team conducted a vegetation survey carried out principally in a protected area within the Menzel Habib project site, where the range was not degraded and hence most rangeland species were represented.

An Egyptian Watershed Management program survey of 45 sites throughout the Sinai Peninsula characterized each by its soil properties, plant community, and the economic properties of its species. 62 species were found, 16 of which were identified as prime fodder species, and 19 of which were identified as medicinal species. Chemical analyses were used to establish their nutritive and pharmaceutical properties. Another Egyptian project activity carried out vegetation transects in 12 land cover types in the Um el Ashtan watershed and identified 53 species, half of which were forages. The project team calculated the relative abundance, cover, and standing crop of all 53 species, and determined their protein, carbohydrate, ether extract, fiber, and ash compositions.

An Israeli survey collected seeds and samples of two wide-ranging high-quality forage species, orchardgrass (*Dactylis glomerata*) and the legume purple clover (*Trifolium purpureum*), from their marginal populations at the desert edge and from more mesic populations. 6,000 orchardgrass and 7,000 purple clover offspring of the sampled field populations were tested in a greenhouse experiment to determine variability in morphological and reproductive traits, the heritability of these traits, and the relations of the variability to the persistence of the populations when exposed to environmental stresses (Figure 62). The Israeli Watershed Management team also conducted a survey of climatic arid–semi-arid transition zones in Israel. The survey revealed that most of the 140 plants species found in the transition area were represented by their peripheral populations. The results of the studies suggest that the rangeland plants in the

Figure 62: Exploring within-species variability and trait heritability of two forage plants, *Dactylis glomerata* and *Trifolium purpureum*, collected along a rainfall gradient in Israel.

transition zones are potentially highly resistant to environmental stresses. They are therefore good candidates for use in rangeland rehabilitation when transplanted to dryland climates that differ from those of their indigenous locations.

Seeds collected and evaluated during field surveys were selectively deposited in genebanks and cultivated in botanic gardens. The genebanks and botanic gardens both provided material to nurseries, which came to be used intensively by the national Watershed Management programs.

The Tunisian Watershed Management team consulted with a range of experts and local informants familiar with indigenous knowledge to identify plant species known to be drought tolerant, well adapted to saline conditions, or useful in stabilizing sand dunes. Some of the species had all three characteristics. The team collected 33 such species— mostly wild herbaceous and woody forage plants—and deposited their materials in a seed bank established at the *Institut National de la Recherche en Génie Rural Eaux et Forêts* (INRGREF) in Tunis. (A second cold chamber was available at the INRGREF Research Station at Gabès.)

The Egyptian team used a number of genebanks to store seeds of promising species collected during the biodiversity surveys of the Sinai Peninsula and the Northwestern Coast, and enlarged a botanic garden to accommodate the seedlings of 25 species for investigation and seed production. Studies in the botanic garden compared the fodder yields of forage species collected during the Um el Ashtan biodiversity survey and other species imported from Jordan and Tunisia. Saltbush (*Atriplex nummularia*) was found to have the highest fodder yield and *Ononis vaginalis* to have the lowest.

The Palestinian team established 13 botanic gardens and one herbarium. The 15 hectare botanic garden in Jericho was fitted with a drip irrigation system. The garden in the Hebron area accommodated 60 indigenous plant species. Another large botanic garden in Idna carried 500 West Bank plant species. The remaining 10 botanic gardens were established in schools in Hebron area villages, and were used to promote public awareness focusing on children audiences (Figure 63).

Nurseries were established and operated by all five national Watershed Management programs and used to propagate plant species selected for their suitability to different local conditions and Watershed Management projects. Seedlings were distributed to watershed users free of charge.

Figure 63: In-situ conservation, establishing an educational protected area; West Bank.

