Mega-Project 1

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

Introduction

By definition, dry areas are water scarce. Rainfall is highly variable and unpredictable, both spatially and temporally, increasing the risks and uncertainties for farming communities. The Management of Scarce Water Resources and Mitigation of Drought in Dry Areas Mega-Project (Mega-Project 1) focuses on strategic research on sustainably increasing water productivity, and has expanded its scope from the farm to the watershed and basin levels. Partnerships within the CGIAR's Challenge Program on Water and Food and with IWMI have been established to achieve a complementary approach whereby ICARDA focuses on assessing and improving on-farm water productivity and IWMI focuses on out-scaling to the basin level.

Mega-Project 1 is placing increased emphasis on the assessment of scarce water resources, including both fresh and marginal-quality water, and their sustainable allocation for 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 in national programs 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 CIHEAM.

Improved options for end-users are developed and disseminated using integrated and multidisciplinary research, and participatory approaches at the community level at selected benchmark sites. Research on policy and institutions is implemented in collaboration with Mega-Project 5 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.

Growing more food with less water in Iran's Karkheh River Basin

ICARDA is helping to coordinate a four-year project to improve water use in the Karkheh River Basin, Iran. This is part of the CGIAR's Challenge Program on Water and Food. The Karkheh Basin (Fig.1.1) is one of nine basins worldwide where the Challenge Program is working to sustainably improve the incomes and livelihoods of resource-poor communities by improving water management.

The Karkheh River Basin was chosen for two reasons. First, it is one of the most important agricultural areas in Iran. But annual rainfall is only 150 mm in the south and 750 mm in the north. A growing population and rising per capita water consumption place huge demands on the basin's limited water resources. Although the new Karkheh Dam will boost water supplies, the need to increase water productivi-

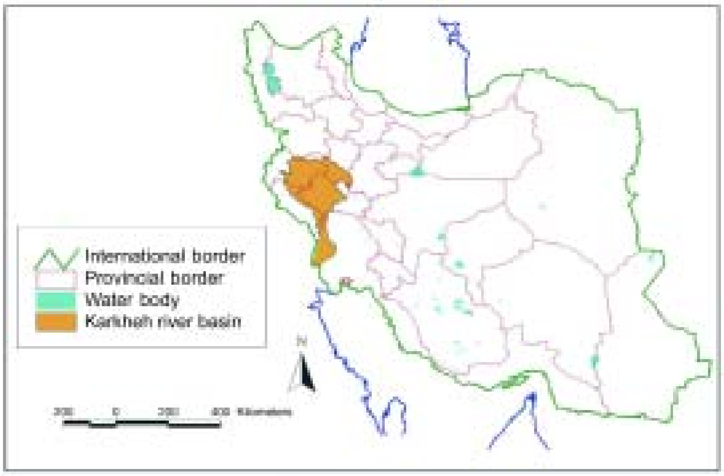

Fig. 1.1. The Karkheh River Basin in Iran.

Management of Water Resources and Mitigation of Drought

The project addresses problems such as waterlogging (left) and severe build-up of salt (right) in irrigated fields in the Karkheh Basin, Iran.

ty is so urgent that Iran has identified improving water productivity (yield per unit of water used) as a top priority in its agricultural strategy.

The second reason that the Karkheh Basin was chosen is because it is typical of basins in the arid to semi-arid Central and West Asian region. The lessons learned will therefore be adapted to other basins as far apart as the Euphrates and the Amu Darya.

To improve farm and basin-wide water productivity and the management of the natural resource base in the basin, researchers selected four sites representing both rainfed and irrigated farming. Work at these four sites focuses on:

- Identifying options to produce more crops with less water in irrigated and rainfed farming,
- Helping farmers adopt new practices and technologies that raise water productivity,
- Assessing and helping develop policies and systems for managing water effectively, and
- Helping institutions and community groups to develop skills in resolving conflicts and managing water.

Researchers, together with farmers, community leaders, local institutions, extension staff, and policy makers, take a problem-solving approach. Because everyone participates, adoption rates for new ways of managing water are high. And groups that are often left out, such as women, are instead fully involved.

To tackle the challenge of improving water productivity, the first step was to understand how water was already being managed and used. This meant doing a baseline study of the entire basin to assess not only water supply and demand, but also upstream and downstream water quality and environmental issues. Researchers used computer models, geographic information systems, and remote sensing technologies to map these features. This baseline information will be crucial in showing the impact of new water management technologies and also in developing effective plans, policies, rights, regulations, monitoring, and water-user groups in the basin.

The Karkheh River Basin has five sub-basins, spans seven provinces, and extends over more than 50,000 square kilometers. The basin is mostly semi-arid but more arid in the south. This means that rainfed crops can only be grown in the upper northern part of the basin. Two-thirds of the population of around 4 million are rural and the per capita income from agriculture is US$230 per year, well below the poverty line.

Surface water provides nearly two-thirds of the water used for irrigation. About 87% of the groundwater extracted is also used for agriculture. The current plan is for the irrigated area below the dam to expand more than three-fold, from 1100 km^2 to 3400 km^2. Since not all of the additional need for irrigation water will be fulfilled by the new dam, a lot less water will have to be used to grow a lot more crops.

To determine ways to do this, researchers looked at current farming practices to pinpoint areas where improvements were needed. They found that yields of the main crops in the upper part of the basin, wheat and barley (76%), and pulses (23%), are low: 920 kg/ha for wheat, 950 kg/ha for barley, and about 500 kg/ha for chickpea. Water productivity is also low, as yields range from 0.3 to 0.5 kg per cubic meter of water. This means that farmers make less than $50 per hectare.

