Figure 74: Treated wastewater trials, Kafr El Sheikh, Egypt. Outdoor experiments.

crops are not. These differences may modify the impact of treated wastewater on annual crops and soils. Both the Israeli and the Tunisian teams tested the effect of tertiary-treated wastewater on annual field crops. The Tunisian Initiative team, together with CITET and IRA, experimented with drip- and furrow-irrigation of green pepper, tomatoes, potatoes, and lettuce using tertiary-treated water on a farmer's plot in the Dissa Perimeter. The team found that fruits and leaves of pepper, potato, and tomato irrigated with tertiary-treated wastewater had bacterial flora similar to the bacterial flora typical of these crops sold in the local market. When these crops were furrow-irrigated with secondary-treated wastewater however, bacterial contamination increased considerably. The Israeli team also explored the long-term effects of tertiary-treated irrigation on a large number of plots subjected to frequent field-crop rotations, in order to monitor the water's cumulative effect on the soil. This soil monitoring was undertaken prior to testing the effects of the tertiary-treated wastewater on crops.

Fodder crop effects. The response of fodder crops to irrigation using treated wastewater was a focus of research among the Israeli, Jordanian, and Tunisian programs. The Israeli team studied the nutritional value of treated wastewater applied to corn grown as fodder, and was able to demonstrate substantial reductions in the amount of fertilizer required. The team found no reduction in crop yield, in spite of increases in salinity parameters in the wastewater-irrigated soil.

The Jordanians used secondary-treated wastewater from the Madaba Wastewater Treatment Plant to irrigate the green fodder sources ryegrass, sudan grass, salex, sorghum, alfalfa, and canola (Figure 75). A two hectare experimental plot in the vicinity of the Madaba facility, and a 17 hectare farmer's field were used as experiment and demonstration sites. The irrigation enabled four to five harvests a year, and increased ryegrass productivity by some 40 percent. On the 17 hectare field, the irrigated ryegrass earned 25 percent more than the barley the farmer had previously cultivated. The soil and the forage were tested for chemical and bacterial composition, and values were found to be compatible with World Health Organization standards for livestock fodder. In addition, fat and milk from cows fed with TWW-irrigated fodder crops were found to be similar to those produced using freshwater-irrigated fodders.

Figure 75: (Primary) Treated Wastewater Reuse in fodder and tree crop production; Jordan.

Blood tests for potentially toxic metals (cobalt, chromium, cadmium, nickel) showed concentrations within EU and Codex Alimentarius standards.

The Tunisian team irrigated furrows of alfalfa and oat fodders in the Dissa Perimeter with secondary-treated wastewater from the treatment facility at Gabès (Figure 76). *Office National de L'Assainissement* (ONAS) technicians regularly monitored water quality. The Dissa Perimeter was intended to eventually receive tertiary-treated wastewater in order to assess the marginal contribution of the tertiary plant in improving the quality of treated wastewater and the productivity of the crops.

Fruit tree effects. Israeli experiments with fruit trees used secondary-treated and tertiary-treated wastewater to irrigate experimental plots in some 140 citrus and avocado orchards (Figure 77). Irrigation using fresh water was employed as a control. The orchards were distributed along an aridity gradient from northern to southern Israel. The investigators monitored chloride, sodium, potassium, boron, phosphorous, nitrogen, and heavy metal concentrations in both leaves and fruit. Boron concentrations in all parts of the treated wastewater-irrigated trees were found to be significantly higher than in trees irrigated with fresh water, and the number of fruits produced per tree

Figure 76: TWW reuse in Tunisia.

Figure 77: Citrus irrigation with treated wastewater; Israel.

declined. Reducing domestic and industrial uses of boron-containing detergents would therefore clearly increase the safety of wastewater irrigation. Tunisian experiments irrigated pomegranate trees in the Dissa Perimeter with treated wastewater provided by the facility in Gabès.

Non-fruit tree effects. Considering the low risk to human health of applying treated wastewater to afforested, ornamental, and fuelwood- and timber-producing trees, these trees received surprisingly little attention in the Dryland Initiative's treated wastewater experiments. The Jordanians investigated the reuse of low-quality treated wastewater on *Eucalyptus camaldulensis* and on *Casuarina equisetifolia* planted at a farm site in Al Hashymeih. The two species were a combination of afforestation, windbreak and ornamental trees, and the low quality wastewater used to irrigate them was generated by the Khirbet As-Samra treatment plant (Figure 78). The team found increases in growth rates, canopy height, and trunk diameter during the growing season when the low quality wastewater was applied. Less favorably, high concentrations of iron, manganese, and zinc were found in roots, stems, and leaves of both species. The Palestinian team used the primary and secondary-treated water generated by their treatment facility at the Al Arroub School to irrigate trees in the vicinity of the school.

Figure 78: Tree crop production with treated wastewater; Jordan.

Figure 80: Cut-flowers irrigated with TWW, drip-irrigation in a greenhouse; Jordan.