The Palestinian Watershed Management team rehabilitated and upgraded a nursery at the Al Aroub School that was supplied with treated wastewater from the nearby wastewater treatment plant that was also operated by the team. The nursery produced thousands of seedlings of some 50 forage and afforestation species used for range and woodland rehabilitation. Over 11,500 seedlings of *Acacia sp.* and *Atriplex sp.* cultivated at this and other Initiative nurseries were planted on a total of 80 hectares at Wadi Nar, Dahria, Ennab Al-Kabirah, Ratheem, and the Al-Kaabneh catchments.

The nursery at the El-Qasr Research Station produced thousands of saplings of nine forage bushes and trees used in the Egyptian rangeland rehabilitation project at Wadi Um Ashtan. The nursery was used to cultivate both exotic and indigenous species of shrubs and trees that were selected by virtue of their drought-tolerance and their forage and fuelwood productivity. The facility was an improved nursery, where production costs were 36 percent lower than in traditional nurseries, and sapling survival rates were 55 percent higher. Seedlings and seeds were distributed to farmers for demonstration and the establishment of small on-farm nurseries. Thirty-thousand seedlings were distributed to farmers in the 2002–2003 growing season alone, and 30 Bedouins were trained in the production of seedlings.

Nurseries were also established to germinate seeds collected during project activities. Two such Tunisian nurseries in Oued Zeyed and Menzel Habib produced thousands of seedlings of a score of species for rangeland rehabilitation from seeds collected at project sites (Figure 64). The Egyptian Wadi Sudr and El Sheikh Zuwayid nurseries produced seedlings from the seeds collected during the Egyptian biodiversity survey of the Sinai Peninsula, which were later planted in newly reclaimed sites on the Peninsula (Figure 65). The Jordanian team established a one hectare nursery for thornless

Figure 64: Gabès Nursery, Tunisia.

Figure 65: Nursery Egypt.

Opuntia cactus in the Wadi Mujib watershed, and helped improve six other government and private nurseries to support cactus plantations.

The *in-situ* conservation of plant genetic resources on farms and rangelands was another focus of Watershed Management activities relating to biological diversity, and included work within protected areas that had eco-tourism components.

The Palestinians compiled a comprehensive biodiversity conservation plan with recommendations for the designation and management of protected areas in the West Bank and in the Wadi Gaza watershed in the Gaza Strip. The Jordanian team surveyed areas along the eastern coast of the Dead Sea and likewise identified a number of places that would make suitable protected areas. The team developed a framework plan for eco-tourism in the areas that were set aside for conservation purposes. Plant cover was rehabilitated at eco-tourism sites using thornless cactus and forage species, and an agreement was made with local Bedouins to protect the area against grazing. A system of paid grazing was tested by the Jordanian team at the Sura Nature Reserve (Al Mafraq) where grazing was banned for four years and reopened for paid grazing of privately owned herds of sheep. The revenues earned were used to maintain the Reserve. Israeli work on *in-situ* conservation included a study of within-species genetic diversity of selected forage plants from the transition zones between arid and semi-arid drylands. These forages exhibited both high between- and within-species diversity that suggested their suitability for rehabilitating degraded rangelands. Based on this research, the Israeli team would recommend the establishment of biodiversity conservation areas in a number of these transition zone rangelands.

Diversifying Farming Systems and Promoting Off-farm Activities

The Egyptian team conducted a baseline survey of dryland farming systems involving 100 land users in the northwestern coastal zone at Wadi Um Ashtan and Halk El-Dabaa, and evaluated a number of rangeland use practices. The Palestinian team conducted a socioeconomic survey of a number of its water harvesting activities, and found that the terracing technique was most preferred by local farmers, even though its construction was the most costly. Income returns from olive cultivation on the terraces was the highest of any of the water harvesting methods tested. The Israeli team examined the benefits accruing to Bedouin herders from purchasing permits to graze in an arid afforestation project, and compared these to the benefits of herding flocks to more distant but more productive agricultural fields where the Bedouins could purchase foraging rights on stubble. The results of these farming systems analyses and other socio-economic studies led the Watershed Management teams to promote the cultivation of a number of non-conventional crops as well as a variety of other land-based income-generating activities.

