INCO –DC n° ERB IC 18 CT 98-0272

**"SUSTAINABILITY AND OPTIMISATION OF TREATMENTS AND USE OF WASTEWATER IN AGRICULTURE"**

# FINAL REPORT

From 1$^{ST}$ October 1998 to 30$^{th}$ September 2002

***Type of contract:*** Shared-cost research project

***Total cost:*** 988,000 EURO

***EC contribution:*** 988,000 EURO, 100 % of the total cost,

***Commencement date***: 1$^{st}$ October 1998

***Duration***: 4 years

***Completion date***: 30$^{th}$ September 2002

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# ABSTRACT

The two designated fields experimented in the frame of this project were **wastewater treatment** to obtain a effluent which can be reused in agriculture and **irrigation techniques which are compatible with sustainable agricultural practices**. The goals were to produce in sustainable way, irrigated crops with wastewater treated by low cost technologies adapted to the Mediterranean environment.

The success of this initiative have resulted from the collaboration of the Mediterranean countries' research teams and the European Union laboratories. The aims of this initiative were to find a favorable field to harmonize analysis procedures, to standardize the contamination tolerance levels of effluent destined to similar uses and to create a common data base. Meetings, exchange and reports all along the project duration has allowed the partners to share their experiments and establish long term solutions to common problems relative to the two chosen fields, even if each participant has specific needs and environmental conditions.

The experiments investigated natural vegetation from the Mediterranean region (Free Water Surface system and Epuvalisation) as well as Long Term Storage in maturation ponds. Such a technologies are low cost effective, appropriate for the existing conditions, adaptable to the Mediterranean environment and appropriate for producing advanced treated effluent, which can be used without restriction for agriculture irrigation.

Impacts of irrigation with WW on irrigation systems were defined. The effects of irrigation with wastewater on the soil/plants complex, plants behaviour, salts accumulation, contamination of soil and plants, soil structure, etc. were experimented. Sustainable agricultural practices were proposed as the optimisation of the irrigation with WW, the nitrogen management, the complementary irrigation on cereal crop, ...

The use of wastewater may potentially have adverse impacts on both the environment and the public health, largely depending on wastewater characteristics, the degree of purification, the method and location of use and the crops irrigated. Soil, groundwater and surface water pollution are among the most important potential disadvantages of the wastewater use. However, scientifically sound planning and effective management of the irrigation or fertilization regime according to water and nutrient requirement of selected crops, can minimize these disadvantages to the level of environmental insignificance. Selection of crops is one of the most powerful means to protect public health. Flowers and particularly those which are dried, industrial crops, crops consumed after transformation, give new dimensions on wastewaters use since they can be used on a profitable and sustainable bases.

# SUMMARY OF FINAL REPORT

The three decentralized wastewater treatment systems investigated by the first part of the project were chosen for their low cost, they are appropriate for the existing conditions, adaptable to Mediterranean environment and appropriate for producing advanced treated effluent with the aim of reuse for agriculture. The high cost of wastewater treatment can be a limiting factor for the treatment and reuse of wastewater, especially in developing countries and in villages in remote areas. Natural biological treatment systems for the treatment of organic wastes and municipal sewage tend to be lower in cost and less sophisticate in operation and maintenance.

The use of Free Water Surface constructed wetlands for treatment of mixture of olive-oil mill and municipal wastewater were tested with four units of 45,5 $m^2$ each. Indigenous aquatic plants were tested. The results of the main experiment is summarized by a removal efficiency of BOD5 of 77,0 and 51,25% with and without recycling.

The storage of reclaimed WW brought significant improvement of its microbiological quality. According to duration and retention conditions, such as temperature and depth of the basins, the bacteriological quality achieved may be used for unrestrictive crop irrigation. The seasonal storage, lasting 7 months did not affect the water quality; after decontamination, the number of indicator and the water quality did not change and no proliferation occurred. Small storage reservoir tested could be established by farmers and had the double role of regulation tool and complementary treatment system.