One of the problems is that when autumn rains are late, farmers sow their winter crops in drier soil or delay sowing and the young plants cannot get a good start before winter sets in. Crop stands are poor and plants are not hardy enough to resist the cold and frost. One solution

Poorly managed water conveyance structures and practices in the basin area: the bank of this irrigation ditch has been cut, to convey water across the road to another field – creating problems of excess runoff.

is to use supplemental irrigation so that crops can be planted early and get off to a good start. But this means that farmers need irrigation water, plus some way of getting the water to their fields. Water and irrigation pipes or channels are expensive.

Scientists from Iran's Dryland Agricultural Research Institute, working with farmers on their farms, are testing low-cost ways of supplemental and deficit irrigation, and improved agronomic practices that use water efficiently. This is helping poor farmers improve water productivity in the upper part of the basin.
In the lower basin, below the new dam, water availability is already improving, even though the irrigation and drainage network is not yet finished. A wide range of crops grow in this part of the basin but crop-water productivity and irrigation efficiency are poor. Soil and water quality are at risk. Water losses from canals and irrigation furrows, poor drainage, and salinity, especially in low-lying downstream areas (e.g. Dasht Azadegan), are severe. Salinization is getting worse because there is more irrigation, and also because the river, now restricted by the new dam, no longer floods and washes excess salt out of the soil.

Research findings bear this out. Average cereal yields in the irrigated area (2300 kg/ha) and water productivity (mostly less than 0.5 kg/m^3) are poor. For example, the overall efficiency of the traditional irrigation networks in the Dasht Azadegan area of the lower basin is only 14-23%. Researchers chose Sorkheh and Dasht Azadegan, two large irrigated areas below the dam, for on-farm irrigation experiments to find solutions to these problems. Researchers from the Agricultural Engineering Research Institute in Karaj, the National Salinity Research Center in Yazd, and the provincial Agricultural Research Centers (Dezful and Ahvaz Stations), are working here with farmers to test improved irrigation systems, salt-tolerant crops, and new ways of managing water and salinity.

Participatory research to improve water management in the Karkheh benchmark basin will provide valuable insights into ways to improve the incomes and livelihoods of resource-poor communities in water-scarce regions.

Early outcomes of the water benchmarks project in West Asia and North Africa

The water benchmarks project

Water scarcity in West Asia and North Africa is critical. Yet farmers do not manage water well because they consider that technologies to improve management are not practical. The reasons for this vary and include technical, socioeconomic and policy aspects. But the most important reason why new technologies are not used is because the communities who were supposed to benefit from them did not participate in the development process.

Working with the community in the badia water benchmark project area in Jordan.

To deal with this problem, ICARDA set up a project called Community-Based Optimization of the Management of Scarce Water Resources in Agriculture in West Asia and North Africa in 2004. This is known as the 'water benchmarks' project. The project is supported by the Arab Fund for Economic and Social Development (AFESD), the International Fund for Agricultural Development (IFAD), and the OPEC Fund for International Development. The aim is to find the best ways of helping farmers in WANA improve their production per unit of water used, and so make a better income.

To do this, scientists are working with farmers in three benchmark sites where water is very scarce. They involve communities in research, development, testing, and adapting technologies. The benchmark sites represent the three main agricultural environments in WANA: one for the drier areas (*badia*); the second for rainfed cropping systems; and the third for fully irrigated areas. The water benchmark areas are based on watersheds, determined using remote sensing techniques and geographic information systems (GIS) to integrate biophysical and socioeconomic factors.

Early successes

Early outcomes of the water benchmark project indicate that the community-based approach is spreading to existing and new projects in WANA, and that water policies are changing as a result of successes in the benchmark areas.

In Jordan, the National Center for Agricultural Research and Technology Transfer (NCARTT) is now using the participatory approach in new projects supported by GTZ – for example in the Yarmouk Development Project in the north of the country, and in the northern and southern *badia*. NCARTT has submitted a US$4 million proposal for a national project to disseminate project results to other areas in the *badia* to the Ministry of Environment as part of the Jordan National Action Plan to combat desertification. What is more, the Ministry of Agriculture and NCARTT will make the water benchmark area a permanent research site for the whole *badia* and will build a research and development station in the watershed.

Water harvesting in the Jordanian *badia*

Water harvesting is a way to manage *badia* rangeland resources in a sustainable and integrated way. By harvesting rainwater, farmers can grow shrubs for fodder and drought-tolerant fruit trees, conserve soil, and rehabilitate natural vegetation. A machine (Vallerani) makes construction of water harvesting bunds for micro-catchments much easier. Now, three times as many farmers use water harvesting, compared to before the project. The government of Jordan, keen to expand and scale up the project, has bought a powerful tractor to operate the machine, and will use it for constructing micro-catchments in other parts of the country.

Micro-catchment water harvesting contours in the Jordanian badia.

Terraced furrows systems in Egypt

Conventional furrow irrigation of wheat and other crops in the Nile Delta uses excessive amounts of water. This type of irrigation encourages weeds and so raises labor costs. In addition, applying large amounts of water leaches out nutrients. ICARDA scientists, working with the Agricultural Research Center in Egypt, therefore introduced terraced furrows to communities in the Irrigated benchmark area. Farmers in this area already use a furrow system and were readily persuaded to reduce the amount of water they applied, halve the number of furrows, and grow crops on beds about 1.2 to 1.4 m wide.