The cultivation of non-conventional crops moved farm production towards higher value crops. These crops included cacti of the genus *opuntia* and a number of herbal and medicinal plants. Opuntia cactus cladodes were cultivated as both fodder and a fruit crop. Though not a traditional animal feed in the MENA region, the thornless cactus produces edible succulent cladodes as well as a marketable fruit. The plant is productive in areas with 150 millimeters annual rainfall, is drought-tolerant, and its water-use efficiency is high. The Jordanian team established six ad-hoc cactus nurseries for propagating the thornless variety, which had been imported from Tunisia. Jordanian farmers and livestock owners readily accepted the cacti, both as a cash fruit crop and as a cheap fodder supplement. 127,000 cacti were planted on 67 hectares on 14 private farms, and in a protected area in the Wadi Mujib watershed. The Jordanian team also co-financed small beekeeping and rabbit husbandry operations together with individual farmers and rural NGOs using microcredit.

Large scale farm cultivation of high market-value medicinal and herbal plant species was hindered by limited access to improved plant stocks, insufficient knowledge as to how to farm them under dryland conditions, and inadequate extension (Figure 66). These species were mainly non-domesticated wild plants traditionally gathered in MENA rangelands. The Jordanian team was particularly active in this area, and first experimented with rainfed cultivation of cumin, fenugreek, black cumin, anise, caraway, and fennel in collaboration with the National Center for Agricultural Research and Technology Transfer (NCARTT). These experiments were followed by tests with irrigated cultivation, which was also applied to oregano, sage, chamomile, rosslle, mellisa and arak. Seed quality, germinability, leaf chemical properties, and weed control methods were improved and field-tested, resulting in recommendations for attaining high yield and high quality of each species. For example, growing thyme under plastic house conditions maximized yield and return, while sage was recommended to be cultivated under open field conditions. For chamomile, the team sought to develop techniques to extend flowering time to increase yield. Arak, mellisa and rosella cultivation was found to be feasible under conditions of high heat and salinity, particularly when mulched.

Figure 66: The Jordanian Initiative team raises awareness for the production of herbal and medicinal plants among rural women.

Figure 67: Jordanian lavender sold on a French market.

The highest dollar value added was achieved with cumin, and was 3.3 times higher than that of traditional wheat and lentil crops. The lowest value added was achieved with fenugreek, which was still 20 percent higher than these traditional crops. Field demonstrations were conducted on several hundred hectares working with more than 100 farmers in 32 villages in three regions, including sites in the Wadi Mujib and Madaba areas. The returns farmers derived from cultivating medicinal and herbal plants was generally greater than the production cost – 240 percent higher for fennel, the most profitable species. Chemical analyses of the active ingredients in thyme, sage, mellisa, rosella tea and arak were conducted in collaboration with the Faculty of Pharmacy at the University of Jordan, and yielded valuable results that were incorporated into the technical assistance provided to participating farmers. The integration of medicinal plant production with beekeeping was also tested. Farmers were interviewed to identify constraints to and opportunities for commercialization, and the team produced a report on the competitiveness and marketing of medicinal and aromatic plants. The report was subsequently used to prepare a successful grant proposal to the Global Environment Facility (GEF).

Farm-based dairy facilities were another focus of farm diversification and transition to higher value production. These facilities would process the milk into higher value products than raw milk, and the products would be directly marketed by participating farming groups. The improved dairy production would increase livestock profitability without any need to raise stocking rates. A women's cooperative in Faisalyia village specializing in milk processing was monitored by the Jordanian team to gather information on the milk market chain, and to illustrate the link between forage production, milk production, and its processing. The cooperative's 25 producers together processed 400 kilograms of milk a day, and the product's successful marketing created 107 jobs down the supply line. Later, following a survey of several communities, the Jordanian Watershed Management team co-financed the establishment and operation of two dairy units which were regularly supplied with fresh milk from neighboring communities. Women in these communities were employed both in processing the milk products and in marketing them. One of the dairy units achieved returns 20 percent higher than the cost of investment and operations. The other dairy unit was not profitable. Livestock producers also benefited from additional fodder sources introduced under the programs; including the rainfed thornless opuntia cactus described above, and treated wastewater-irrigated rye grass (Figures 68). These represented non-conventional fodder sources with zero impact on surrounding rangelands.

