	1.61	-	-
IVS			1084	1.14
IV/V			450	0.47
V	34801	36.63	-	-
VA			26726	28.13
VW			6050	6.37
VAW			2025	2.13
VI	24940	26.25	-	-
VIA			23350	24.58
VI/M			1050	1.10
VI/R.B			540	0.57
VA+III	391	0.41	391	0.41
Total	**95000**	**100**	**95000**	**100**

Based on the sample profiles tests, the saline surface soil of Dashte-Azadegan region can be divided into saline soil and saline-sodic soils. The characteristics of these two types of soil are:

a) Saline-sodic soils: much of Dasht-e Azadegan is consisted of this type of soil which has the following characteristics:

- an EC more than 4 dS/m
- an ESP more than 15%
- pH less than 8.5

High saline concentration in soil solution creates concentrated absorbed cation layers and thus enhances the quality structure of this soil and higher infiltration rate. However, thick cation layers may give unfavorable responses to agricultural activities. Basically, in saline, sodic or saline-sodic soils with concentrated soil solutions do not bring any major change to the soil structure, but after flushing the soluble salts and exit of the soil cations with an increase of sodium ions ratio, it is expected that due to its permeability and clay dispersion the soil structure will be damaged. Thus care should be taken in terms of the irrigation water and correctives qualities during soil correction period.

Table 16: Classes and Sub-classes of irrigable lands in the Dasht-e Azadegan Plain (Mahab-e Ghods 1992b).

Land classes	Area (ha)	(%)	Sub-class	Area (ha)	(%)
I	5396	5.86	-	5396	5.86
II	17933	18.88	IIA	10907	11.48
			IIW	1046	1.10
			IIS	1102	1.16
			IIAS	2365	2.48
			IIAW	1879	1.99
			IIASW	634	0.67
III	33011	34.75	IIIW	1950	2.05
			IIIA	18073	19.02
			IIIS	9525	10.03
			IIIAS	3072	3.23
			IIIAW/A	391	0.42
IV	1084	1.14	IVS	1084	1.14
V	35536	37.40	VA	26926	28.34
			VW	5720	6.02
			VAW	2890	3.04
Other	2040	2.15	-	2040	2.15
Total	**95000**	**100**	**-**	**95000**	**100**

Table 17: Salinity and Sodicity classes of Soils in the Dasht-e Azadegan Plain (Mahab-e Ghods 1992c).

Salinity and Sodicity class	EC (dS/m)	ESP (%)	pH	S.A.R	Area (ha)	(%)
S_0A_0	<4	<10	<8.5	<8	70	0.07
S_1A_0	4-8	<10	<8.5	<8	11670	12.28
S_1A_1	4-8	10-15	8.5	8-13	2935	3.10
S_2A_0	8-16	10	8.5	8	1150	1.21
S_2A_1	8-16	10-15	8.5	8-13	3055	3.22
S_2A_2	8-16	15-30	8.5-9	13-30	21588	22.72
S_3A_2	16-32	15-30	8.5-9	13-30	20825	21.92
S_3A_3	16-32	30-50	9-9.5	30-70	7926	8.34
S_3A_2						
S_2A_2	8-32	15-30	8.5-9	13-30	391	0.41
S_4A_3	32	30-50	9-9.5	30-70	11540	12.15
S_4A_4	32	50	9.5	70	11810	12.43
Other	-	-	-	-	2040	2.15
Total	**-**	**-**	**-**	**-**	**95000**	**100**

b) Saline soil: the smaller portion of this region is covered by this type of soil with the following characteristics:

- an EC more than 4 dS/m
- an ESP less than 15%
- pH less than 8.5

The unstable salinity limit in these lands facilitates the soil reclamation compared to saline-sodic soil type lands. Only leaching of the soil can reclaim the soil and reduce the salinity. High levels of Dasht-e-Azadegan groundwater resources and deep percolation losses from the current irrigation systems impose numerous restrictions on irrigation development in the area. The ground water level under area ranges from 1 to 3 m. The lands are usually composed of heavy surface texture with low or very low permeability rate that are more in form of wetlands, also the runoffs resulting from precipitation and irrigation of the upstream lands remain on the surface for a long time. Soil in the region has a heavy texture on the surface and deeper layers and soil permeability is of slow or very slow rate, which weakens the performance of the irrigation system and offsets the leaching of saline lands.

As indicated before, saline-sodic soil constitutes a vast area of Dasht-e Azadegan region and this relatively increases the sodium ions ratio to calcium and magnesium ions, therefore, make sodicity of the soil and as a consequence intensifies clay dispersion and destruction of the soil structure. In addition to the above factors, other influential parameters that contribute constantly to the soil salinity are irrigation of the lands in the region with saline water and considerable quantities of saline minerals carried along by river streams. These soluble salts are washed away by river flow especially during floods and this brings several thousand tonnes of salt and mud to the region. Wastewaters of the lands also enter Karkheh River system and as it approaches the end its water quality suffers. It is evident that any irrigation with such water quality will enhance the soil salinity in the lands downstream of Karkheh River.

Dasht-e Azadegan soil studies showed that more than 99% of the area of the region have been faced with either high or low salinity and sodicity for a long time. Overall natural and man-made factors are involved in soil quality of the region.

In order to study the reaction of the soils to salinity and sodicity reduction through leaching in the region, the leaching tests were carried out using the amendments at 33 stations. Table 18 presents the location, series, salinity and sodicity classes, some physical characteristics, applied water resources and their quality in soil reclamation experiments for Dasht-e Azadegan region. Table 19 also shows the results of soil chemical analysis before and after leaching experiments as an example.

