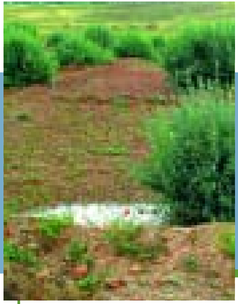

Mega-Project 1

Management of Scarce Water Resources and Mitigation of Drought in Dry Areas

Introduction

The Management of Scarce Water Resources and Mitigation of Drought in Dry Areas Mega-Project focuses on strategic research on sustainably increasing water productivity, and has expanded its scope from the farm to the watershed and basin level. Partnerships within the Challenge Program on Water and Food and with IWMI have been established to achieve a complementarity whereby ICARDA focuses on assessing and improving on-farm water productivity and IWMI focuses on out-scaling to the basin level. Increased emphasis is being placed on the assessment of scarce water resources, including both fresh and marginal-quality water, and their sustainable allocation to various uses. By linking to other Mega-Projects of ICARDA, Mega-Project 1 integrates research on drought preparedness and mitigation through the optimal management of water resources and use of adapted crops and crop varieties and appropriate cropping patterns. The research and capacity building across the dry areas on developing drought mitigation packages is conducted within a network with FAO, CIHEAM and NARS. The drought network benefits from the intergovernmental system of the FAO and the strong Mediterranean partners of ICARDA and CIHEAM.

Greater emphasis is given to the dissemination of improved options through integrated and multidisciplinary research, and the use of participatory research approaches at the community level at selected benchmark sites. Research on policy and institutions is also included in the Mega-Project 1 portfolio, and implemented across all benchmark projects and activities with a view to model the biophysical and socioeconomic components of the system and develop improved policy and institutional options.

Making wastewater use safer in Syria

Water resource management is especially important in dry areas with fast-growing urban populations. Growing cities such as Damascus and Aleppo in Syria require more clean water while producing larger amounts of domestic and industrial wastewater. To maximize the safe use of wastewater and minimize threats to the environment and human health, ICARDA and IWMI assessed the production, treatment, and use of wastewater in the Aleppo region of the Euphrates-Aleppo Basin.

The Qweik River, which has been polluted with wastewater from Aleppo, Syria. In 2005, researchers from ICARDA and IWMI assessed the production, treatment, and use of wastewater in the Aleppo region, to help maximize the safe use of wastewater and minimize threats to the environment and human health.

Wastewater treatment

Findings show that nearly one-third of Syria's wastewater is treated before it is used for irrigation or discharged into rivers or the sea. In 2006–2007, new wastewater treatment plants will be completed, increasing the amount of wastewater treated by 30% (Table 1).

Wastewater use by farmers

Farmers prefer to use wastewater for irrigation, and researchers found three main reasons for this. The most important, given by 57% of farmers, was the year-round availability of wastewater. The second most important reason (26% of farmers) was the high nutrient content of wastewater, which reduces or even eliminates the need for expensive chemical fertilizers. The third reason (17% of farmers) was that pumping wastewater costs less than pumping groundwater.

Wastewater is used on less than 5% (69,000 ha) of Syria's irrigated land, and treated wastewater is used on only half of this area (37,000 ha). However, although the area irrigated with wastewater is small, it is economically important.

Wheat is the most important crop grown on half the wastewater-irrigated area, followed by cotton, faba bean, and vegetables. Less than 7% of the area under wastewater irrigation is devoted to vegetables, mainly because a 2003 Syrian code of practice prohibits the use of wastewater on vegetables that will be eaten raw.

Costs and benefits of wastewater irrigation

A comparative cost-benefit survey in the Aleppo region indicates that when irrigated with wastewater, wheat produces twice as much benefits as when irrigated with groundwater (US$5.31 per US dollar invested, compared with US$2.34; Table 2). Wheat irrigated with wastewater produces higher yields because of the high nutrient content of the wastewater. Farmers also save on the costs of fertilizer (US$95/ha) and pumping.

Table 1. Capacity of wastewater treatment plants in 2005 and of those planned for 2006–2007 in Syria.