Epuvalisation system is a low-cost biological treatment of wastewater based on the principal of hydroponic culture. Plants are grown on an impermeable surface to which a thin film of water is continuously applied. Root production on the impermeable surface is high and the large surface area traps and accumulates matter and pathogen microorganisms. Plant top growth provides nutrient uptake, shade for production against algal growth and water removal in the form of transpiration, while the large mass of self-generating root systems and accumulated material serve as living filters. Bacteria attached to the submerged roots and stems of the aquatic plants are of particular importance in the removal of soluble and colloidal BOD from a wastewater. This third technique was tested in Greece and Cyprus. In Greece, the system of WW purification with anaerobic treatment, maturation and epuvalisation reduced significantly BOD5, but did not achieve the accepted level for WW discharge in eutrophically sensitive areas, as defined by European directive. Adding a new shallow basin, after the maturation one, to improve the aeration, would probably increase the performance of the system and would achieve the permitted level for WW discharge.
In Cyprus, from the results obtained, the systems reduced the nitrates up to 30-40% and the suspended solids up to 45%, depending on the season, the rate flow of WW and the effluent quality. There was no significant reduction of BOD5, pH and electrical conductivity of the water.

The second part tested the impact of the WW reuse on irrigation system, on the soil/plant complex and on the soil structure; but also irrigation techniques compatible with sustainable agriculture, such as complementary irrigation of cereal crop and the nitrogen fertilisation adjustment when WW reuse occurs.

The WW impact on irrigation system was tested on a potatoes field. It showed that the performance of the irrigation system depended of the screen system. It demonstrated the link between irrigation uniformity and yields obtained. The integrated emitters presented a weak sensitive to clogging problems and gave the better yields. At the opposite were mini-sprinklers and derived emitter with PC. The results converged with laboratory experiments.

The effect of WW on the soil/plant complex was tested to optimise the irrigation with WW and its impact on cultivation. First on citrus trees and the results pointed out that, beyond the importance

of the adequate irrigation system, WW could be valorised as well as fresh water. Second on olive table trees; their behaviour depended on variety, quality of irrigation water and irrigation systems. Study of the impact of WW reuse on bacterial contamination on soil and crop showed that soil irrigated with secondary effluents were significantly more contaminated by faecal indicators than reference plots; the concentration of micro-organisms decreased wit soil depth through the various results obtained, drip irrigation appeared to be the best system when using WW. This would enable the management of this resource to be optimised, while limiting the harmful effects due to salinity and microbial load.

The effect on soil/plant complex studied by the nitrogen balance and salts accumulation under treated WW irrigated vegetables crop demonstrated the high value of WW reuse when appropriate practices are applied. A conjunctive use of WW and conventional water to dilute the salts level and nitrates concentration was recommended. The treated WW resulted in similar to better growth and yield as well as the same quality of crop irrigated with reclaimed waste water in comparison to the control. The nitrogen mass balance for the tested crops receiving treated wastewater indicates the high risk of nitrate leaching to ground water table reserves.

Experiments were led on the optimisation of irrigation with WW and indicated that high salt concentration in wastewater can be a limiting factor for the production of sensitive plants, probably due to the slower uptake of water and fertilizer by the plant. Mixing of wastewater with freshwater could give good results by lowering the salt concentration of the water and also providing some nutrients to the plants. The water coming out the epuvalisation channels had a nitrogen deficiency load. The level of addition of N fertiliser in treated WW was essential when used for irrigation and depended on the plants cultivated and the quality of the effluent.

The field grown chickpea contributed to the understanding of nutrient management with and without sewage water in large and small scale experimental plots. It was demonstrated that addition of mineral nitrogen fertilizer is not adding any increase in yield and most of it is disappear from the soil most probably by denitrification. Subsurface trickle irrigation in large field scale was tried and no yield benefits or deficits were found as compared to surface trickle irrigation. However the E.coli pathogens in the surface soil was the same as background samples suggesting a safer method of irrigation though not always the maximum yields are obtained.