CONCLUSIONS AND RECOMMENDATIONS

- Soil salinity and water logging, in addition to the other sources of inefficiencies in agricultural WP improvements, are the major limiting factors in the LKRB.
- These problems are due to physical characteristics of the region (soil, hydraulic gradient), but are mainly man-made problems and can be managed by proper measures, including infrastructure activities (hardware) and to greater extent by proper field water management (software) measures.
- In the hardware part: Irrigation and drainage networks are developing in the area, but till now unfortunately it is mainly limited to the main canals/drains and the lower order canals/drains that are necessary for the implementation of proper water management are lacking.
- In the software part: many studies and

Table 18: Location, series, salinity-Sodicity class, some physical characteristics, water resources, and their quality in the soil reclamation (leaching) studies of Dasht-e Azadegan Plain (Mahab-e Ghods 1993b).

Row	Exper-iment	Soil series	Salinity and Sodicity class	Water table depth (m)	Hydraulic conductivity (km/d)	Depth of Impermeable layer	Basic infiltration rate (cm/hr) Value	Description	Class of applied water
1	1 & 2	Hofel	S_3A_2	0.5	0.98	4	0.36 & 0.6	Medium Slow	C_3S_1
2	3 & 4	Karami	S_3A_4	1.5	0.43	3.5	0.14 & 0.22	Medium very Slow	C_4S_2
3	5 & 6	Karami	S_4A_4	0.5	0.65	4	0.18 & 0.22	Slow Rapid	C_4S_3
4	7 & 8	Finikhi	S_2A_1	1.0	0.75	4	2.22 & 3.44	Very rapid	C_4S_2
5	9	Yazd No	S_4A_3	4	0.06	4	1.74	Rapid	C_3S_1
6	10 & 11	Abo Hamizeh	S_4A_1	0.75	0.09	4	1.51 & 2.42	Very rapid Rapid	C_3S_1
7	12 & 13	Koot	S_2A_2	0.5	0.30	4	0.93 & 1.56	Rapid Medium	C_4S_4
8	14	Mojrieh	S_4A_2	4	0.13	4	0.37	Slow	C_4S_2
9	15 & 16	Lolieh	S_4A_2	2.5	0.27	3.5	0.24 & 0.27	Slow	C_4S_2
10	17	ABo Hamizeh	S_2A_2	0.75	1.09	3.5	1.32	Rapid	C_4S_2
11	18	Karkheh	S_4A_3	0.75	1.04	3.5	0.33	Slow	C_4S_3
12	19 & 20	Golbahar	S_3A_2	1.0	0.05	3.5	1.42 & 1.77	Rapid	C_3S_1
13	21	Karami	S_4A_3	1.5	0.04	3.5	0.21	Slow	C_3S_1
14	22 & 23	Hoveizeh	S_4A_3	1.5	0.88	4	0.59 & 1.0	Medium	C_4S_3
15	24 & 25	Ahmad Abad	S_2A_2	0.75	0.01	3.5	0.25 & 0.26	Slow	C_3S_1
16	26 & 27	Ahmad Abad	S_4A_3	1.5	0.04	4	0.32 & 0.43	Medium Slow	C_4S_2
17	28 & 29	Sarieh	S_4A_3	0.5	0.04	3.5	0.32 & 0.82	Medium Slow	C_4S_4
18	30 & 31	Hamidieh	S_3A_3	0.75	1.26	3.5	0.32 & 0.43	Slow	C_3S_1
19	32 & 33	Koot	S_3A_3	1.5	-	3.5	0.17 & 0.22	Slow Very slow	C_4S_2

Source of applied water is Karkheh river

network designs (in the project level) are conducted in the area by consultant engineers and other expert organizations. But these are mostly classic studies and application of new approaches and tools such as use of proper models relevant to the plant, farm, system, and basin levels are lacking or not applied sufficiently. This weakness, even in the comprehensive plans of the basin, is also evident.

- The detailed studies are done mainly at the project level. There is no detailed or semi-detailed studies at the basin level.
- Responsible organization in the region or even in the headquarters in Capital suffer from a clear and well-defined strategies and policies for water management in the Khuzestan province, and especially in the L-KRB, where 2/3 of the country's water recourses flows.
- Wetland interactions with the upstream irrigated agriculture developments could be optimized and managed using proper planning and coordination inside and with outside of the country.
- Water limitations (required for the agricultural lands in the LKRB and all of the aforementioned issues) suggest that we should efficiently use water in the KRB and the policy of WP improvement in the KRB should be given higher priority.

Table 19: Result of soil analysis before and after salt leaching from the soil profile Station: L.1 *(Mahab-e Ghods 1993c).

Applied water (cm)	Soil Depth (cm)	EC (dS/m)	SAR
0	0-25	28	23.4
	25-50	25.5	16.6
	50-75	24.2	21.5
	75-100	24.2	16.8
	100-150	26.4	15.5
25	0-25	18.5	17.2
	25-50	25.3	-
	50-75	23.6	15.6
	75-100	22.9	16.5
	100-150	7.3	18.4
50	0-25	8.3	9.9
	25-50	15.8	-
	50-75	22.9	17.2
	75-100	26.4	19.3
	100-150	5.1	19.9
75	0-25	7.6	5.8
	25-50	10.8	9.2
	50-75	24.5	17.6
	75-100	24.8	20.9
	100-150	8.9	20.8
100	0-25	8.3	12
	25-50	10.1	11.6
	50-75	11.1	14.5
	75-100	19.3	13.5
	100-150	-	19.3

*Characteristics of soil profile in location of L1 were: Soil series: Hofel; Soil texture: Silt-Loam; Soil salinity-sodicity class: S3A2; Water table depth: 0.5 m, Hydraulic conductivity (K): 0.98 m/d; Depth of impermeable layer: >4 m, Basic Infiltration rate 0.6 cm/hr (low), Salinity class of applied water: C3S1 (EC=1.75 dS/m, SAR= 1.8, pH= 7.6) (Mahab-e Ghods 1993d).