This made irrigation more efficient and reduced the costs. Farmers could not over-irrigate because there were fewer furrows to apply water to. When tested in farmers' fields and compared with the conventional system, the terraced furrow system used 30% less water, reduced the cost of pumping and labor for preparing land, irrigating, and weeding by about 35%, while giving the same or higher yields. As the terraced furrows used less water, crop-water productivity (the yield per unit of water used) increased by over 30%, and farmers' net income increased by about 15%. Overall, the net return per unit of water increased by about 20%. Many farmers have already adopted this system or are seeking help to do so. Other development projects in the Delta are taking up the system, as are six other governorates in the Delta and central Egypt where wheat and faba bean are grown.

Early sowing and supplemental irrigation in Morocco

Late first rains are a major limitation in rainfed cropping areas because they delay sowing. In Morocco, and in most of WANA, the first rain may not arrive until a month after the best date for sowing. But, if wheat is sown in October or early November, yields improve by 10-50%. Scientists at the Institut National de la Rechèrche Agronomique (INRA) worked with farmers in Tadla, Morocco, the water benchmark site for rainfed areas, to sow wheat early and apply 50-70 mm of supplemental irrigation. Yields increased by 30% with only 50 mm of supplemental irrigation . This means that, for wheat, supplemental irrigation water productivity was between 1.1 and 1.4 kg/m^3.

Crops in rainfed systems also become stressed in late spring when rains tail off. Supplemental

Wheat crop in Morocco sown early in November with 40 mm of supplemental irrigation (right) as compared with conventional sowing in December.

irrigation at this time greatly increased both yields and water productivity. Existing systems for full summer irrigation can be used for supplemental irrigation instead.

Applying supplemental irrigation early in the spring means that water allocation policies need to change because water is currently allocated to fully irrigated crops. The Office Régionale de Mise en Valeur Agricole de Tadla (ORMVAT), the agency responsible for water allocation in Tadla, is a partner in the rainfed benchmark area and is participating in the analysis to develop a more robust system that will give the highest return on the limited water available for irrigation. Reallocating surface and ground water will be necessary to increase water productivity and improve drought-preparedness.

The 'Water Wand': a simple, cheap probe to detect soil wetting depth

In areas where water is scarce, farmers can grow better crops if they know how much water is in the soil. So, tools that help them find out how far down rain or irrigation water penetrates into the soil, how much soil water is available to plants, and whether there are any soil layers that prevent water filtering down, are helpful.

The Water Wand is a low-cost, easy-to-use probe for estimating soil moisture and compaction.

The Water Wand

Most of the instruments used to measure water in the soil are expensive. They are designed for high-value crops, large farms, and scientific research rather than for farmers in developing countries.

The Brown Moisture Probe, originally developed in Montana, USA, is used by scientists and farmers to determine the depth of soil wetted by precipitation or irrigation. Although this type of probe has been available for over 50 years, it is not commonly used in the dry areas of WANA. So, scientists at ICARDA developed a simple hand-push probe, the Water Wand, based on the Brown Moisture Probe, so that farmers could quickly and easily measure soil moisture.

The probe is a stainless steel rod, 10 mm in diameter and 1.2 m long, with a spherical tip 15 mm in diameter, and a round handle. As the diameter of the tip is 5 mm more than the diameter of the rod, the probe penetrates wet soil but stops when it gets to dry soil. Rocks and gravel may also stop the probe, but can be differentiated from dry soil by a metallic click when the probe is tapped. The probe works on the principle that wet soil is less resistant than dry soil. Resistance to the probe increases rapidly as the soil becomes drier. The probe stops abruptly and begins to flex when it gets to dry soil or a compacted layer.

Scientists tested the Water Wand at ICARDA's Tel Hadya research station in deep heavy clay soil. They wetted four small basins once a week with four wetting regimes. They measured water in the soil profile using neutron scattering (at 150 cm intervals) through tubes installed in the center of each basin.

In 2006, they measured the depth of wetting at several places in each basin twice a week for three months by pressing the Water Wand firmly into the ground until it stopped. To measure how far water had penetrated down into the soil, they placed a hand on the probe at ground level and removed the probe, noting how much of the probe was below the surface.

There was a very strong correlation between the depth of penetration by the Water Wand and the amount of soil water in the four basins. On average, the total amount of soil water (mm) is about 3.2 times the depth of Wand penetration (in cm). The amount of water held by the wet soil depends on soil texture, so this relationship applies only to the heavy clay soil at ICARDA.

Penetration of the Water Wand to 120 cm in the heavy clay soil at Tel Hadya represents about 400 mm of total soil water. The estimated volume of water in this soil at the wilting point is 22%. Subtracting this amount (264 mm) from the total amount (400 mm) leaves 136 mm of soil water available to plants in the 120-cm profile. Further tests on fallow fields and on wheat fields also show strong relationships between the amount of rainfall (or soil wetting) and the depth of penetration by the Water Wand.

Practical use of the probe

By taking measurements with the probe across a field, farmers can estimate the amount of soil water and extent of soil compaction, and can thus manage water more efficiently. If they know how much water is in the soil at the beginning of the planting season they can decide which crop to plant. Rainfall data for previous seasons tells them how much rain they can expect in the growing season. Measuring soil water precisely is time-consuming and expensive. However, the tests with the Water Wand show that the depth of wet soil is another measure of the amount of available soil water for plant use. Each field needs to be probed separately because the variations in soil texture, precipitation, previous crop and tillage practices, and topography all affect soil moisture.

Rainfed cereals and legumes need adequate soil water at crop establishment, and grain-filling and ripening stages. So, the Water Wand is a very useful tool for farmers to estimate soil water routinely during the growing season and schedule supplemental irrigation for these critical periods.