Year	Estimated capacity of wastewater treatment plants m^3/day	m^3/year	% of total wastewater treated
2005	978,000	357,000,000	31
2006–2007	1,300,000	475,000,000	41

Table 2. Comparison of the cost-benefit ratio of irrigating with wastewater and groundwater.

Crop	Cost benefit ratio† Wastewater irrigation	Groundwater irrigation
Wheat	5.31	2.34
Cotton	5.17	5.23
Faba bean	5.30	2.93
Vegetables	7.48	3.29

†Calculated as the ratio of gross income to the cost for each crop.

Irrigation with wastewater does raise concerns about soil and water pollution. However, because no data is available on the background levels of metal and metalloids in Syrian soils, it may not be possible to work out how much contamination is being caused. Contamination is likely, however, because less than half of the wastewater used is treated, and treatment plants are designed to treat domestic wastewater, not industrial wastewater.

Over one-third of farmers know that direct contact with untreated wastewater may affect their health and that of their family members. Data from other sources in two areas where wastewater is used for irrigation—Ghouta, a peri-urban area of Damascus, and the study area in the southern part of Aleppo—showed that 75% of the population suffered from dysentery.

Recommended interventions

The researchers have recommended interventions to maximize the benefits of wastewater irrigation while minimizing the risks.

1. Optimize the performance of wastewater treatment plants
2. Prevent industrial wastewater from entering domestic wastewater treatment plants
3. Encourage industries to treat their wastewater
4. Restrict the disposal of untreated wastewater to stop surface water from being contaminated
5. Monitor harmful contaminants in surface and groundwater
6. Monitor the build-up of chemical pollutants in crops and soils.
7. Enforce the 2003 Syrian code of practice on wastewater treatment and use
8. Evaluate the socio-economic impact of wastewater on farming communities

The study also found that there was a critical shortage of trained Syrian staff to monitor and analyze solid and liquid wastes. Only a few staff have the technical skills to operate, maintain, and monitor industrial wastewater treatment plants. Capacity building is, therefore, needed to enable government staff to implement, on a large scale, new options for wastewater treatment and use.

This is important because responsibilities for the treatment, disposal, and use of wastewater span institutional boundaries. Research leading to new wastewater use technologies could help communities to benefit more while minimizing adverse environmental impacts.

Benchmark sites for water research in the dry areas

There are three major agro-ecosystems in the dry areas: irrigated, rainfed, and marginal rangelands (*badia*). Shortage of water is the key constraint in all these environments. The most critical issue for farmers is how to increase and sustain productivity with limited water. ICARDA has established representative research sites (benchmark sites) in all three agro-ecosystems (Fig. 1).

In partnership with national research systems and rural communities, the Center is using these ‘field laboratories’ to develop and test technological options for improving productivity and sustainable use of water. Benchmark sites for the irrigated, rainfed, and *badia* environments were established in Egypt, Morocco, and Jordan, respectively. Successful technologies will be transferred to other similar agro-ecosystems.

Problems that are not represented in the benchmark sites, but which occur in similar agro-ecosystems elsewhere, are addressed in ‘satellite’ sites in other countries. The satellite sites complement benchmark sites and are used to outscale the results to other areas. The irrigated satellite sites are located in Iraq and Sudan; and the rainfed sites in Algeria, Tunisia, and Syria. The *badia* satellite sites are located in Saudi Arabia and Libya.

Selection and characterization of the *badia* benchmark site

The *badia* climate is harsh, with insufficient rainfall for crop production. The little water available is poorly managed and much of the rainwater is lost through runoff and evaporation. Water harvesting—concentrating runoff for beneficial uses—is perhaps the most promising way of improving productivity in the *badia*. The watershed level was selected as the most appropriate for water-harvesting studies because the techniques will affect both upstream and downstream users.

To select a benchmark site for water-harvesting research in the Jordan *badia*, researchers mapped the boundaries of the main watersheds and sub-watersheds based on contour lines and drainage systems. They identified 226 main watersheds, ranging from 0.3 to

Fig.1. Water benchmark sites in CWANA.