- 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 stalled in this region. Water logging and resource salinity are major threats to water productivity and sustainable agricultural activities in the lower KRB region and sound solutions that are adoptive and adaptive by farmers are necessary.
- 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, which have been postponed to the next phase of the CGIAR Challenge Program on Water and Food (CPWF).

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CHAPTER V

Causes and Management of Salt-Prone Land Degradation in Lower Karkheh River Basin

S.A.M. Cheraghi[1], Y. Hasheminejhad[2], and N. Heydari[3]

[1]Director, National Salinity Research Center (NSRC), Yazd, Iran
[2]National Salinity Research Center (NSRC), Yazd, Iran
[3]Agricultural Engineering Research Institute (AERI), Karaj, Iran

INTRODUCTION

Salt-prone land and water resources are major impediments to the optimal utilization of crop production systems in many arid and semi-arid regions of the world including Iran (Alizadeh et al., 2004; Moghaddam and Koocheki, 2004). The salinization of land and water resources has been the consequence of both anthropogenic activities (causing human-induced or secondary salinity and/or sodicity) and naturally occurring phenomena (causing primary fossil salinity and/or sodicity) (Ghassemi et al., 1995). The main cropping systems in the country are based on irrigated agriculture where at least 50% area (4.1 Mha) falls under different types of salt-affected soils (Cheraghi, 2004). Therefore, the dependency on irrigated agriculture is at stake in areas where salt-prone land and water resources degradation has increased over time.

Human-induced salinization of land and water resources has occurred mostly in unique topographic conditions of semi-closed or closed intermountain basins where irrigated agriculture has been practiced for centuries. The slightly and moderately salt-affected soils are mostly formed on the piedmonts at the foot of the Elburz (Alborz) Mountains in the northern part of the country. The soils with severe to extreme salinity are mostly located in the Central Plateau, the Khuzestan and Southern Coastal Plains, and the Caspian Coastal Plain (Koocheki and Moghaddam, 2004).). The extent and characteristics of salt-affected soils in Iran has been investigated by several researchers (Dewan and Famouri, 1964; Mahjoory, 1979; Abtahi et al., 1979; Matsumoto and Cho, 1985; Banie, 2001).

Owing to abundant water resources, fertile lands and sufficient extraterrestrial energy, Khuzestan province in the southwest Iran is one of the potentially most suitable regions for agricultural production. However, salinization of land and water resources has become a serious threat to efficient use of these valuable resources. It is estimated that out of the total 6.7 Mha of the province, 1.2-1.5 Mha (18-22% of total area) are faced with the dual problems of soil salinization and water logging (Anonymous, 2000).

Karkheh River Basin (KRB) is one of the major river basins in the Khuzestan province consisting of two main sub-basins namely Karkheh Olia (upstream) and Karkheh Sofla (downstream). The Karkheh River Basin is, most notably, the eastern flank of the 'cradle of civilization' (ancient Mesopotamia) and a boundary between the Arab and Persian cultures. This major river system of western Iran has unique agricultural and hydrological aspects; but also much in common with other catchments around the world, e.g., rural poverty and land degradation, low water and agricultural productivity, a dry climate, and growing upstream-downstream competition for water. Agriculture in the upstream basin is mainly rain fed, while the downstream basin is mostly irrigated. The drainage outlet of the KRB, which also is a basin outlet, is the Hoor-Al-Azim swamp in southwest Iran and on the Iran-Iraq border (Figure 12). At present, there are very limited modern irrigation and drainage networks under operation within the KRB and agriculture is yet to be fully developed. However, the government has started constructing irrigation and drainage networks with the goal of improving the traditional irrigation systems, e.g., in the Dasht-e-Azadegan (DA) plain in southern parts of the Lower KRB (LKRB).

In southern parts of the Lower KRB (LKRB), available data and surveys show that the problem of soil salinity is magnified by lack of availability of new and improved farming practices and farmers' knowledge about salinity and shallow water table management under irrigation. In general,