In irrigated fields, the probe can be used a few hours after irrigating to monitor the depth of water, or used before and after to estimate the amount of water that has been applied. Measurements across a field help determine the uniformity of irrigation. Farmers find it hard to determine the cut-off, or cut-back, time of irrigation in long furrows and borders. By probing the lower end of the field while it is being irrigated, the farmer can monitor the depth of wetting

The Water Wand was tested at ICARDA's Tel Hadya station, on uniform, deep, heavy clay soil.

and use that information to cut-back, or cut-off, irrigation.

The probe has other uses, for example to quickly check soils in parks, gardens, and tree planting holes for compacted layers with minimal disturbance. If the probe penetrates the soil easily this mean plants develop deep roots, water moves freely down the soil profile (no hardpan), and the soil is easy to till. If the soil is wet and the probe still does not penetrate, this means that the soil is compacted near the surface and prevents water infiltrating and penetration of roots.

Enhancing the productivity of high-magnesium soil and water resources

In 2006, ICARDA researchers continued work to overcome problems caused by soil and water containing high levels of magnesium in Central Asia. The project is funded by the Asian Development Bank.

Excess magnesium in soil leads to a severe degradation of soil structure, and thus lowers water infiltration rates, hydraulic conductivities, and crop growth. More than 30% of the irrigated area in southern Kazakhstan has excess levels of magnesium: exchangeable amounts are generally 25-45%, and in some cases as high as 60%.

Plowing high-magnesium soils typically forms massive clods that impede water flows down furrows and across irrigated fields, and leads to poor water distribution. The problem is compounded when the magnesium content of water is higher than that of calcium.

The Arys-Turkestan canal command area in southern Kazakhstan is a typical example of an area where there is excess magnesium in soil and irrigation water. This has led to a gradual fall in the yields of cotton, with a large impact on farm profitability, since farmers rely heavily on cotton. Winter wheat (*Triticum aestivum*) yields are similarly affected.

Adding enough calcium, often as gypsum or phosphogypsum, can restore the productivity of high-magnesium soils, by counteracting the effects of magnesium. Phosphogypsum is widely available in Kazakhstan and could increase

High levels of soil magnesium have a negative impact on hydraulic properties of soil, and plowing forms massive clods that interfere with water flow rates.

productivity of high-magnesium soils in the Arys-Turkestan canal command area and elsewhere in Central Asia at low cost.

Phosphogypsum can be applied in winter before snowfall or after preparing seedbeds, and is often incorporated into the soil by plowing. In low-rainfall years, harrowing the field is recommended to incorporate the phosphogypsum and reduce the risk of it being blown off by the strong winds common in the region. Snowmelt and rainfall in winter make phosphogypsum dissolve more quickly and increase soil calcium levels. These processes can be further accelerated by irrigation. The calcium then replaces magnesium on the soil's cation exchange complex. The replaced magnesium is leached deeper into the soil profile by excess irrigation or rainfall. In such ameliorated soils, there is greater water and air movement, greater root penetration and seedling emergence, and less runoff and erosion. Water-use efficiency is increased and the greater activity of plant roots improves crop growth and yield.

Applying phosphogypsum also improves soil nutrient availability. Studies have shown that 4.5 t/ha of phosphogypsum

Table 1.1. Levels of phosphorus (P_2O_5, kg/ha) in the soil as affected by applying phosphogypsum. Figures in brackets represent the percentage increase from initial levels of P_2O_5.

	Phosphogypsum (4.5 t/ha)		Phosphogypsum (8 t/ha)	
Soil depth (m)	Initial soil	Post-amendment	Initial soil	Post-amendment
0.0-0.2	82	106 (29)	88	141 (62)
0.2-0.4	75	89 (19)	87	112 (29)

increased phosphorus (P_2O_5) levels by 29% and 19% respectively in the top 0.2 m of soil and the 0.2-0.4 m soil layer (Table 1.1). Applying more phosphogypsum (at a rate of 8 t/ha) led to increases in phosphorus of 62% and 29% in the same two soil layers. Applying phosphogypsum also slightly increased soil potassium levels, by 3-5%.

Applying phosphogypsum nearly doubled cotton yields in long-term field studies (Fig. 1.2), partly due to better germination, and better bud and boll formation. Cotton yields increased by 93% in the 4.5 t/ha phosphogypsum treatment and 114% in the 8 t/ha treatment, compared with the control. Adding phosphogypsum increased calcium levels and thus improved the soil's ionic balance and physical properties.

The appropriate rate of phosphogypsum addition to a high-magnesium soil is crucial and depends on the initial soil magnesium level. Applying phosphogypsum at below the actual requirement only partly ameliorates the soil, while applying more than is needed is costly for farmers.

The effects of phosphogypsum applied to a high-magnesium soil may last for several years. Studies by ICARDA researchers have shown that where high-magnesium water is used to irrigate ameliorated soils, the magnesium levels tend to increase and calcium levels gradually decrease 4-5 years after applying phosphogypsum. Under these conditions, booster applications of phosphogypsum are needed to maintain desirable magnesium levels and good crop yields.

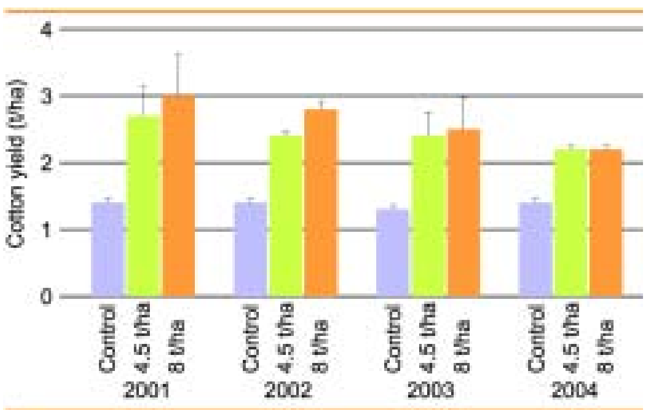

Fig. 1.2. Cotton yields with phosphogypsum application rates of 0 (control), 4.5 and 8 t/ha on a high-magnesium soil in southern Kazakhstan.