The Tunisian program used secondary-treated wastewater from the treatment facility in Gabès to irrigate tree seedlings that were then distributed to schools and communities in the vicinity.

Herbal and medicinal plant effects. Herbal and medicinal plants that produce commercially valuable volatile oils are other non-edible crops that can be irrigated with lower quality treated wastewater without significant risk to human health. The Jordanian and Tunisian teams were active in this area. The Jordanian team used treated wastewater from the Ramtha Wastewater Treatment Plant to irrigate an adjacent experimental field of melissa, geranium, and lavender (Figure 79). This treatment plant produced water with trace elements and heavy metal concentrations well within compliance with Jordanian standards for irrigation water. Though soil salinity in the irrigated plots increased, nutrient ion in the soil increased as well, and the condition of the plants and the quality of their volatile oils were not impacted.

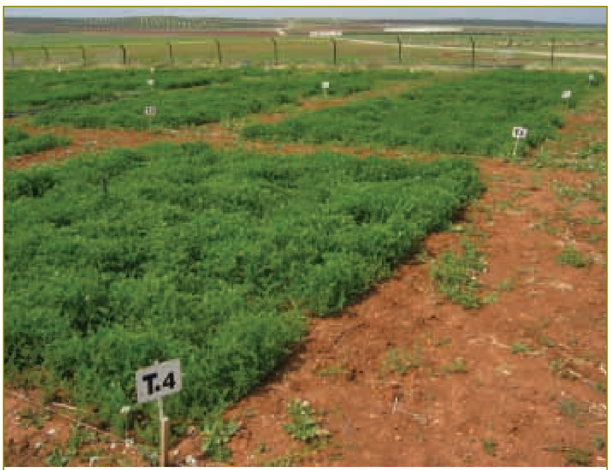

Figure 79: Herbal and medicinal plants irrigated with treated wastewater; Jordan.

Brackish Drainage Water Reuse in Agriculture

The Egyptian Treated Wastewater team explored the effects of drainage water collected from irrigated sugarbeet, wheat, and rice fields on its Kafr El-Shikh project site in the Nile Delta. After determining the water's chemical properties, the water was used to irrigate a variety of crops in lysimeters. The team ran experiments to determine the levels of salinity and concentrations of lead, boron, cobalt, and nickel that can be tolerated by several field, vegetable and medicinal crops without putting the soil at risk. Being somewhat higher in salinity and pollution content than typical drainage water, the water could still be used if diluted with freshwater in order to achieve the recommended concentrations (Figures 81 and 82).

The study also experimented with field preparation, and found that the drainage-irrigated crops benefit substantially when soil hydraulic properties are improved by deep ploughing and by the removal of excess salts away from the active root. The removal of salts was achieved using laser leveling technology

Figure 81: Mixtures of drainage water, freshwater, and TWW used in crop production (sugar beet), on-farm trial; Kafr el Sheikh, Egypt.

Figure 82: Mixtures of drainage water, freshwater, and TWW used in crop production (sugar beet), on-farm trial; Kafr el Sheikh, Egypt. Salt crust building up.

to thoroughly level the fields. The Egyptian Socio-economy and Policy team also calculated the cost-benefit ratio of different combinations of drainage-water irrigation and field preparation.

Biosolids Treatment and Use in Agriculture and Energy

The Initiative experimented extensively with a variety of biosolids, including sludge generated by wastewater treatment facilities. The experiments tested composting and digestion methods, the effects of applications on numerous crops and soil types, and a number of non-agricultural uses, including the production of biogas.

The Jordanians experimented with manures generated by the large Hamodah dairy farm in Khaldeah and a number of poultry farms in the Mafraq governorate (Figure 83). The experiments sought to provide farmers with safer and more effective composting alternatives to the current practice of applying raw manure. The team systematically monitored temperature and carbon dioxide levels during the composting processes. Carbon-nitrogen ratios and plant nutrient concentrations were determined by the laboratory at the National Center for Agricultural Research and Technology Transfer (NCARTT).

The Israeli, Palestinian, and Tunisian programs concentrated on the composting of sludge mixed with varieties of other biosolids. The Palestinians experimented with composts of virtually every biosolid source generated at the Al Arroub agricultural school, including tree trimmings, grass, straw, cow and chicken manure, slurry from their biogas facility, and sludge and harvested duckweed from their pilot wastewater treatment facility. They constructed a fully operational composting plant and demonstrated successful techniques to students and visitors. The Tunisian team experimented with composts from the secondary sludge of the Gabès treatment plant, to which they added different quantities of straw and olive oil production byproducts, testing their effects on increasing carbon-nitrogen ratios in the composts (Figure 84).

Figure 83: Manure treatment, Jordan.

Figure 84: Composting sludge, ONAS Plant in Gabès, Tunisia. Drying sludge before grinding.