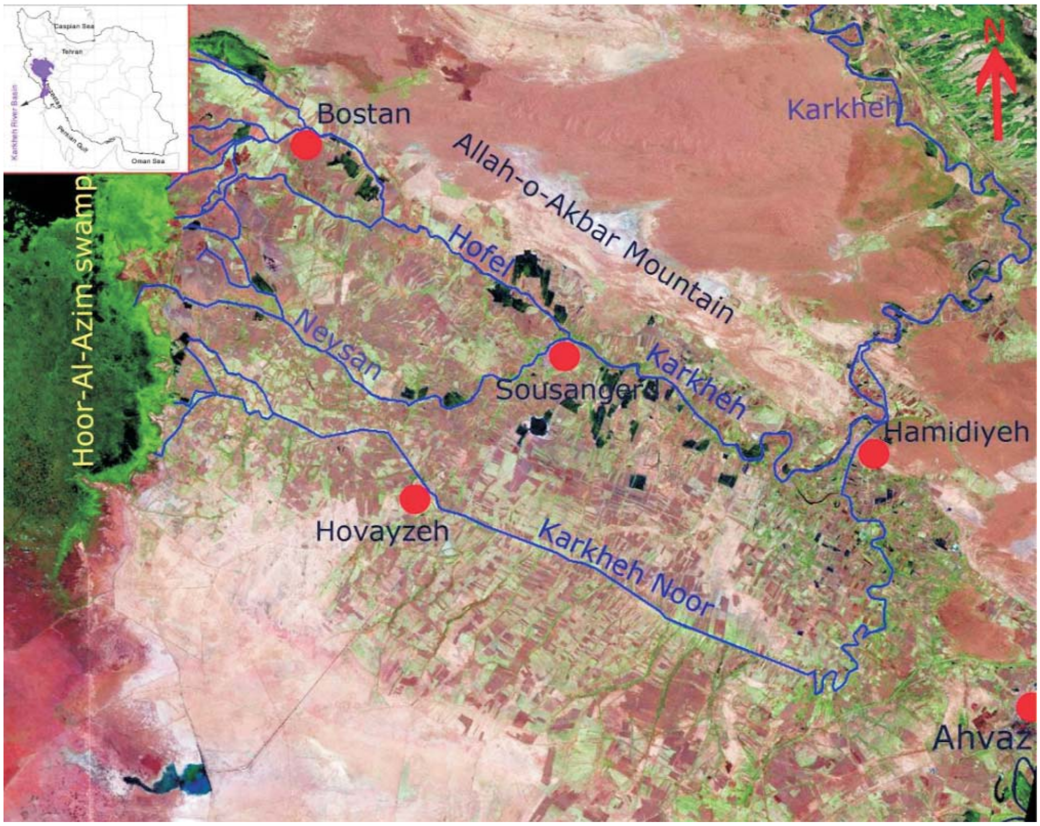

Fig. 12. Lower part of Karkheh river basin in Khuzestan province.

the main cause of soil salinity in the LKRB is high water-table, often less than 2 m; usually 1.2-3.0 m below the soil surface, (Anonymous, 1989). If left without appropriate management, the problem is likely to worsen considering the current plans for expansion of irrigation networks.

Dasht-e-Azadegan consists of three subdivisions (or towns), namely Sosangerd, Hoveyzeh, and Bostan. The total area of DA is 334,000 ha, of which only 70,000 ha (20%) is currently cultivated due to shortage of available water resources and conveyance networks. Upon completion of the planned irrigation networks, an additional area of about 60,000 ha will be added to the irrigation area. Only in the southern part of Hoveyzeh (see Fig. 12), there are 60,000 ha of non-cultivated arable land. Total population of DA is almost 160,000 people, of which 65% are living in the towns. The total number of villages at present is 180, a number that was nearly twice before many were displaced in early 1980s by the Iraq-Iran conflict (Anonymous, 1989).

The source of irrigation water is mostly by pumping from the Karkheh River into conveyance irrigation canals. There are also limited constructed irrigation networks in the region. The main canals and drains are mostly completed or under construction, but there are no secondary or tertiary irrigation canals or drain laterals. At present, despite the construction and operation of main drains in the area, the system is not properly functioning at all areas. This is mainly due to technical and excavation problems (i.e., improper slope of drainage lines) and due to problems concerning the outlet. Gravitational drainage to outlet is practically not feasible and pumping is required. Negative environmental impacts regarding drainage flow directly into the Hoor-Al-Azim swamp is also another concern that should be considered.

The soils of the area are alluvial formed originally by the floods of the river. The alluvial areas are flat and soil permeability is low with a little slope and poor natural drainage. The groundwater level is close to the surface and a slow salt accumulation has occurred. Salinization has occurred primarily in the top soil layers and is dominated by chloride salinity, as evidenced by the high correlation between chloride ion concentration and electrical conductivity shown in Figure 13. River banks and elevated areas are slightly saline to non-saline, whereas strong salt accumulation is observed in depressions remote from the river where salt is build up by water seeping from the river. An estimate of the total salt-affected soils exceeds 225,000 ha, out of which only 92,000 ha is suitable for irrigation (Anonymous, 2000).

Besides the above-mentioned factors, secondary salinization is also an important cause of salinity in the area. Seepage from irrigation channels most of which are unlined and deep percolation losses from conventional surface irrigation methods largely contribute to groundwater rise and salinization of soil.

This paper presents major causes of soil salinity along with a review of some of the research work carried out in the lower KRB with respect to soil salinity. The article concludes by drawing attention to areas where research is needed.

MAJOR CAUSES OF SOIL SALINITY IN THE LOWER KARKHEH BASIN

Major factors causing soil salinization in the lower Karkheh Basin can be classified as follows (Balali, et al., 2000; Ghobadian, 1969):

1. High groundwater table
2. Salt containing layers
3. Inadequate drainage facilities
4. High evaporation
5. Salt intrusion by wind
6. Sediment transport during flood periods

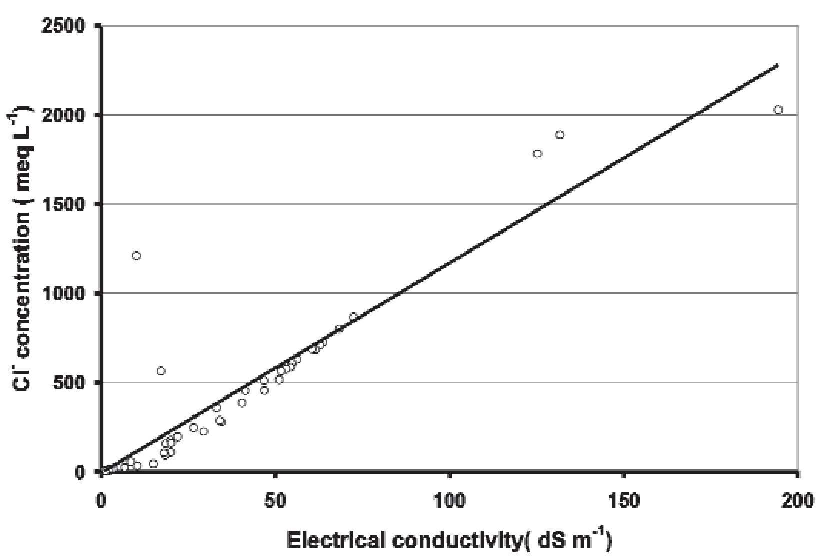

Fig. 13. Correlation between electrical conductivity (dS m^{-1}) and Cl$^-$ concentration (meq L^{-1}) for water and soil solution samples in DA.