Excellent growth of cotton on a high-magnesium soil, after applying phosphogypsum.

The beneficial effects of phosphogypsum on cotton productivity on high-magnesium soils have been clearly demonstrated in farmers' fields. This is a practical economic recommendation for Central Asia that is also applicable to other crops such as wheat.

Watershed modeling to help decision-making on water use

Over many centuries and in many places in Tunisia, a wide range of small- to medium-sized water-gathering structures have been introduced to make the land productive. Water harvesting is especially important in the arid southeast, where the rainfall of 150-230 mm/year is too low for crop production.

There are many water users, from rainfed farmers in upstream areas and foothills, pastoralists that graze the downstream plains with camels, goats, and sheep, to groundwater users and providers that serve towns, tourism, and industries. The many users and changing socioeconomic conditions has led to demand for a management scheme at the watershed level to allow fair and productive partitioning of water between users.

Traditionally, water-harvesting was confined to *wadi*-courses in the mountain zones, where local communities built small stone dams to capture water and sediments. The resulting fertile terraces, known as *jessour*, were planted with fruit trees and often with small rows of field crops. During the last 50 years there has been a gradual extension of cultivated fields, especially of olive trees, along the mountain foothills, and earthen dikes and diversions on the gently sloping lands distribute the water among these so-called *tabias*.

In the 1990s, the Ministry of Agriculture invested in the system by developing check dams in the main *wadis* in the mid and downstream areas. These check dams slow runoff water, improve groundwater recharge, and allow diversion of water to newly established *tabias*. Migration of the younger generation to towns and cities is reducing the labor available for maintenance of traditional water-harvesting systems in upstream areas, creating the potential for flooding disasters during large rainfall events.

Jessour water-harvesting system in Oum Zessar watershed, Tunisia: olive trees prosper on the runoff water and sediments captured by the stone dike.

To better understand the effects of the diverse natural and man-made landforms on the water flows in these arid environments, researchers from Tunisia, ICARDA, and Purdue University (USA), modified the GIS-based watershed model SWAT. Research focused on Wadi Oum Zessar (Fig. 1.3), a 340-km^2 watershed in southern Tunisia, which stretches from the Matmata Mountains across the Jeffara Plain before it spreads its flood waters along the large salty plains (*sabkhat*) downstream and disappears into the Mediterranean Sea.

The watershed model was adjusted for typical Mediterranean cropping conditions and special subroutines were developed to simulate the capture and use of runoff by different water-harvesting systems at the sub-watershed level. Basic data layers were constructed using available maps, remote sensing images, and fieldwork. Thus, a database containing parameters for the model was set up and evaluated using historical runoff records. The modeling improved understanding of the system and the water distribution between different watershed uses.

Typically for arid environments, the great variation in rainfall in space and time made it difficult to accurately simulate all recorded runoff events. However, the model captured the behavior of the system and simulated the overall water balance components well.

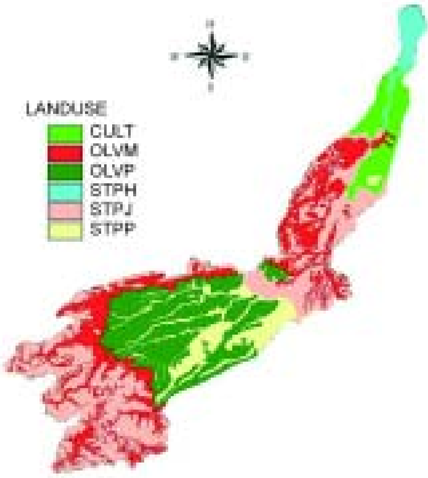

Fig. 1.3. Land use map of Oum Zessar watershed with olive trees on the jessour terraces (OLVM) and tabias (OLVP) in the upstream and midstream areas, and rainfed cereals (CULT) and sparsely covered rangelands (STPH, STPJ, STPP) occupying the remainder of the watershed.

Evapotranspiration was the largest water user in the upstream and midstream areas, using 80% of the average annual rainfall of 184 mm for the 12-year evaluation period. Around 13% of the rainfall percolated from the predominantly shallow soils, 5% recharged groundwater through transmission losses from the *wadi* beds, and 4% flowed to the downstream plains. Researchers are currently modeling the effect of land use changes on water use and productivity in the watershed, using the results of the established baseline scenario.

Integrating water harvesting and soil conservation to combat desertification

In 2000 the United Nations Convention to Combat Desertification (UNCCD) launched a Sub-Regional Action Program (SRAP) to combat desertification and drought in West Asia. This program involves several national and international partners, including ICARDA. As part of the program, pilot projects were launched in Jordan and Lebanon.

Pilot project, Jordan

ICARDA has established a pilot project in cooperation with the National Center for Agricultural Research and Technology Transfer (NCARTT) at Fa'a, Mufraq province, in the north of Jordan. The 15-km^2 watershed, inhabited by 348

Low-cost check structures have proved effective in stopping runoff water and retaining the soil it carries.

This nursery provides seedlings of medicinal and other valuable plants introduced by the project for the farmers to grow using harvested rainwater.

households, is steeply sloping, gullied, and has shallow, easily eroded soils. Runoff in the upper catchment is the main cause of desertification, although only 160 mm of rain falls per year.