Tests on Faba bean and chickpea cultivars indicated that one out the three cultivars, namely Bolgarit, can be irrigated with TWW without any loss in its biological indicators as compared to irrigation with fresh water. Furthermore the chemical and biological analysis of seeds and leaves indicated no significant difference between cultivars irrigated with TWW as compared with that irrigated with FW. Irrigation using subsurface drippers improved the sanitation of the soil and plant to certain extent. However, it suffered from more frequent clogging due the algae that were developing in the TWW pond.

The needs for improving wastewater-use efficiency in wheat production and sustainable reuse of treated wastewater are clearly urgent. The study optimised the use of wastewater for maximum crop yield or profit, but taking into account the cost of the irrigation water and minimizing the risks for soil salinity and deep percolation of nitrate. It was demonstrated that flowering stage is the most critical growth stage and also that there is a high value of the treated WW reuse as supplementary irrigation. In other investigations, tertiary WW treatment met environmental goals but did not match the crop nutrition requirements.

Management of nitrogen fertilisation with WW reuse was optimised. The yield results indicate the superiority of the treated wastewater and the possibility of producing high yields without additional N fertilizers. In this case yield might not be the highest but with no additional N, pollution problems are minimized. The plant nutrients load in the wastewater can be an important factor in saving costs of fertilizers needed for crop production. It is therefore advisable that recommendations to the farmers concerning fertilisation be different for the effluent and freshwater.

The third part concerned the economical study of 8 WW treatment plant of the project partners. First occurred consultancy of the sites and second, a survey of the WW treatments economy.

**Main publications**

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**Dialynas, G.E., E.G. Dialynas, T.V. Manios, and A.N. Angelakis. 2002**. Use of Free Water Surface Constructed Wetlands for Treatment of Mixture of Olive-oil Mill and Municipal Wastewater. In: Proc. of IWA-Regional Symposium on Water Recycling in Mediterranean Region, (A.N. Angelakis et al., Eds). Iraklion, Greece, 26-29 September 2002, 2: 127-130.

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**Trad-Raïs M., Xanthoulis D., and N. Gardin** (2002) – Storage of secondary effluents for safe reuse in agriculture. *International Symposium on Environmental Pollution Control and Waste Management, 7-10 January 2002, Tunis.*

**Trad-Raïs M., Xanthoulis D., and N. Gardin** (2002) – Seasonal storage of reclaimed wastewater in Tunisia: A means of upgrading microbiological quality. *International Conference on Environmental Problems of the Mediterranean Region. 12-15 April 2002, Near East University, Nicosia, North Cyprus.*

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**Mojtahid A., Lamiri M., Choukr-Allah R., Hamdy A. and El Omari H**. Best management of reducing nitrogen pollution under irrigated sweet paper with treated wastewater. ICID-CIID International Workshop on Wastewater Reuse Management, September 2001, Seoul, Korea. p: 55-62. Editors: Ragab Ragab; Geoff Pearce ; Ju-Chang Kim ; Saeed Narizi and Atef Hamdy.

**U. Kafkafi, S. Abbo and G. Tavori** Nitrate and sodium chloride influence on P and Mo uptake by Faba bean and 2 chickpea cultivars. The Hebrew University of Jerusalem, Faculty of Agricaultural, Food and Envirinmental Quality Sciences, Department of Field Crops, Vegetables and Genetics, PO Box 12, Rehovot 76100, Israel

# CONSOLIDATED SCIENTIFIC REPORT

## OBJECTIVES

The goals of the project were to produce in sustainable way, irrigated crops with wastewater treated by low cost technologies adapted to the Mediterranean environment.

The three decentralized wastewater treatment systems investigated by the first part of the project were chosen for their low cost, they are appropriate for the existing conditions, adaptable to Mediterranean environment and appropriate for producing advanced treated effluent with the aim of reuse for agriculture. The second part aimed to test the impact of the WW reuse on irrigation system, on the soil/plant complex and on the soil structure; but also irrigation techniques compatible with sustainable agriculture, as the complementary irrigation of cereal crop and the nitrogen fertilisation adjustment when WW reuse occurs.