The Egyptians applied lime-treated sludge compost, and sludge composted with rice straw to crops at the Sakha Agricultural Research Station in the Nile delta. Electrical conductivity, sodium absorption ratios, and lead concentrations varied depending on the crop. The experiments measured the effects of these lime-treated and rice straw-mixed sludge composts on the chemical properties of a range of crops, including mango, maize, soybean, rice, sugar beet, canola and sweet pepper. In all treatments and crops, biosolid application increased nitrogen, phosphorous, and potassium concentrations in the plants, but also increased those of boron, cobalt and lead. The findings suggested that sludge produced from wastewater treatment can in most cases be used safely, and reduce the need for mineral fertilizers when mixed with rice straw.

Israeli experiments measured the effects of a wider variety of mixed biosolids applied as composts and mulches to wheat in dryer semi-arid areas, using municipal waste compost, partially digested primary and secondary sludge, and mulches of sludge, sludge compost, and wood chips (Figure 85). The Egyptian and Israeli experiments both increased soil nutrients and soil organic matter substantially. The increased soil organic matter measurably increased soil moisture in the strictly rainfed plots in Israel, but a number of the Israeli treatments increased soil concentrations of heavy metals, some of them to levels above international standards. (The lime-treated sludge used by the Egyptian team at Sakha actually reduced the heavy metal content of surrounding soils.) The Israelis found that application of sludge increased the wheat grain yield, with no differences between the mulched or the incorporated application. High levels of application (100 cubic meters of sludge per hectare) brought about increased protein content, but a significant decrease in the specific weight of the grain. Most importantly, the biosolid application was found to totally replace commercial nitrogen fertilization. During dry winters however, fields were prone to nitrogen excess, since water shortage reduces growth and therefore nitrogen use. These relations between biosolid application and natural between-year rainfall variations prompted a large scale experiment of 160 wheat plots with and without biosolid application in private and cooperative farms along a rainfall gradient of 750–250 millimeters. Israeli farmers were directly involved in all of the experimental applications of biosolids.

A number of Initiative activities experimented with the use of biosolids to produce ***biogas*** for domestic energy generation in rural communities. Biogas is a mixture of methane and carbon-dioxide that is generated when bacteria degrade biological material in the absence of oxygen. The mixture is

Figure 85: Experimental cereal crops with sludge application (herbizide application to separate two different treatments); Israel.

Table 2: Overview of treated wastewater and biosolids field work under the RIDM.

	Treatment facility & scale	Wastewater treatment level	Irrigation system for wastewater reuse	Crops irrigated with TWW	Biosolid application techniques
Tunisia	Pilot plant	Tertiary	Drip (gravity) Surface	Fruit trees Vegetables	Composting
PNA	Pilot plant (small scale)	Secondary & Tertiary	Sub-surface Drip Surface	Forages Olives	Composting Biogas
Jordan	Municipal Plant (large scale)	Secondary	Sub-surface Surface	Forages Wood trees Cactus	Composting Biogas Direct Application
Israel	Municipal Plant (large scale)	Secondary	Sub-surface Drip (pressure)	Fruit trees	Direct Application (surface cover & incorporation)
Egypt	Municipal Plant (large scale) Open drains & Canals	Drainage Primary Secondary Blended	Subsurface Drip (pressure) Gated pipe Surface	Field crops Vegetables (in plastic houses)	Composting Biogas Direct Application (injection)

flammable and can be used for cooking, heating, light, and even absorption refrigeration, although the low compressibility of methane makes the biogas difficult to store. The non-digested remains make superb animal fertilizer, with the advantage that it is free of weed seeds and of pathogenic micro-organisms which are destroyed by the anaerobic digestion.

The Palestinian team constructed three biogas units for experimental and demonstration purposes. Two of the units, near Hebron and near Dura, used manure from nearby animal farms. The other unit was a bio-digester built at the Al Arroub School, which used manure from the school's farm and sludge generated by the school's wastewater treatment plant to produce slurry used by the composting facility.

The Egyptian Initiative team established and operated three biogas units in Kafr El-Sheikh Governorate, cost-sharing them with local farmers and feeding them with farm-produced cattle manure (Figure 86). Rates of pathogenic microorganism removal and gas production were systematically monitored, and the units were found to be highly efficient both in terms of biogas energy production and environmental safety. Women farmers participating in the project proved to be enthusiastic beneficiaries, using manure and its agricultural residue in the household backyard for safe and odorless indoor cooking. A cost-benefit analysis of the activity indicated that returns to the investment in construction and maintenance were some 30 percent higher than cost. The team recommended the biogas technology be disseminated among small farmers who own less than five large ruminants, and who would be willing to manage the animal waste on a cooperative basis. Government subsidized cooking gas bottles in these areas would however impede the dissemination of the technology. The Egyptian experience encouraged the Jordanian team to install similar units at three sites in Madaba and Shamra. The treated wastewater and biosolids field work implemented under the RIDM is summarized in Table 2.

Figure 86: Biogas generation, Egypt.