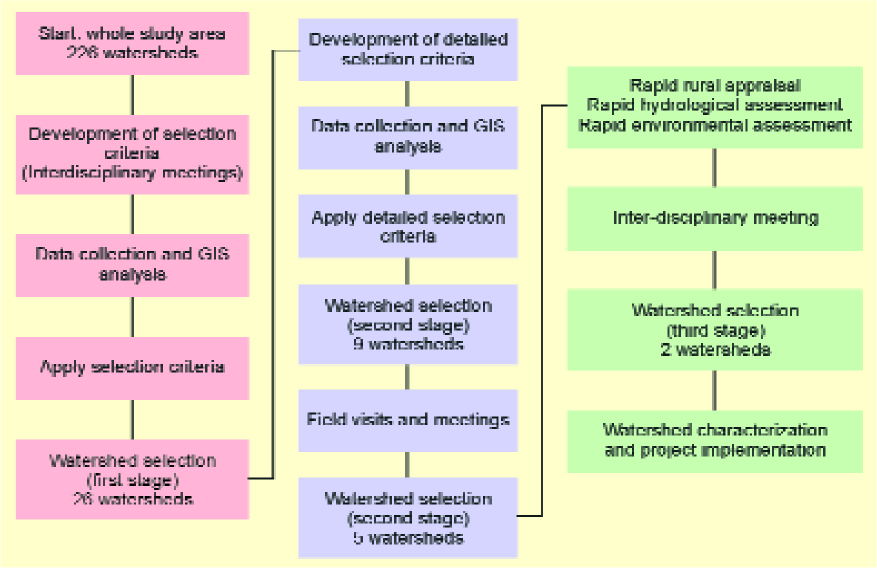

Fig. 2. The benchmark site selection process.

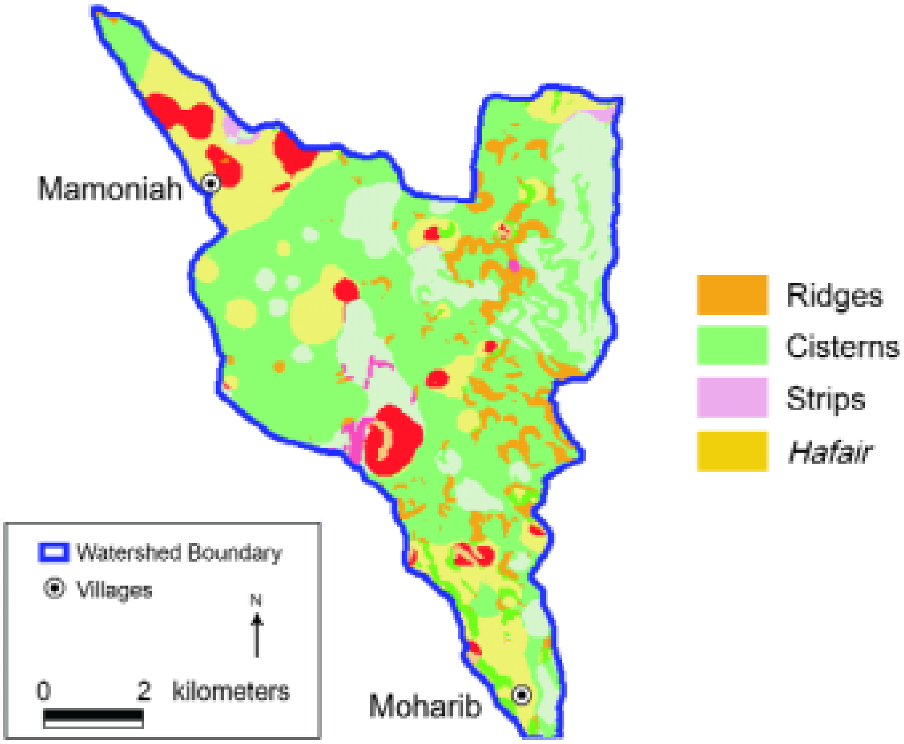

Fig. 3. Suitability map for various water-harvesting techniques in the Moharib watershed, Jordan.

266 km^2 in a zone of 'transitional *badia*' with average annual rainfall of 100–200 mm.

A multidisciplinary team of experts then scored the watersheds using five main selection criteria: rainfall, location of communities, soil type, watershed area, and topography. Forty watersheds scored highly, but 14 of them were excluded because part of their area fell outside the *badia* or crossed international borders. This first-stage selection provided 26 potential watersheds (Fig. 2).