Cultivation of barley on slopes and the edges of gullies accelerates erosion. Soils are rapidly losing fertility. Livestock production – a mainstay of the local economy – has declined because the rangeland no longer provides enough grazing, and farmers cannot afford to buy feed concentrates.

Communities have tested several methods of preventing erosion. For example, planting cactus in rills and gullies to prevent them from expanding; and building check structures and bunds to stop and divert runoff. They also built parallel stone ridges, 5-10 m apart, to stop runoff water and soil loss. These contour ridges collect runoff from immediately upstream or uphill and channel the water to 1000 fodder shrubs. The combination of well-designed ridges and drought-tolerant shrubs helps communities rehabilitate rangeland and improve fodder supplies.

Another method was strip cropping, i.e. alternating strips of crops and fallow, with the latter acting as miniature rainwater catchments. The ratio of cropped to fallow area ranges from 1:1 to 1:3, depending on the slope, soil type, and rainfall. This system doubles or triples the amount of rainwater harvested, giving much higher and more stable yields.

The project also introduced techniques for building water reservoirs. Small ponds are easy to build, even on slopes. Farmers simply choose a suitable depression and block off the lower end with a masonary wall. On a slightly larger scale, a low-cost earthen dam can meet most of a community's needs for domestic water, supplemental irrigation, and livestock. The size of the reservoir can be matched to the amount of runoff and the labor and material available for construction. In the pilot project, the community built a pond and a mini dam, which together store about 6000 m^3 of water. The cost was shared between the pilot project (60%), and the government and the community (40%). Villagers also used the water harvested to grow new crops brought in by the project, such as medicinal plants, which can be grown in home gardens and are quite profitable.

Pilot project, Lebanon

Two pilot sites in the Lebanese mountains, Yemouneh and Deir El-Ahmar, were established in cooperation with the Ministry of Agriculture. These areas are often affected by flash floods, resulting in sheet and gully erosion. Erosion reduces the soil's capacity to store water, so it retains very little moisture. Yemouneh is 1360 m above sea level, with significant snowfall and an average precipitation of 650 mm per year. The community of 3500 people cultivates 541 hectares of the 2950-hectare catchment. The other pilot site, Deir El-Ahmar (population 15,000), is mainly community-managed rangeland and forest.

Twelve farmers built stone and earth structures to harvest water in their fields, which was then used to irrigate fruit trees. These structures also conserve soil. Similar small structures on steep slopes support shrubs and forest trees.

The construction of ridges and dikes was timed so that seedlings could be planted in

Small water reservoirs were built at project sites in Lebanon, to collect and store runoff water for use by livestock.

the right season. Project staff advised farmers on how to water the plants until they were established. The farmers planted fruit trees, including some seedlings of drought-tolerant trees, such as almond.

Water reservoirs were constructed at both Yemouneh and Deir El-Ahmar. The reservoir at Yemouneh, ointly managed by the community and the municipality, harvests and stores 5500 m^3 of water, which is used to water orchards and vegetables. The reservoir in Deir El-Ahmar holds 6000 m^3. The efficiency of the reservoir averages 75%, meaning that 4500 m^3 of water is available for irrigation. In winter the reservoir stores surplus water which is then used for irrigation in summer.

Lessons learned from the pilot projects

Although most members of the communities now acknowledge the fact that land degradation is threatening their livelihoods, their demands for improvements are directed towards short-term economic gains, and improving their livelihoods.

The project found that in the pilot site areas, public and communal land was threatened more by degradation than were private lands. The open access policy to rangeland causes severe degradation.

The Lebanese pilot study in particular showed that land degradation cannot simply be explained by an increase in population pressure. Land degradation on slopes happens when the land is neglected, or not farmed for want of labor. As there is considerable out-migration from the pilot area because of unemployment, only major changes would attract people to live in rural areas and work in agriculture.

The project concluded that appropriate rainwater harvesting, together with soil conservation, can improve productivity and reduce soil erosion.

Simple water harvesting techniques provide water for irrigating fruit trees.

Rainwater harvesting is a useful way of improving the vegetation cover to combat desertification in environments similar to those in the pilot sites. A preliminary assessment shows that low-cost, simple technologies, such as those tested in the pilot sites, are easy to adopt and replicate. These serve both productivity and conservation, and thus are sustainable.

Harvesting water in micro-catchments to combat desertification

More than half of the land area in the eastern Mediterranean is rangeland and most is degraded to some extent. To rehabilitate rangeland and provide more feed for animals by planting fodder shrubs, ICARDA scientists are working with communities to test techniques for harvesting runoff and directing it to individual plants. This is known as micro-catchment water harvesting. The three-year project, financed by the Swiss Development Cooperation (SDC), began in 2004 at three pilot sites, two in Syria and one in Jordan (Table 1.2).

Researchers and farmers worked together to test the Vallerani plowing implement, pulled by a tractor, which constructs contour ridges and bunds mechanically and which has already proved successful in large-scale water-harvesting projects in Central Africa. The Vallerani implement makes an angled furrow and piles up the excavated soil on the lower (downhill) side. This soil forms a ridge that stops or slows down runoff water. The implement can be used either to create continuous furrows or intermittent ones. The effectiveness of the Vallerani implement was compared with a similar Pakistani plowing implement that also creates continuous furrows, and with manual construction of intermittent semi-circular micro-catchments

Researchers and farmers then planted shrubs at the lowest part of each micro-catchment, where the run-off water collected. Three shrub species were planted: *Atriplex halimus, Atriplex leucoclada*, and *Salsola vermiculata*. Researchers gathered and analyzed data on rainfall, vegetation cover, and the survival and growth rate of the shrubs. They also measured soil water content (using 108 access tubes), and soil erosion (using 21 runoff collecting tanks, erosion measurement pins, Gerlach troughs, erosion bridges, and weirs).