The success of this initiative resulted from the collaboration of the Mediterranean countries' research teams and the European Union laboratories. The aims of this initiative were to find a favorable field to harmonize analysis procedures, to standardize the contamination tolerance levels of effluent destined to similar uses and to create a common data base. Meetings, exchange and reports all along the project duration has allowed the partners to share their experiments and establish long term solutions to common problems relative to the two chosen fields, even if each participant has specific needs and environmental conditions.

## ACTIVITIES

The first low cost **treatment technique** tested in the **first part** of the project, adaptable to Mediterranean environment was investigated by partner 2 (Greece, Iraklio) by the **Free Water System**. They tested the Use of Free Water Surface constructed wetlands for treatment of mixture of olive-oil mill and municipal wastewaters. Decentralized wastewater management systems of low capital cost and very well adapted to the environment, such as constructed wetlands, which can return the bulk of the treated effluent for reuse should be tested, particularly when olive oil wastewater is considered. It is the best way to face such problems particularly in the rural areas of both developing and developed countries in the temperate regions. In such systems, various endangerous (water tolerance) plant species could be used. The principal arrangements for the application of constructed wetlands systems used are Free water surface (FWS) and Subsurface water flow (SWF). Usually, depths of 0.1-0.45 to 0.45 to 1.0 m are used for FWS and SWF systems, respectively (Angelakis and Tchobanoglous, 1995; Angelakis, 2001). SWF systems have the advantages of smaller land area requirements and avoidance of odour and mosquito problems as compared to the FWS systems. Disadvantages of SWF systems are the increased cost due to the gravel media and the potential for clogging of the media used (Crites and Tchobanoglous, 1998). One FWS unit is located in Pompia, Messara valley, Crete. In the last four years the plant's vegetation reached the size of two meters. Four such units of FWS have been constructed of 45.5 $m^2$

each. Indigenous aquatic plants Phragmites communis, and Typha spp. are used. In addition, post-treated olive-oil production wastewater is used in mixing with pretreated municipal wastewater including recycle. Besides effectiveness of the aquatic plants used, design criteria for formulating such constructed wetlands will be experimented and using reclaimed wastewater will test irrigation of vineyards by using reclaimed wastewater as well. In order to avoid the mosquito nuisance factor in Pompia plant a fish species (*Gambusia* spp.) was inserted in the wetland lifecycle. Very good quality water is locate in the outlet of Pompia plant.

The second low cost wastewater treatment technique tested to obtain water for agriculture was investigated by partner 4 (Tunisia). They tested **the long term storage** of reclaimed wastewater for reuse in agriculture. The objectives were to confirm and complete the first results already available concerning the effect of many factors (retention time, ambient temperature and depth of the basin) on bacterial indicators die-off, to evaluate the impact of several months of storage on the main characteristics of wastewater, to produce a relationship linking the die-off coefficient of faecal coliforms to various physical, chemical and meteorological factors and to study some modes of management and determine the most suitable one for a such scale of storage basin. The tests were done in 3 storage basins developed to this end on an experimental station situated in north-east Tunisia. These basins were 2, 3 and 4 metres deep, with respective capacity of 75 , 220 and 275 cubic metres. Secondary effluent used in the various tests came from an activated sludge treating plant (SE4), located 7 km. from the experimental site. Samples of wastewater were taken from the storage basins, three times a week, and were analysed in the laboratory. Bacterial concentrations were determined by the most probable number technique for faecal coliforms (FC) and faecal streptococci (FS).