The second stage of selection assessed various criteria, including soil depth, slope steepness, location of communities, land use, watershed size and accessibility, land tenure, and availability of basic data. Plotting data on GIS overlays and superimposing these on the base map of watershed boundaries allowed different experts to visualize and review data and modify the criteria over many rounds of assessment. This process eliminated all but nine watersheds, which were later narrowed to five.

Based on information from stages 1 and 2, the specialists then undertook three types of study: (1) rapid rural appraisal of the socioeconomics of the communities; (2) rapid hydrologic study to assess the suitability of the watersheds for water harvesting; and (3) rapid environmental review to assess the potential impact of water harvesting.

They concluded that two sites would be needed to represent the wide range of biophysical and socioeconomic conditions found in the *badia*. These were the Moharib (the main research site) and Umenaam (a complementary research site) watersheds.

The researchers collected detailed baseline data for the benchmark watersheds and developed suitability maps for various water-harvesting techniques, after consultation with farmers (Fig. 3).

The results indicate that several water-harvesting options (cisterns, ridges, strips, *hafair*, etc.) may work in any one biophysical unit within the watershed. This means that farmers have several options and that other socioeconomic issues can be taken into account when deciding which option to use.

Integrating expert knowledge in GIS to locate biophysical potential for water harvesting: a case study at country level in Syria

Water harvesting covers various techniques to collect rainwater from natural terrain or modified areas and concentrating it for use on smaller sites or cultivated fields to improve crop yields. Few farmers in Syria have adopted water harvesting methods. One reason is that the agricultural research and extension support services in Syria lack specific and systematic knowledge on potential areas and suitable locations for water harvesting. The objective of this study was to provide a rapid GIS-based analytical technique to assess suitability for various water harvesting systems in Syria, with the ultimate objective to adapt the technique for use across the CWANA region.

The assessment was undertaken by matching in a GIS environment simple biophysical information, systematically available at country level, to the broad requirements of the specified water harvesting systems. The systems evaluated include 13 micro-catchment systems, based on combinations of 6 techniques and 3 crop groups, and 1 generalized macro-catchment system.

The environmental criteria for suitability were based on expert guidelines for selecting water-harvesting techniques in dry environments. They included precipitation, slope, soil depth, texture, salinity, land use/land cover and geological substratum. The dataset included interpolated surfaces of mean annual precipitation, the SRTM1 digital elevation model, a soil map of Syria, a land use/land cover map of Syria, and a geological map of Syria.

The evaluation had two stages: scoring of the land attributes according to the individual criteria, followed by the combination of the individual scores in a multi-criteria evaluation. Fuzzy membership functions were used to evaluate suitability for continuous variables, such as precipitation and slope. The functions are fully defined by their shape (either sigmoid or linear) and inflection point positions.

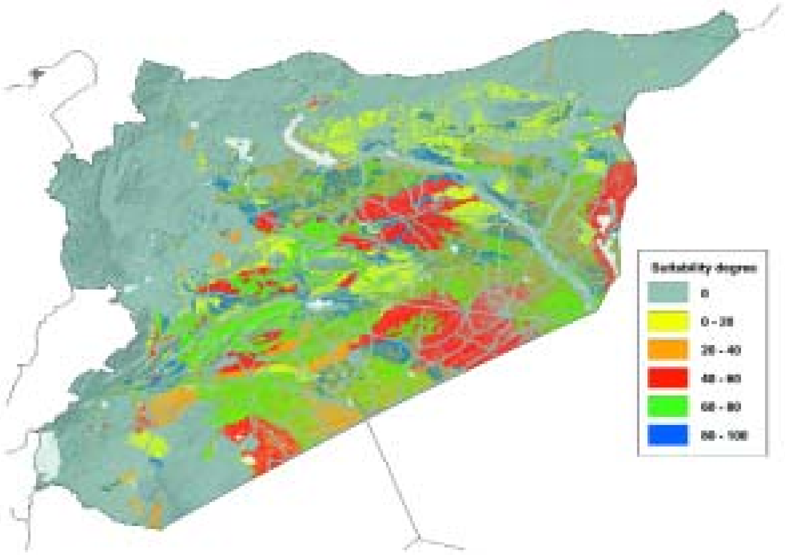

Fig. 4. Suitability map for macro-catchments. Areas in blue are highly suitable as catchments, areas in red highly suitable as target areas; where they occur close to each other, the terrain meets all conditions for a macro-catchment system.