Three main lessons have been learned from the pilot projects. First, water harvesting can help to establish shrubs where there is very little rainfall and the likelihood of success would otherwise be very slim. Second, water harvesting also improves the growth rate of shrubs significantly in higher rainfall sites (150-220 mm) and, third, mechanizing construction improves the efficiency of water harvesting.

Table 1.2. Characteristics of pilot sites in Syria and Jordan and details of micro-catchment water harvesting experiments conducted at each.

Description	Qaryatein, Syria	Sheikh Hilal, Syria	Muhareb, Jordan
Annual rainfall (mm)	120	220	152
Watershed area (ha)	300	50	60
Size of experimental site (ha)	100	12	13
No. of participating farmers	17	12	5
Techniques for making micro-catchments tested†	Vi, Vc, P, Manual	Vi, Vc, Manual	Vi, Vc
Spacing of ridges (m)	6 and 12	6 and 12	4 and 8
Total length of ridges created (km)	85	4	5
No. of shrubs planted	10,000	500	1200

†Vi = Vallerani implement used to make intermittent furrows (this creates small basins); Vc = Vallerani implement used to make continuous (unbroken) furrows; P = Pakistani implement used to make continuous furrows

In Syria, micro-catchments developed using the Vallerani plow collect rainwater (left) and support good production of shrubs (right).

In the low-rainfall site of Qaryatein, Syria (120 km east of Damascus), water harvesting added considerable amounts of water to the soil. Runoff from slope lengths of 6 m and 12 m (the distance between ridges, Table 1.2) was 5 and 8 liters per square meter respectively. After 24 hours of rainfall there was far more soil moisture where shrubs were planted than in the catchment area (Fig. 1.4). This means that the micro-catchments were successful in capturing runoff and directing the water to the plants where it was needed. The survival rate for shrubs in the first year of the project was very good: 77-99% for *Atriplex halimus*. In the second year (2005/06) survival rates dropped, as the site received only 40 mm of rain – just one-third of the average. The survival rate was highest for shrubs grown in semi-circles and lowest for the Pakistani plow.

In Sheikh Hilal, Syria (50 km north-east of Salamieh), water harvesting improved the growth rate of shrubs significantly. The soil-moisture content for the areas where water was harvested rose on an average by 16% in February, 14% in March, and 16% in April compared to areas where water was not harvested.

The survival rate of shrubs was excellent (97% for A. *halimus*, 96% for *S. vermiculata*, and 93% for *A. leucoclada*) and did not differ much between the various water harvesting techniques. When water harvesting raised the soil-moisture content by less than 10%, there was no difference in the performance of shrubs in the areas where water was harvested and those where it was not. The survival rate of shrubs in Sheikh Hilal was higher than in Qaryatein probably because the rainfall was higher.

In Muhareb, Jordan (65 km southeast of Amman), the soil-moisture content was highest in February and lowest in October following a long rainless period. In order of effectiveness, the best techniques for directing runoff to plants, in terms of soil-moisture content, were the Vallerani intermittent micro-catchment (8 m spacing between ridges), followed by the Vallerani continuous micro-catchment (8 m spacing) and the Vallerani intermittent micro-catchment (4 m spacing). Soil erosion from rain splash was least in the unplanted control area (13.75 t/ha), more in the test areas (20.75 t/ha), and even higher on ridges (24 t/ha) and in barley fields (30 t/ha).

The harvesting of runoff water per unit area was most efficient in the 4-m spacing micro-catchments. These also trapped the most soil per meter of slope. The survival rate of shrubs ranged from 78% to 97% and there was not much difference between

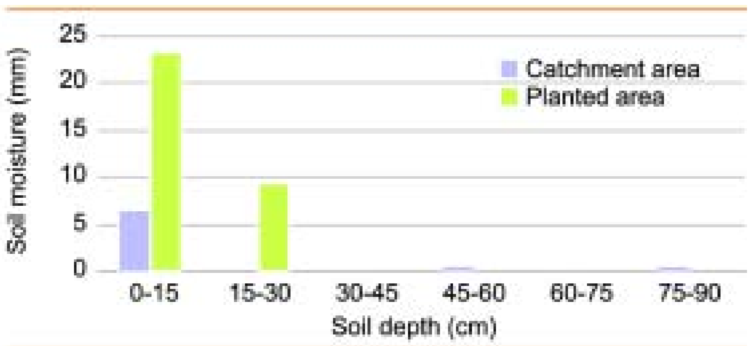

Fig. 1.4. Change in soil moisture 24 hours after rainfall in Qaryatein, Syria. In the parts of the water-harvesting areas where the shrubs were planted, soil moisture levels had increased far more than in the catchment area.

Scientist measures shrub growth and productivity (left); improved feed supplies directly benefit livestock (right).

treatments. Plants produced relatively more biomass in water-harvesting treatments as compared to the control, but again there was not much difference between the treatments.

This means that in higher annual rainfall areas (150-220 mm), water harvesting can improve shrub growth rates significantly. The tractor with the Vallerani implement created micro-catchments on 1.2 hectares per hour, and used 46.3 liters of fuel per hectare. A preliminary benefit-cost analysis showed an average net return of around US$30 per hectare. This means that using the Vallerani equipment to mechanize construction improves the efficiency of water harvesting. However, the performance of the equipment in shallow soils needs to be investigated further. Researchers will study this in 2007.