High Groundwater Table

High water tables is the major factor of soil salinization in Khuzestan province. The salt concentration in groundwater is extremely high, exceeding 100 g L^{-1} in many cases. It should be mentioned that groundwater could cause salinity in cases where its level is higher than a certain depth. This specific depth of groundwater is called critical depth, which varies between 2.5-3.5 m. It means that soil salinization due to capillaries and its accumulation in the plow layer will be expected if the distance between the soil surface and the water table is smaller than the above-mentioned depth.

In arid and semi-arid regions such as Khuzestan province where upward water flux due to high evaporation is considerable, even fresh groundwater causes soil salinization because of high groundwater level. Investigations have shown that in most parts of Khuzestan, groundwater level is higher than the critical depth. This case is especially true for the regions where extended agriculture had developed. It is observed that in non-arable lands, the groundwater level is usually deeper than the critical depth, but near villages where agricultural practices are more intensified, the problem is more severe. In LKRB, the groundwater level in non-arable land (or specific locations which had not been cultivated during the Iran-Iraq war 1979-1989) varies between 4-7 m while its level is about 1.2-3.0 m in cultivated land. This difference shows the significance of agricultural return flow effects.

A high groundwater level for extended periods, especially in the hot season, causes specific morphological characteristics in the soil profile, which are the results of periodic oxidation- reduction conditions due to variations of the ground water level. These specific symptoms are more pronounced in the presence of organic carbon and sesquioxides. One of the most popular signs of this kind is mottling (segregation of subdominant color different from surrounding region's color). In Ahmadabad soil series (west of Dasht-e-Azadegan), which is heavy textured and has a hard massive structure, gley spots are observed in some profiles below 1 m depth.

In Abohomayzeh soil series, weak gley spots and mottling can be observed. West of the Bostan- Pol-e-Ramazam road and near Shatt-e-Abbas, Machriyeh, Jarrahieh, and Lulieh soil series, which are generally flooded during early winter up to late spring, the soil, is usually waterlogged half of the year. Therefore, the soil moisture regime at the moisture control section of these profiles is aquic with diagnostic symptoms of mottling and gley spots.

Salt Containing Layers

A salt containing layer is a horizon or a layer of geological material in which salt content is not only high, but also higher than the rest of the soil profile. If these layers are located in a depth less than 0.5 m below the soil surface, especially in heavy textured soils, top soil salinization occurs as in the case of Khuzestan.

In DA plain, despite high calcium carbonate and calcium sulfate content of the soil, no calcic or gypsic diagnostic horizons were identified. However, accumulation of hygroscopic salts such as $CaCl_2$, $MgCl_2$, $MgSO_4$, and KCl in combination with NaCl can be observed in both sides of river banks. High temperature differences between river, lateral canals and irrigated land causes moisture diffusion and evaporation that in turn leaves huge amounts of salt on the soil surface. Salic diagnostic horizons had been identified only in Abohomayzeh, Kout and Jarahyeh soil series. In Abohomayzeh and Jarahyeh series, soil surface is highly dispersed.

Inadequate Drainage Facilities

Most of Khuzestan's soils are heavy textured and have a slight slope and therefore, the importance of adequate drainage facilities is obvious. However, in many cases little attention has been paid to this problem. Drains, which had been dug, are generally the main drains and are deep. Although these drains can partly absorb the drainage water of the surrounding area, their effective radius is small. Natural drains, which discharge to the main outlet of the region (Hoor-Al-Azim), are not functioning well due to technical and environmental problems and due to the very low slope of land. Problems associated with inadequate drainage are more serious in low lands and areas with low slope.

The West side of DA is usually flooded during winter and spring. During summer, salts, which have been leached into the sub-soil, tend to rise and accumulate on the soil surface due to the high evaporation. The surface of these soils is often cracked during the hot and dry season, which is related to the high clay content of these soils. As a result, infiltration rates are low.

High Evaporation

One of the factors which accelerate soil salinization under high ground water condition is high evaporative demand, which causes continuous upward flux of salt containing water to the top soil or at least in the warm season. Critical depth of groundwater table which will cause soil salinization is highly dependent on evaporation rate beside the soil type. For example in Khuzestan it had been reported to be variable between 2.5 and 3.5 m based on soil type and evaporation demand. Occurrance of 260 dry days in Hamidieh, and 290 dry days in Ahvaz, are some climatic characters of the region. In Hamidieh, annual precipitation is 245 mm while annual evaporation is 2205 mm, or evaporation to precipitation ratio exceeding nine. Surface evaporation is one of the most important meteorological factors in the region affecting soil genesis processes significantly. High evaporation leads to capillary rise of soluble salts and their accumulation at the soil surface. Table 20 presents some climatic characters of Khuzestan province.