Other relevant factors, such as soils, land use or geological materials, could at the national level only be described qualitatively. In addition, for these datasets it is quite normal that the pixels are not homogeneous but contain mixtures with different properties. Monte-Carlo simulation was used to estimate the approximate proportion of a pixel affected by one constraint or another.

The individual factors were then scored on a common scale (0-100) and combined through the Maximum Limitation Method (MLM) as a special case of Boolean overlay. An example of a suitability map for a micro-catchment water harvesting system is shown in Fig. 4. The scoring is on a scale of 0 to 100.

To identify areas suitable for macro-catchment systems, two separate assessments were undertaken, the first one to evaluate suitability to serve as a catchment, and the second to evaluate suitability as a target area, with the additional condition that the areas should be within a certain distance from each other. The evaluation for catchment suitability included fuzzy membership function for precipitation and slope, in which the scores were adjusted by taking into consideration the soil hydrological properties.

Assessing the potential of groundwater in a drought-prone area

The Khanasser Valley is located on the edge of the Syrian steppe and receives only 210 mm of rainfall on average annually during the cropping season from October to May. Coupled with variation in rainfall from year to year, this means that farming conditions are marginal. Climate change may be adding further stresses to the Valley's agricultural systems. However, the current climate change models cannot be used to assess this, because they do not consider the smaller scale processes that affect local precipitation. ICARDA has therefore been using different methods to assess variability in rainfall, as well as groundwater use and its predicted effects.

Assessing rainfall variation

Trend tests on data from the climate stations in Aleppo and the Khanasser Valley show that rainfall has not decreased in the last 75 years. Although this data does not provide evidence of climate change, limitations in the quality of the data may mask trends.

A view of the Khanasser Valley from the Jabel Al-Hoss plateau, near Aleppo, Syria.

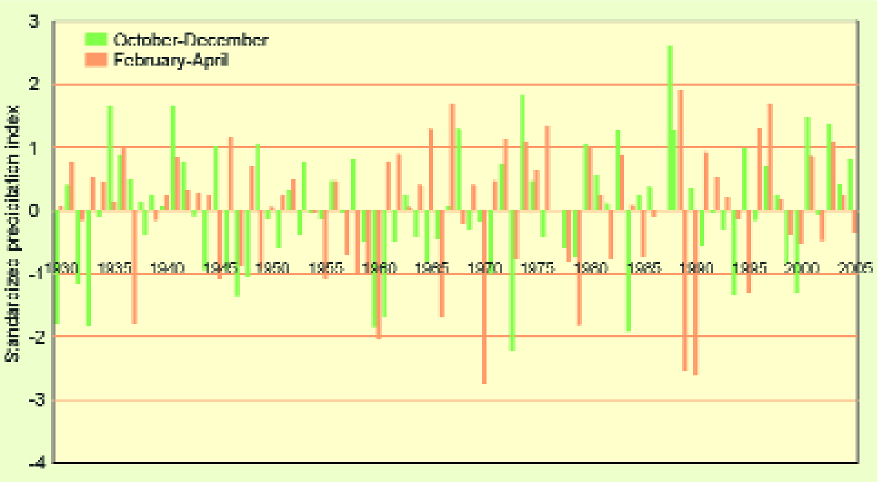

Fig.5. Standardized precipitation index for the Khanasser Valley (1929–2005).

To assess the frequency of drought in the Khanasser Valley, therefore, researchers plotted standardized precipitation index (SPI) values for October to December (planting) and February to April (crop development and flowering) for 1929 to 2005 (Fig. 5). SPI values equal to or less than –1.0 indicate drought.