Figure 68: Rye Grass is being fed to sheep, reducing pressure on over-exploited rangeland; on-farm trials; Jordan.

B. The Treated Wastewater and Biosolids Re-use programs of the Dryland Initiative

Wastewater Treatment

In Tunisia, Initiative funding was used to assist the government's *Office National de l'Assainissement* (ONAS) in upgrading the treatment plant in Gabès. The existing plant employed a secondary treatment process with capacity to produce 17,000 cubic meters of treated water a day (Figure 69). The Tunisian Treated Wastewater and Biosolids Reuse team invested US$120,000 in the construction of an infiltration and percolation pilot station that generated 150 cubic meters of tertiary treated water a day (Figure 70). The pilot station was constructed near the existing wastewater treatment plant, and the Tunisian team purchased a variety of laboratory equipment that was used to test water quality. Experimenting with the tertiary treatment process, the team explored the potential of a sandy layer in filtering the water, and determined optimal filtration rates. Experiments with filtering agents, with systematic monitoring of water quality, were carried out on silvo-pastoral, ornamental seedlings, and vegetables cultivated in a nearby nursery. The experiments were likewise conducted on vegetables on experimental plots in the Dissa irrigation perimeter, making for somewhat greater

Figure 69: Secondary treatment of wastewater in Gabès, Tunisia.

Figure 70: Tertiary wastewater treatment funded by the Initiative; Gabès; Tunisia.

approximation of cultivation under less controlled conditions. The results enabled the team to identify the water quality and treatment levels required to support the different types of plants. Water treatment could therefore be tailored as necessary to support specific plant species.

At the outset of the operation there was no demand for treated wastewater for agricultural use. Lack of local irrigation infrastructure, technical extension, and knowledge of treatment levels appropriate to individual crops made it difficult to coordinate the pilot facility activities with the needs of prospective customers. Towards the end of the Initiative, the tertiary-treated water was being routinely used to irrigate the garden of the treatment plant and fruit trees of one farmer in the Dissa perimeter, and its demonstrated usefulness is hoped to stimulate demand if publicized. Some of the treated water was used to recharge local groundwater following its use in irrigation. The rest was disposed at sea, a marked improvement to disposing raw sewage or secondary treated wastewater into the Mediterranean.

The Palestinian Wastewater Treatment and Biosolids Re-use program was the only other Initiative program to construct and operate its own wastewater treatment facilities. Whereas the Tunisian team worked on transforming secondary treatment to tertiary treatment, the Palestinian team was initially engaged in primary treatment and later secondary treatment processes. In 1997 the Palestinian team installed a treatment system for the wastewater produced at the Al Arroub Agricultural School in the Hebron area (Figure 71). The facility was intended to serve both educational (demonstration) and experimental (research) purposes. The small facility processed between 300 and 400 cubic meters of wastewater a month. The facility was later upgraded with a mechanized treatment unit, which was useful in comparing its performance with that of Palestinian wastewater treatments that used duckweed.

Duckweed (*Lemna*) is a tiny floating, flowering plant which has proven effective in reducing biological oxygen demand (BOD) and in removing total suspended solids (TSS) and nitrogen and phosphorus levels in the water. Owing to its fast growth rates, duckweed can serve as a supplement or even a substitute to the bacteria and algae used in conventional wastewater treatment. But duckweed has an additional advantage in that its high protein content makes it a valuable fodder. The Palestinian team investigated the use of duckweed and systematically monitored the system's performance. They also conducted experiments in composting harvested duckweed. The duckweed-treated wastewater was used to irrigate plants in a nursery, in a botanic garden, and in other experimental plots. Palestinian experiments were purposefully conspicuous and demonstrations were often targeted at public audiences with regular emphasis on students in addition to the documentation of findings among professional scientists.