The third wastewater treatment low cost technique, adaptable to the Mediterranean environment was investigated in Greece by partner 2 and Cyprus (partner 6). The main objective for partner 2 was the valorization of **Epuvalisation** as a new method, based on the principle of hydroponic crops, for purifying wastewater. As secondary objectives were concerned the determination of the reduction of the organic matter contained in the wastewater, the determination of the alteration in the chemical composition of wastewater, the alteration of the micro organisms contained in the wastewater, the comparison of the purification yield of each line and the optimization of the epuvalisation system. The experimental field was established nearby the small village of Linaria. Linaria village is located on the Greek island Skyros. There has been done rehabilitation of the wastewater treatment station of Linaria, which was out of service. The new treatment plant is sized to process 50 $m^3$ treated wastewater per day and is composed of an anaerobic basin, a maturation basin and four channels for the epuvalisation system. The whole system is equipped with the proper pumps and pipes. The plants that were tested in this epuvalisation system were *Zantedeschia aethiopica* (Calla lily), *Phragmites australis*, *Arundo donax (Giant reed), Apium graveolens* (Celery) and *Setaria viridis*. The various samples of wastewater, necessary for the analysis of the parameters, were taken in compliance with international standards for water analysis (ISO 5667). Five replicates were made for each measurement At the beginning and at the end of the experimentation, five plants per treatment were harvested and the fresh weights were determined. The dry weights were obtained by drying the plant at 85$^{o}$C to constant weight. The growth rate was determined by the ratio: dry weights of plant at the end / dry weights of plant at the beginning.

The same technique was also investigated in Cyprus, by the partner 6. An epuvalisation system has been installed for tertiary treatment of secondary treated wastewater coming from a nearby activated sludge treatment plant treating domestic waste. The aim of the experiment was to test: the effect that different hydroponics plants, used in the channels, will have on the purification efficiency of the wastewater and, the use of the treated wastewater for irrigation of agricultural

crops. The system consisted of 2 channels, each 20 m long made from four 5m x 50cm galvanized channels. Each channel was capable of treating 8-12 tones of water. Secondary treated wastewater from a nearby activated sludge treatment plant treating domestic waste was stored in a pond and pumped in 4, 2tonne water tanks using a solar pump. Water was pumped into the 4 water tanks in order for the two channels to have enough water to work during the night when the solar water pump was not working. From the 4 tanks wastewater flew by gravity into the 2 channels and after treatment stored separately at the end of each channel into a 2tonne water tank in order to be used for irrigation. In each 20-meter channel, 240 plants were placed bare-rooted 10 cm apart, and the rate of water flow in the channels was kept constant, in order to test the effect that plant would have on the purification of the treated wastewater.

The use of wastewater (WW) may potentially have adverse impacts on both the environment and the public health, largely depending on wastewater characteristics, the degree of purification, the method and location of use and the crops irrigated. Soil, groundwater and surface water pollution are among the most important potential disadvantages of the wastewater use. However, scientifically sound planning and effective management of the irrigation or fertilization regime according to water and nutrient requirement of selected crops, can minimize these disadvantages to the level of environmental insignificance. The project, in its **second part** experimented the **impact of WW reuse** on irrigation system, on the soil/plant complex and on the soil structure; but also irrigation techniques compatible with sustainable agriculture, such as complementary irrigation of cereal crop and the nitrogen fertilisation adjustment when WW reuse occurs.

The WW **impact on irrigation system** was tested on a potatoes field in Tunisia, by partner 4. In order to evaluate the durability and the technical and hydraulic performances of micro-irrigation emitters with conventional and treated wastewater, and to study the efficiency of the different techniques of irrigation used for potatoes, tests have been led during 1998/99, 2000 and 2001. The study was conducted at the experimental station of Nabeul on a field of potatoes of 1ha witch was divided on two plots. Every plot was irrigated with a quality of water: the first with the treated wastewater and the second with the underground water (conventional water). The two plots have been equipped by the same irrigation systems as following: 10 laterals with integrated emitters spacing 40 cm and flow rate of 4 l/h under a pressure of 1 bar; 5 laterals with derived emitters with pressure compensation and 4 l/h for flow rate under a pressure of 1 bar with 40 cm spacing between emitters; 5 laterals with derived emitters without pressure compensation and 4 l/h for flow rate under a pressure of 1 bar with 40 cm spacing between emitters; 4 laterals with mini-sprinkler system corresponding to 20 lines of potato. 15 mini-sprinklers by lateral. The flow rate was 80 l/h and a reach of 2,5 meters under a pressure of 1 bar; and finally, 20 modernised furrows with water intake all 10 meters by a regulating valves. The assessment at field of the hydraulic performances of the different emitters has been based on the Keller and Karmelli method. Concerning the wastewater plot and during the progress of irrigations, the manual intervening for maintenance and cleaning of emitters having there flow rate or completely clogged, has been posted.