Farmers often encounter difficult conditions, e.g. wet conditions at planting followed by dry conditions during crop development, or vice versa. During the frequent droughts that affect the area, they often have to leave their villages in search of feed for their flocks or to find work in cities. During the drought of 1958–60, for example, Syria's sheep population was reduced by half and many families migrated to western Syria and Lebanon, and returned only when the drought ended.

Traditional groundwater systems

During drought years, groundwater can supplement rainfall and stabilize crop production. However, groundwater is often also an important source of drinking water for rural communities and their livestock. The Khanasser Valley has a long history of groundwater use. Between the 4th and 7th centuries, and perhaps even earlier, *qanat* systems were dug into the hillside to tap the groundwater. By letting groundwater flow out into the valley through a slightly sloping horizontal tunnel, these *qanats* ensured that no more water was used than could be recharged naturally.

Researchers have found five such *qanats* in the area, two of which dried up in the 1970s when motorized pumps were introduced and groundwater levels fell rapidly. Two other *qanats* had already collapsed earlier. However, in an undisturbed Valley area in the foothills of Jabel Al-Hoss, one small community still uses the water that flows from a *qanat* for its daily needs.

Studies on groundwater recharge

Syria's rural population has more than doubled over the last three decades, and anecdotal evidence suggests that the same is true in the Khanasser Valley. This is putting increasing pressure on groundwater resources. Because rainfall is low and evaporation rates are high, the aquifers receive little replenishment.

Researchers found that present-day recharge mainly takes place on the adjacent Jabel Al-Hoss and Jabel Shbayth basalt plateaus. Analyses of isotopes in water pumped from aquifers in the Khanasser Valley have shown that some of the water used today entered the aquifers more than 3000 years ago.

Predicting the effects of groundwater pumping

Researchers used a numerical flow model (MODFLOW-2000) to investigate the dynamics of the groundwater system in the Khanasser Valley and its response to external influences, such as the introduction of groundwater pumping. The model was calibrated with groundwater-level and flow data from the 1970s—before groundwater pumping began.

These data were supplemented by recent measurements from locations where groundwater levels were not likely to have been greatly affected by pumping. Researchers calibrated the model for a range of recharge values, to allow for any variation in the quality of the available data. Results indicate that average recharge in the study area is just 1% of the long-term average annual precipitation, with an uncertainty range of 0.24% to 2.4%.

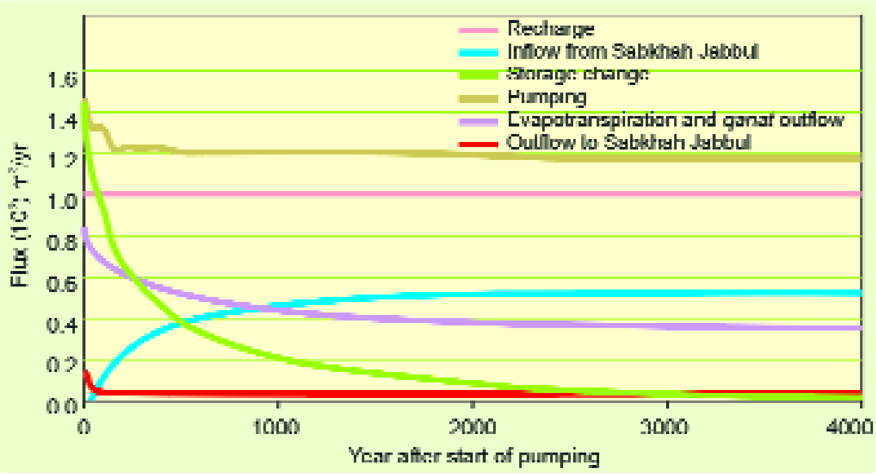

Fig. 6. Simulated changes in flow in the Khanasser Valley groundwater system at the current pumping rates.

Groundwater levels are more vulnerable to changes in pumping rates than to droughts. The results of a 30-year simulation indicated that, without pumping, groundwater levels would generally vary by less than 0.4 m over time. However, at the present pumping rates (1.4 million m^3 per year in average years and 1.2 and 1.7 million m^3 in wet and dry years, respectively) the simulation showed that the water level would fall by 1.4 m on average over 30 years.