Table 20: Long-term meteorological data of selected stations in Khuzestan province.

station	mean annual evaporation (mm)	Mean air temperature (°C)			absolute temperature (°C)		total precipitation (mm)	mean relative humidity (%)
		Max.	Min.	Mean	Min.	Max.		
Abadan	4077	32.7	17.7	25.2	-5	53	155	46
Omidie	3514	33.0	17.2	25.1	-2	51	260	48
Ahvaz	3517	32.8	17.2	25.0	-7	54	233	43
Izeh	2667	27.8	13.9	23	-6.8	46	637	41
Bostan	3619	31.7S	15.3	23.5	-4	50.8	217	47
Behbahan	3446	32.2	16.8	25.1	-2.8	50.6	332	42
Ramhormoz	2981	32	18.6	25.3	-0.6	50.2	301	40
Dezfoul	2334	31.4	15.3	23.4	-1.8	50.5	370	46
Shooshtar	3665	32.8	20.1	27.6	-0.2	51.8	317	39
Mahshahr	3944	32	17.9	24.9	-2	51	220	45
Masjed Soleyman	3246	31	18.9	25	-4.4	51	450	38

Salt Intrusion by Wind

The dominant directions of winds in this region are west, northwest, and southeast, which occur as dust storms. They carry huge quantities of sediments that are mostly deposited on the surface of the plains. It had been estimated that in each storm event about 5-50 kg salts ha^{-1} is deposited on the soil surface, which accumulates to about 200-1000 kg ha^{-1} annually. It is suggested that the deposited salts originate from the coastal lands of both sides of the Persian Gulf and of the Gulf of Oman. They are salt intrusion by wind erosion. These salt deposits are translocated within the region. It has been estimated for Khuzestan province that 10-50 mg salts ha^{-1} are translocated from one point to another. It should be mentioned that the risk of accumulation of these salts is more serious around the villages (Ghobadian, 1969).

Sediment Transport in the Flood Periods

The origin of most of the soil series in DA derives from the sediments of Karkheh River and its branches except for the low lands. Hence, the salt content of sediments from Karkheh River affects salinity and sodicity of these soils. In the low lands, there is no horizontal stratification of the soils, although this fact may be related to pedoturbation in heavy textured soils as the case of Shat-e-Abbas soil series. Except for Jarahyeh series, which is highly saline and sodic, the other soil series of this region are naturally leached by Karkheh River and its branches.

The groundwater level in these areas is highly variable and is affected by the different seasons. During winter and spring, soils are completely waterlogged. In contrast, during early summer the groundwater table is relatively high while it is low in fall. After flood periods, large parts of the region are submerged. During the dry season, water drawing back from land of higher elevation leads to the formation of small swamps (Hour) and permanent ponds in the low lands. Typical examples are the small swamps around the Hour-Al-Hoveyzeh. In 1968, about 3000-4000 km^2 of Khuzestan province were flooded with estimated sediment loads of about 1.5 million tonnes of salt on the soil surface (Ghobadian, 1969)

PAST RESEARCH AND DEVELOPMENT

Soil desalinization and land reclamation research in Khuzestan province has a relatively long history when compared to other provinces. Mohajer Milani and Javaheri (1998) summarized the result of a series of experiments conducted by the Soil and Water Research Institute (SWRI) on leaching behavior of soils throughout the country. In a general conclusion, they pointed out that for leaching 80% of salts of a soil layer, approximately the same depth of water is required (Fig. 14).

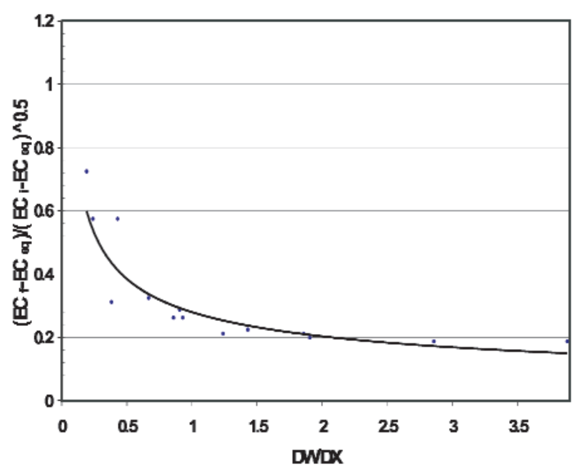

Fig. 14. Soil desalinization curve for south Khuzestan 1986. (After Mohajer Milani and Javaheri, 1998).

DW is the depth of the leaching water (m), DX is the soil depth (m), ECi is the initial salinity of soil saturation extract before leaching (dS/m), ECf is the final salinity of soil saturation extract after leaching (dS/m) and ECeq represents the salinity of soil saturation extract obtained after salinity has reached an equilibrium under specified local conditions.

In another study by Pazira and Sadeghzadeh (1998), the desalinization curve and equation for some soil series of Khuzestan was determined (Fig. 15).

For the studied soils, the following equation was developed:

$$(EC_i - EC_{eq}) / (EC_f - EC_{eq}) = 0.0761(DS/ \quad Dlw) + \quad 0.023 \ldots\ldots(1)$$

where Dlw is the depth of the leaching water (m), DS is the soil depth (m), EC_i is the initial salinity of soil saturation extract before leaching (dS/m), ECf is the final salinity of soil saturation extract after leaching (dS/m) and ECeq represents the salinity of soil saturation extract obtained after salinity has reached an equilibrium under specified local conditions.

Pazira (1974) studied the effect of drains spacing on soil chemical properties and wheat yield. It was found that a horizontal distance of the drains of 150 m improved soil chemical properties, but its effect was not significant on grain yield. A study carried out by SWRI (1972) indicated that leaching in combination with rice and clover cultivation improved the physico-chemical properties of salt-affected soils.

Saremi (2000) evaluated the effect of phytoremediation of saline-sodic soils using forages like Kallar grass (*Leptochloa fusca L. Kunth*). The results showed that the grass cultivation had reduced soil salinity in 0-0.3 m depth layer by 70% and sodium adsorption ratio (SAR) by 60% while producing about 22 tonnes fresh forage ha^{-1}.