Irrigation methods to improve water productivity of cotton in Syria

Water deficits in Syria are already severe, and getting worse. National water consumption is estimated at 14.7 billion m^3/yr. Estimated available water resources are 12.94 billion m^3/yr, leaving an annual deficit of 1.73 billion m^3. Water balance in most basins is negative, except for coastal areas and the Euphrates basin. For example, at Tel Hadya in northern Syria, the water table has fallen by 35 meters in 20 years.

Springs in several parts of the country have dried up. Rapid expansion of irrigated land (supported mainly by groundwater extraction) and inadequacies in water delivery and use are the major causes.

Agriculture accounts for 89% of the country's total water consumption. The largest consumer is cotton, which uses 3.7 billion m^3/yr, or 30% of agricultural water. Cotton is the most important cash crop in Syria. Nearly one-fifth of the economically active population derives all or part of its income from cotton production and processing. However, over 95% of cotton in the country is grown using inefficient (even wasteful) methods of water management, such as low-efficiency surface irrigation and excessive water applications. ICARDA is working with Syrian partner institutions to develop and promote technologies to improve water-use efficiency in cotton irrigation.

Complementing national efforts

In 2001, the Syrian government adopted a modernization plan aimed at sustainable water resources and irrigation development. Old irrigation projects are being rehabilitated and modernized. Farmers are being encouraged to adopt modern techniques like drip irrigation to improve on-farm irrigation efficiency, by providing tax-free low-interest loans to cover the initial capital costs. However, adoption of these technologies is growing only slowly. To complement national efforts to promote modern systems, ICARDA researchers focused on ways to improve existing, inefficient surface-irrigation systems. Given the widespread use of such systems, the returns to such research are potentially huge.

Average seasonal irrigation for cotton in Syria is about 15,000 m^3/ha, and much higher application rates are not uncommon. In fact, seasonal water requirements for the crop are only 7000-8000 m^3/ha. Because of over-irrigation, cotton water productivity in areas using traditional surface irrigation is 0.07-0.09 kg of lint cotton per cubic meter of applied water. Compare this with water productivity in surface-irrigated fields elsewhere: 0.13-0.16 kg/m^3 in Turkey, 0.23-0.39 kg/m^3 in USA and Argentina. The low water productivity of cotton in Syria is a major factor in the country's water deficit, although a number of low-cost, practical solutions are available.

Improved irrigation management methods are available that can significantly increase water productivity in cotton.

Field experiments at ICARDA and Syrian research stations have clearly demonstrated the potential for producing more cotton per unit of water – higher yields with the same amount of water, or the same yield with less water – by sound irrigation and agronomic practices. One Syrian study showed that water productivity of seed cotton can increase from 0.2 kg/m^3 under flood irrigation to about 0.4 kg/m^3 under furrow irrigation, with irrigation efficiency increasing from 40% to about 65%. Another study in hot, dry central Syria showed that drip irrigation could reduce irrigation requirements by 35 to 55%; and that drip irrigation combined with fertigation gave nearly 50% higher yields than conventional surface irrigation.

A two-year cotton-wheat rotation experiment at ICARDA's principal research farm at Tel Hadya showed that water requirements of cotton could be fully met with 7900 m^3 of water using drip irrigation, and an improved irrigation schedule based on soil water depletion. This corresponds to a water productivity of 0.51 kg/m^3 of seed cotton (or 0.18 kg/m^3 for lint) – double the national average. The experiment produced an average yield of 4008 kg/ha of seed cotton, which is the same as the national average, but used less than half the water typically used by farmers in Syria. In other words, *double* the crop per drop!

Farmer innovation in Syria: improved irrigation techniques and locally fabricated delivery systems.

Methods to improve water productivity

One important way to enhance water productivity, particularly in dry areas, is by improving irrigation scheduling, based on regular monitoring of soil moisture conditions during the season. Most farmers in Syria lack the knowledge or the tools to monitor soil water depletion for proper scheduling. Traditional methods, such as 'soil feel' and 'soil probe' are fairly effective, but users must have sufficient experience. A practical approach would involve considerable effort by local agricultural extension staff to compute and publicize daily or weekly crop water requirements for the main crops in the area.

There are many examples of effective, low-cost methods to improve irrigation efficiency. These include use of furrow irrigation, lined canals to reduce seepage, collapsible or solid conduits for head ditch delivery, siphon tubes and gated pipes for better furrow flow control and flexibility, land grading for enhanced flow and distribution, and surge flow and cutback methods for improved furrow efficiency. Experience shows that simple improvements can produce significant benefits.

Two other management practices are important. One is skip furrow (or alternate furrow) irrigation, where the farmer irrigates only every alternate furrow. With half the furrows skipped, excess irrigation is automatically cut back. This technology requires no capital or time investment and can be easily implemented. Further testing in Syria is needed to quantify the large potential water savings. The other practice is deficit irrigation, which could help farmers manage limited water supplies and mitigate the effects of drought. At present, most farmers irrigate their crops with a view to maximize yield per unit of land. This strategy – maximum irrigation for maximum production – is both unwise and unsustainable in basins where water is being withdrawn faster than it is being replenished. But more sustainable alternatives such as deficit irrigation are perceived to be less profitable. Government incentives and policy support will be needed to encourage adoption.

The Syrian government's irrigation modernization plan is expected to produce national water savings of 2.9 to 4.1 billion m^3/year. This would more than wipe out the current national deficit of 1.73 billion m^3, and could support expansion of irrigated land and/or meet other demands such as for drinking and industry. Part of these savings will come from better irrigation efficiency. Water productivity is expected to double, through adoption of drip irrigation, improving the existing surface irrigation methods, encouraging sound on-farm water management, and strengthening extension support.

As water supplies become even more scarce, efficient irrigation is critical – and so are targeted policies to encourage resource-poor farmers to adopt new irrigation and water management technologies.