The simulation results also showed that after 15 to 62 years of pumping at the present rate, saline water from the Jabbul Sabkhah, a large saline depression north of the Valley, would be drawn into the aquifer. This outcome results from high pumping rates in the Valley bottom, where water is needed for irrigation. But it would take almost 4000 years for the groundwater system to stablize again (Fig. 6).

To find options for sustainable groundwater use in this drought-prone area, researchers modeled various scenarios and found that redistributing production wells—giving each village an equal share—could help sustain higher pumping rates than those of current production wells.

They estimated that villages could pump between 800 and 30,000 m^3 per year. This would provide larger communities with barely enough groundwater to fulfill their domestic needs, though smaller communities would be able to pump some water for their livestock or irrigate small areas of cropland.

Efficient and sustainable use of water in Central Asia

In 2000, ICARDA and national scientists in the Central Asian countries of Kazakhstan, Kyrgyzstan, Turkmenistan, Tajikistan, and Uzbekistan initiated a three-year applied research project on soil and water management with funding from the Asian Development Bank (ADB). The project addressed the major challenges in on-farm soil and water management and aimed to increase agricultural production through maintenance of soil fertility, enhancement of nutrient use efficiency, and improvement of water productivity. The results have demonstrated that adoption of improved technologies could enhance productivity, income, and household food security. It could also contribute to the conservation of natural resources and sustainable agricultural production in the region.

Following the success of the project, a proposal for the second phase was developed, which was approved by the ADB in November 2003. This phase included an expansion of the project to Azerbaijan. The objective was to promote the adoption by farmers of sustainable technological and institutional innovations that conserve soil and water, improve input-use efficiency, and generate greater economic returns. Twenty-two on-farm trial sites were established during the first phase of the project and additional sites in the second phase. Several activities were carried out in 2005 under the project.

At Pobeda and Jambul Agricultural Experimental Station, Kazakhstan, raised-bed planting with cutback irrigation gave higher yield in winter wheat and more efficient use of water than raised-bed planting with furrow irrigation and conventional planting with strip irrigation. Application of ameliorant phosphogypsum to winter wheat and cotton increased water-use efficiency and yield (1.4 kg/m^3 and 3 t/ha when 2.5 t/ha phosphogypsum was applied compared with 0.6 kg/m^3 and 1.8 t/ha with no phosphogypsum). Similar results were obtained for cotton (1.4 kg/m^3 and 3 t/ha with 4 t/ha phosphogypsum compared with 0.6 kg/m^3 and 1.8 t/ha with none).

Winter wheat sown on raised beds in Kazakhstan.

Two irrigation methods, irrigation in sown furrows and contour furrows, were tested in a sloping area of Sokuluk district in Kyrgyzstan. Sowing on beds and furrows with cutback irrigation gave higher water-use efficiency and yield in winter wheat (1 kg/m^3 and 4.1 t/ha) than sowing on beds with furrow irrigation (0.6 kg/m^3 and 2.9 t/ha).

Contour furrows gave higher water-use efficiency in sugar beet. In Tajikistan, several irrigation techniques were tested in persimmon and cotton fields. The drip-jet furrow irrigation produced better height, trunk diameter, and crown size in persimmon than drip-jet irrigation alone, while micro-furrow irrigation produced better growth, number of buds, flowers, and bolls in cotton than conventional furrow irrigation. In Turkmenistan, sprinkler irrigation and alternate furrow irrigation also gave higher water-use efficiency and yields, respectively, in carrot and maize than the conventional furrow irrigation.

In on-farm demonstrations on the benefits of saline soil leaching, cotton produced 2.06 t/ha, 1.36 t/ha and 0.2 t/ha after leaching salts with drain water, blended water and without leaching, respectively. This indicates that leaching can help rehabilitate soils that are affected by high salt content.

In Uzbekistan, the yields of grapevines were 17.72 t/ha, 13.44 t/ha and 12 t/ha, and water-use efficiency was 3.8 kg/m^3 and 2.9 kg/m^3 and 2.1 kg/m^3 under low pressurized drip, drip-jet, and furrow irrigation, respectively. The zigzag furrow recorded higher cotton yield and water-use efficiency (2.6 t/ha and 0.24 kg/m^3) than traditional furrows (2.3 t/ha and 0.21 kg/m^3). The yields and water-use efficiency of winter wheat were higher under sprinkler than conventional furrow irrigation.