The effect of different irrigation methods under saline conditions on wheat yield was studied in Khuzestan province (Soleiman Nejad, 1998). Results of his trails in DA showed that border irrigation gave maximum yield in comparison to furrow and traditional systems. The difference in yield between border and furrow irrigation was 292.5 K ha^{-1}, which was statistically significant at 0.01 levels. This difference was 172.5 K ha^{-1} when compared to traditional system and was not significant. On the other hand, it was mentioned that soil sur-

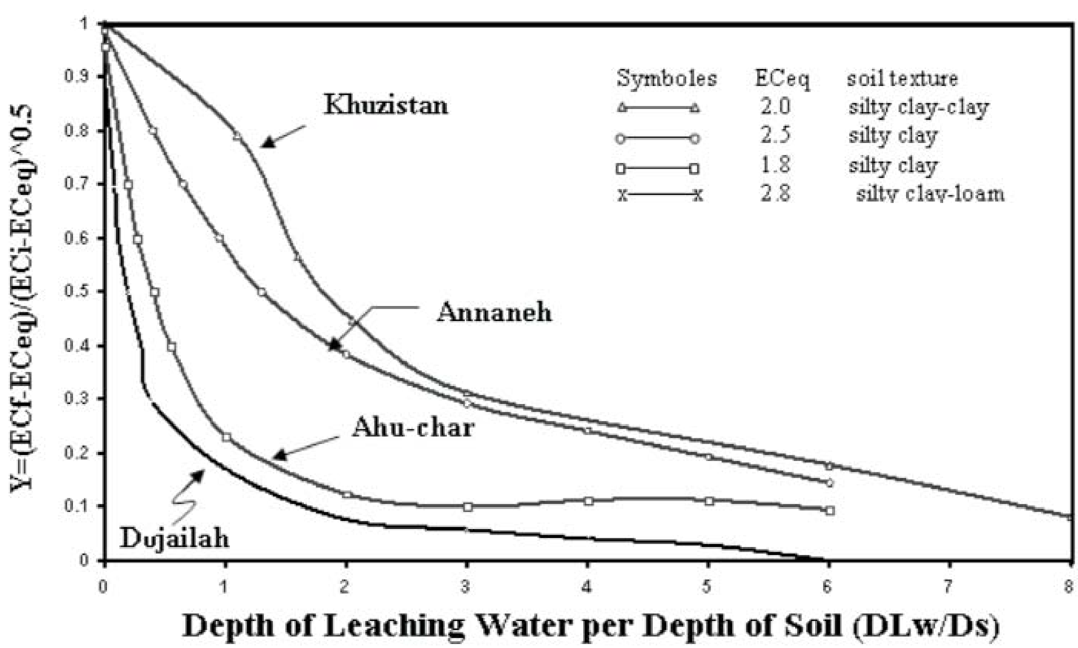

Fig. 15. Soil desalinization leaching curve for some saline soils in Iran. (After Pazira *et al.*, 1998).

face salinity in late summer is 2-5 times higher than its salinity in early spring due to upward transport of salts after harvest. Therefore, soil leaching before sowing is a pre-requisite.

Little information is available on the effect of different soil conditioners on ameliorating soils' physico-chemical properties. It seems that most efforts have been concentrated on the effect of different fertilizer sources and amounts on crop production under saline conditions of this province. Balali et al. (2000) presented a computer model for fertilizer recommendation of wheat. In this model, the production potential of wheat for different provinces of the country is determined and fertilizer recommendation is presented based on this value. However, under saline conditions the recommendation is adjusted due to the type of fertilizer and level of salinity.

So far, no salt-tolerant crop variety suitable for saline conditions of the province has been released. Two wheat cultivars cultivated in saline areas, namely Chamran and Verinak, were originally released for dry land and warm climates in Khuzestan province (SPII, 1990), and were not necessarily salt-tolerant varieties. Their pedigree is Vee kf/ Nac kf and Attilla 50, respectively. Another wheat variety that is common in this region is Yavarous, which is durum wheat.

FUTURE RESEARCH AND DEVELOPMENT

Existence of drainage is fundamental to improving the quality of salt-affected soils. It reduces the adverse effects of shallow water tables and water logging, and hence, improves crop production. There is no doubt that one of most important needs for the study area is to complete an adequate drainage network for the entire irrigated area. Encouraging efforts has been initiated in this regard, but the drainage system is incomplete. Lateral connections are lacking, and the drainage system covers only a limited area under irrigation. It is noted that agricultural management practices cannot serve as a substitute for adequate drainage of salt affected and waterlogged soils. Most efforts in improved management to reduce the impact of salinity are suggested to have a rather temporary effect. To avoid further salinization of agricultural soils, the communities and agricultural agencies are called to apply sound management practices until an adequate drainage is installed.

The agricultural cropping systems and practices in the subject area are suboptimal and should be improved. Appropriate irrigation schedules based on soil moisture depletion or climatic data would prevent excess losses of irrigation water into the subsoil or groundwater. To increase the efficiency of water use, irrigation water must be applied uniformly. Land levelling could improve water distribution and limit waterlogging problems. At present, the crop varieties used by farmers are not adapted to the prevailing soil conditions and significant improvements in production could be realized by introducing salt-tolerant varieties.

Another important factor limiting crop production is the accumulation of salt in the top soil, which mainly occurs during the fallow period when the soil is uncultivated. Leaching of salts before sowing can reduce the adverse effects of salt on crop establishment. Other suitable practices are trash mulching and suitable crop rotations. There are also knowledge gaps on the effect of chemical amendments on ameliorating physical-chemical properties of sodic soils.

One of the most important pre-requisites to enable permanent crop production in this region is the development of a monitoring network comprising monitoring the effect of different management practices on the salt content of groundwater as well as salt and water balance of the root zone. These regular measurements will provide the data required to suggest the best methods to prevent salinity in the root zone and groundwater. On the other hand, water and salt balance studies at the watershed scale will increase our ability to predict the role of any hydrological unit in the fate and behavior of catchments.