Partner 6 in Tunisia also tested the **impact of micro-irrigation** systems on three varieties of olive trees under two qualities of water. This experimentation targets two objectives: the reuse of treated wastewater in irrigation and saving irrigation water by micro irrigation systems. In this research action we proposed to follow on the same field plot the behavior of clementine citrus and five varieties of olive trees under two qualities of water: treated wastewater and conventional water and different micro irrigation systems. The experiment assessed the water needs of citrus orchards irrigated with nozzles « emitting holes » and « bubblers » techniques using clear water and

reclaimed wastewater; and the olive trees water needs drip irrigated with clear water and treated wastewater. At the orange plot, every tree had two emitters: emitting holes with flow rate of 30 l/h and bubbler with 56 l/h. At the olive table trees field, the integrated emitter with 4 l/h was used with double lines and three different spacing between drippers: 40 cm, 50 cm and 100 cm on three different varieties: Picholine, Manzanille and Meski. Irrigation scheduling was realized with "Watemark" tensiometer and calibrated with gravimetric and TDR (time domain reflectometrie) methods. The irrigation uniformity was evaluated with Keller and Karmelli method.

The effect of **wastewater reuse** for irrigation **on bacterial contamination** of the soil and the crop was tested by another department of partner 6, in Tunisia. The work consisted in a comparison of the state of microbial contamination of soil irrigated with secondary effluents by three different techniques : drip irrigation (DI), micro-sprinkler (MS) and furrow irrigation (FI). An assessment was also made of the hygienic quality of the crop according to the irrigation system. The tests were done in the same one hectare potato field divided into two plots fitted out with the same irrigation systems. The first plot was irrigated with secondary effluents from an activated sludge treatment plant and the control was irrigated with ground water.

The optimisation of irrigation, of water requirement and efficiency, the use of additional nitrogen fertilisation when wastewater is reuse were tested by several partners. The **impact on the soil/plant complex** was evaluated. The main objective was to draw sustainable practices and recommendations when WW is reuse for agricultural crop irrigation in Mediterranean countries.

Since the sixties, **Morocco** has emphasis all his effort on maximizing the capture of the country's surface water and encouraging for their optimal use in irrigated agriculture. Nonetheless, the increasing demand aggravated by the rapid growing population, and accentuated by the frequent drought requires the resort to unconventional resources (wastewater and brackish waters). Due to the pronounced water deficit, Agadir region is using sand infiltration system to treat its wastewater to be reused in agriculture and landscaping. This technology generates high nitrate concentration in the effluent ( more than 500 mg/l). This indicates the high risk of nitrate leaching and nitrogen pollution of the ground water. This risk is amplified by the soil type (sandy soils) and the hydrogeologic analysis of this studied region. Therefore, there is a necessity to develop adequate management practices to attenuate this risk. Several experiments were undertaken within the framework of this project by partner 5 in Morocco in order to: master the water-nitrogen interactions by increasing the water efficiency and reducing the nitrate leaching by testing different rates of water; evaluate the water and the nitrogen use by different crops taking into account their nitrogen and water requirement; and, evaluate the potential risk of ground water pollution and salt accumulation for the different treatments. The first three years experiments were conducted under plastic tunnel for vegetables and cut flowers, and in the open field for cereal's crops. The fourth year experiments was conducted under open field. Using drip irrigation, and 120%ETM regime, the first year three type of irrigation water were compared (sand infiltration treated wastewater, epuvalisation treated wastewater, well water to which we added nutrients). Two varieties of eggplants and geranium were compared. Using drip irrigation, several irrigation regime were applied on chrysanthemum (60, 80, 100, 120%ETM) and on zucchini (100,120%ETM) the second year and treated wastewater was compared to well water to which nutrients were added. Three irrigation practices were applied the third year : treated wastewater rich in nitrate nitrogen (651 mg/l); saline well water to added with nutrients according to crop requirements and alternating well water with treated wastewater based on the nitrogen requirements of chrysanthemum and pepper crop. During the first growing stage of these two crops, well water was used since needs for nitrogen is very limited, and switch to treated wastewater during the vegetative growth and fruit development. The combination of these three treatments with two water regimes (100% ETM and