Winter wheat gave higher yields and water-use efficiency under furrow irrigation with portable chutes than with no portable chutes. Water-use efficiency and yields in winter wheat, sunflower, maize, sesame, and cotton were higher with the use of fresh water and conjunctive fresh and drain water than with drainage water. Similarly, polyethylene mulch increased water-use efficiency and yield in cotton.

Deficit irrigation: gaining more crop per drop

Despite the shortage of water in the dry areas of CWANA, most farmers still use inefficient irrigation techniques. They irrigate their crops to maximize yields per unit of land. However, using maximum irrigation is unwise and unsustainable in areas where water is scarce and the water table is dropping fast. Maximizing yield per unit of water rather than per unit of land would be a better option.

ICARDA researchers have, therefore, been testing deficit irrigation as one way of increasing water productivity to gain 'more crop per drop'. They have tested deficit irrigation in maize and cotton (two common summer crops) for three years at the Tel Hadya research station.

They found that applying less irrigation water than the amount needed to completely satisfy the crops' water requirements decreased productivity per unit of land, but increased productivity per unit of water.

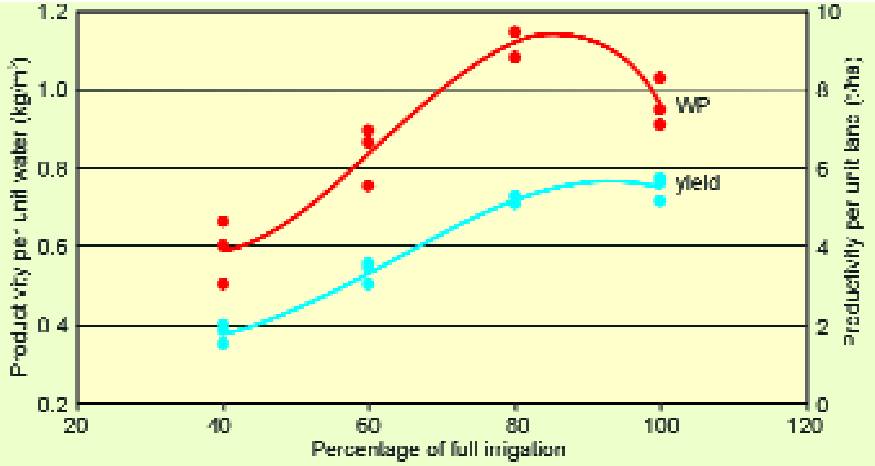

Fig.7. Water productivity and maize yields under different irrigation regimes at Tel Hadya, Syria, 2005.

In the maize trials, for example, reducing irrigation to 80% of the water requirements increased water productivity from 0.9 to 1.1 kg/m^3, but reduced yields only slightly, from 5.7 to 5.3 t/ha (Fig. 7). This indicates that deficit irrigation could save substantial amounts of water. The water saved could then be used to (i) extend the irrigated area, (ii) irrigate higher value crops, or (iii) provide supplementary irrigation for rainfed winter crops.

Although farmers would not produce as much per hectare, irrigating a larger area could increase the total amount produced per

Deficit irrigation trials on cotton at ICARDA Tel Hadya station. Left: Cotton grown under full irrigation (no stress). Right: cotton grown with deficit irrigation (at 40% of full irrigation).

farm. Farm profits would also increase if the additional costs of irrigating more land (such as outlays for labor and new canals or pipes) were lower than the extra benefits from producing more crops.

Using deficit irrigation for winter crops in CWANA would also mean that crops would benefit more from unexpected rainfall during the growing season. This is because deficit irrigation does not saturate the crop root zone, allowing the soil to store rainwater, which is then available to the crop.

The researchers, therefore, suggest a revision of the recommendations for irrigating crops in water-scarce areas. Irrigation practices should take account of the availability and sustainability of water resources in specific basins. ICARDA is working on new guidelines for crop water requirements and irrigation scheduling for the important crops in the dry areas. These new guidelines could help farmers manage limited water supplies, cope with drought, and optimize water productivity and profits.