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Project National Team in Iran

Dr Z. Shoaei - Director General, Dept of Intl Scientific & Research Affairs, AREO, and Focal Person for CPWF projects in Karkheh River Basin (KRB), Tehran

Dr A. Javadi - Director, Agricultural Engg Research Institute (AERI), and National Coordinator of Water Productivity Project, Karaj

Dr M.H. Davoudi - Director, Soil Conservation & Watershed Mgmt Research Institute, Tehran

Dr S.A.M. Cheraghi - Director, National Salinity Research Center, and Principal Investigator of Water Productivity Project, Yazd

Dr A. Ghaffari - Director, Dryland Agricultural Research Institute, Maragheh

Dr F. Abbasi - Deputy Director Assistant Coordinator of Water Productivity Project, AERI, Karaj

Dr N. Heydari - CPWF Karkheh Basin Coordinator, Irrigation & Drainage Dept, AERI, Karaj

Dr H. Dehghanisanij - Irrigation & Drainage Dept, AERI, Karaj

Dr M. Akbari - Irrigation & Drainage Dept, AERI, Karaj

Dr S. Ashrafi - Irrigation & Drainage Dept, AERI, Karaj

Engr. A. Keshavarz - Senior Irrigation & Water Mgmt Scientist, Principal Investigator and former National Coordinator of Water Productivity Project, Tehran

Dr S.A. Asadollahi - Director General and Under Secretary of Iranian National Committee on Irrigation & Drainage, Ministry of Energy, Tehran

Dr E. Pazira - Professor, Azad Islamic University, Research Science Division, Tehran

Engr. M. Moayeri - Director, Safi Abad Research Station, Dezful

Engr. B. Hessari - Irrigation Researcher, AERI branch in West Azarbaijan Ag. Research Center, Uromieh

Engr. S. Absalan - Agricultural Engg Research Div, Khuzestan Ag. Research Center, Ahwaz

Engr. E. Dehghan - Agricultural Engg Research Div, Khuzestan Ag. Research Center, Ahwaz

Engr. A.F. Nato - Research Staff, Safi Abad Ag. Research Center, Dezful

Engr. Y. Hasheminejhad - National Salinity Research Center, Yazd

Engr. G.H. Ranjbar - National Salinity Research Center, Yazd

Engr. M.H. Rahimian - National Salinity Research Center, Yazd

Engr. A. Anagholi - National Salinity Research Center, Yazd

Engr. A. Abayani - Khuzestan Agricultural & Natural Resources Research Center, Ahwaz

Engr. A.R. Tavakoli - Irrigation Researcher, DARI, Kermanshah

Engr. H. Asadi - Research staff, Seed & Plant Improvement Research Institute, Agricultural Economics, Karaj

Engr. A. Ayeneh - Seed & Plant Improvement Res. Div., Khuzestan Ag. Research Center, Ahwaz

Engr. F. Mazraeh - Extension Div. of Azadegan and Sorkheh Agricultural Mgmt Dept, Khuzestan Agricultural Organization, Ahwaz

Engr. M. Ghamarinejad - Head of Agricultural Service Center of Sorkheh Agricultural Mgmt Dept, Khuzestan Jihad-e-Agricultural Organization, Dezful

Project International Team

Dr. T.Oweis - Director, Integrated Water & Land Management Program, & Project Manager of Water Productivity, International Center for Agricultural Research in the Dry Areas - ICARDA, Aleppo, Syria

Dr. H. Farahani - Integrated Water & Land Management Program, & Assist. Project Manager of Water Productivity, ICARDA, Aleppo

Dr. H. Siadat - Integrated Water & Land Management Program, & Facilitator/Coordinator of Water Productivity, ICARDA, Tehran

Dr. A. Bruggeman - Integrated Water & Land Management Program, ICARDA, Aleppo

Dr. M. Qadir- Integrated Water & Land Management Program, ICARDA, Aleppo

Dr. K. Shideed - Director, Social, Economic & Policy Rsrch.Prog., & PI of Water Productivity project, ICARDA, Aleppo

Dr. E. De Pauw - Head, Geographic Info. Systs. Unit, & PI of Water Productivity project, ICARDA, Aleppo

Dr. J. Anthofer - Integrated Water & Land Management Program, ICARDA, Aleppo

Dr. M. Pala - Integrated Water & Land Management Program, ICARDA, Aleppo

Dr. T. Hsiao - Prof., University of California at Davis, & PI of Water Productivity project, Davis, California, USA

Dr. A. Qureshi - International Water Management Institute, & PI of Water Productivity project, Karaj

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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 Karkheh River Basin (Project no. 8)

Project partner institutions and contacts
Website: http://www.karkheh-cp.icarda.org/karkheh-cp/default.asp

ICARDA
Theib Oweis
P.O. Box 5466, Aleppo, Syria
Tel.: +963 21 2213433, Fax: +963 21 2213490
E-mail: t.oweis@cgiar.org

IWMI
Asad Qureshi
P.O. Box 3185-845, Karaj, Iran
Tel.: +98-261 2716840, Fax: +98-261 2716921
E-mail: a.sarwar@cgiar.org

AREO (AERI, SCWMRI, NSRC, DARI)
Arzhang Javadi
P.O. Box 31585-845 Karaj, Iran
Tel.: +98-21 3130078, Fax: +98-261 2704846
E-mail: email2arzhang@yahoo.com

University of California, Davis
Theodore Hsiao
Davis, CA 95616, USA
Tel.: +1-530 7520691, Fax: +1-530 7525262
E-mail: tchsiao@ucdavis.edu