120% ETM) resulted in six treatments randomly distribute in a Latin scare design. Six lysimeters of $1m^2$ corresponding to each treatment were installed to collect leachate in order to monitor water and nitrogen balance during the crop cycle. Soil samples were analyzed for nitrogen contents before planting and at the end of the harvest. Total yield for four month growing cycle was recorded for each treatment. Two water regime (100% ETM, and 120% ETM) were applied the last year , and two vegetable crops (green beans, tomato) were evaluated for their growth and yield responses. Four lyzimeters of $2m^2$ corresponding to the treatment 120%were installed to collect leachate in order to monitor water and nitrogen balance during the crop cycle. The plant response evaluation, in terms of mineral content, dry matter, quality of the fruits, and total nitrogen leached from the soil solution was collected in the lyzimeters. Salts accumulation were also monitored during the whole crops cycle by measuring the saturated paste electrical conductivity of the soil under the two water. Soil samples were analyzed for nitrogen contents before planting and at the end of the harvest and total yield for seven months growing cycle was recorded for each treatment.

In addition to water benefit to the irrigated land, treated municipal wastewater can provide significant amounts of plant nutrients, especially nitrogen and phosphorous, which can improve the fertility of soils, benefit plant growth, improve crop production and reduce the total requirements of commercial fertilizers needed to be applied, increasing the total economic return to the grower. *Gerbera jasmesonii* is one of the leading cut flowers in Europe and **Cyprus**. The aim of the experiment, lead by partner 6 in Cyprus, was to test the effect of water quality and fertilization on flower production and flower quality of Gerbera plants. An experiment was carried out for two years using Gerbera of the red variety "testarosa" as the experimental plant, in order to evaluate the effect of four different sources of water with and without fertilization on flower production and quality. The four sources of water were: secondary treated wastewater, treated wastewater from epuvalisation system, borehole water and fresh water. Fertilization consisted of 150ppm N (Ammonium Nitrate), 40ppm P (Urea Phosphate) and 180ppm K (Potassium Nitrate). Once a month 5gr/plant of Fe chelate was applied to all treatments as Gerbera plants are sensitive to iron deficiencies. The plants were grown under 70% shading on ridges 30 cm wide and 40 cm high. The experimental plots were irrigated by drip irrigation using 10lt drippers. Water was pumped from the storage tanks near the epuvalisation system with ½ hp electric pumps generated by an electric generator. The experimental design was factorial with six replications. Each replication consisted of 10 randomised plots, each plot being a 6m long row (ridge) with 13 plants 50cm apart. The distance between rows was 120 cm with a central 120 cm wide corridor separating the three replications. The number of flowers produced, stem length, flower weight and flower diameter were measured.

Partners 7 and 8 (Israel and Palestine) collaborated in the frame of this project, working on the impact of WW reuse on the soil/plant complex. They closely collaborated till 2000, the second year of the project. By after, due to the known events in the Middle East, collaboration stopped, but they continued their experiments, separately.