Figure 71: Wastewater Treatment Plant at Al Arroub Agricultural School, West Bank.

Treated Wastewater Reuse in Agriculture

The effects of the differently treated wastewater on irrigated soils were measured using soil samples that were sent to certified laboratories in Egypt, Israel, and Jordan. Samples of soils irrigated with treated wastewater were compared to soils irrigated with freshwater for control purposes. The results depended on soil type, crop, and the amount of rainfall as well as on the quality of the water used (Figure 72). Boron concentrations (both naturally occurring and resulting from the amount of detergents in the treated wastewater), increased in both the Egyptian and the Israeli plots. The Israelis found these boron concentrations to depend on the amount of absorbing clay and on the intensity of leaching by rainfall.

Figure 72: (Primary) Treated Wastewater. Visual appearance gives first indication of water quality and often causes social rejection of wastewater reuse, especially on food crops.

Phosphorous concentrations, salinity, and sodium absorption ratios (SAR) increased in the Israeli and Jordanian herbal and medicinal plots. (The SAR is particularly important in its effect on soil structure, aeration, and infiltration rate.) But in Jordanian plots of woody trees, where soils were relatively saline, salinity and SAR values decreased. The results of irrigation therefore depended on the type of crop, and also varied by soil type, soil depth, and season. In the Israeli plots of annual field crops, differences in salinity between wastewater- and freshwater-irrigated soils depended on their location in relation to the country's north-south rainfall gradient, and on the proportion of sand in the soil composition. Concentrations of heavy metals increased in Egyptian, Israeli, and Jordanian plots, but remained at levels well within those recommended for long term irrigation. A few Israeli soil samples exhibited fluoride concentrations higher than US Environmental Protection Agency regulations would permit. The Egyptian team also conducted microbiological tests and revealed, as expected, a higher incidence of pathogenic organisms in the treated wastewater-irrigated soils.

Treated Wastewater and Biosolids Re-use program experiments on the effects of treated wastewater irrigation on crops classified these crops according to their importance to human health and consumption. By this criterion, field and fodder crops were purposefully prioritized, followed by fruit- and fiber-yielding trees, and finally afforested trees. The effects of the treated wastewater were tested by comparing chemical composition, crop health and condition, and yield to the same crops irrigated with non-wastewater sources.

Field crop effects. The effects of treated wastewater irrigation on field crops were researched by the Egyptian, Jordanian, and Tunisian teams. Egyptian experiments worked with a traditional integrated farm management system in the Nile delta in which the same field is used to cultivate five different crops in sequence; soybean, sugar beet, sunflower, canola, cotton and maize. The crops were irrigated sequentially or alternately with freshwater and drainage water. Three irrigation sources were tested: secondary-treated wastewater, treated wastewater alternated with fresh water, and drainage water alternated with fresh water. The overall exposure of crops to treated wastewater was therefore diluted in a number of the experiments. Each of the treatments was applied through both surface and drip irrigation, and each of the crop species (grown in sequence) was tested both in the field and in lysimeters (Figures 73 and 74). The quality of the irrigation water was measured against World Health Organization standards. Based on its findings, the team recommended that drip irrigation be used in the alternation of fresh water with each of the marginal water types. Undiluted wastewater was found entirely suitable for cotton and canola cultivation. The plants remained healthy with each type of treatment, and the alternations with marginal water sources achieved fresh water savings of up to nearly 50 percent.

There is an important distinction between annual field crops and perennial crops like citrus – annual crops require far less water throughout the year than perennials, and they are tilled whereas perennial

Figure 73: Treated wastewater trials, Kafr El Sheikh, Egypt. Indoor experiments.