Since 1975, treated water effluents is collected in open man made dirt ponds for regeneration of sewage water in **Israel**. During that period a vast knowledge was gained and implemented.Recently, large plants of Reverse Osmosis Sea Water Desalination (ROSWD), are suggesting producing Desalted Sea Water at costs of $\$0.53m^3$(ex. plant) and reducing salinity to 50ppm.TDS. These results are a of significant importance to the whole region, as it dictates the upper limit of the economics of Waste Water Treatment (WWT) and provides the potential volumes of added water resources, with very low salinity, to be supplied to the growing urban populations. This new development will reduce the potential problem of irrigation with high saline effluents. Moreover, it gives a powerful indication to the potential costs of WWT, enabling the supply of Treated Waste Water (TWW) for unlimited uses, at no risk, and a solution to the soil and plant

problems, as a result of the continued use of recycled TWW for a couple of decades. The increasing usage of treated wastewater effluent in recent years is part of stage in the development of the water policy in the region. The increase in the amount of treated effluent usage for irrigation is due to the reallocation of potable water from the agriculture sector in Israel to the urban population, and an increase in the amount of treated waste water effluent irrigation to non edible field crops like silage corn, cotton and chickpea. Fruit trees are more sensitive to effluent water quality (total dissolved salts, sodium, and boron) than field crops. The main restriction in using treated wastewater effluent for irrigation is the chemical water quality. Wastewater effluent usually contains higher concentrations of suspended organic and inorganic materials. The results of a water quality survey showed the range of electrical conductivity between 1.5-2.35 dS $m^{-1}$, chloride concentrations were 170-360 mg $l^{-1}$, boron concentrations between 0.3-0.9 mg $l^{-1}$, and SAR values between 4-5. However, higher values than quoted above were found in several places in central Israel. The current water quality of some waste water may cause damage to agriculture crops, and if continued to be used for a long period may cause pollution of ground and surface water sources. In certain cases the damage may be intense, immediate and easily identifiable. In other cases the damage may develop over time in various plants and soils. The damage to the soils in their capacity to support plant life and decrease in yield's in due time should be addressed.

In the **Palestinian** sector the use of TWW was not existent when we started this project. The waste water of AlQuds university was partially diverted to the recycling unit, accumulated in a small open pond and pumped back for irrigation of the experimental plots. This report bring the conclusion from their joint research and draw some suggestions that will enable safe use of TWW for long periods without causing damage to the soil or crops. After 1993, when the Palestinian authority resumed control of the major cities in West bank and Gaza strip, strategic plans were developed by different Palestinian ministries for wastewater collection, treatment and reuse. On this domain, several state of the art wastewater treatment plants were installed at Albeireh, Gaza and other cities that produce treated wastewater of good quality. These projects were feasible and are funded by different EU countries and the United States. Other projects are planned to be constructed in the near future. Small scale wastewater treatment technologies are adopted in the agriculture strategic plan for the treatment of wastewater generated from the different villages in Palestine and the reuse of the effluents in irrigating different crops. The objectives of this project were firstly, to test the performance of small scale wastewater treatment plant installed in an environment which mimics a Palestinian village; secondly, to assess the response of legumes to irrigation with treated wastewater as compared to fresh water using two irrigation technologies; surface and subsurface. Furthermore, the effect of irrigation with treated wastewater on soil chemical properties and salt buildup are also investigated. The experiment was conducted on the field of Al-Quds University, the field was divided into two main plots (125m), one plot for surface drip irrigation, while the other is for subsurface drip irrigation (25-30cm), each plot was divided to two halves, one for irrigation with FW, the other with TWW, a fixed nitrogen level (80kg/ha supplied as liquid) was provided for the field using computerized irrigation system, both plots were subjected to 4mm of irrigation per day for 100 days of the growing season. The seeds were planted on both sides with 12 seed/m in three replications, germination of the seeds was achieved by applying sprinkler irrigation, and germination was obtained after two weeks. Soil samples were collected for analysis from three different depths (0-5, 5-30and 30-60cm) on tow different sampling dates: before plantation and after harvest. Plant samples were collected on two sampling dates after 50% flowering and at harvest time, three plants from each replicate were collected, dried at 70c for three days and analysed for its minerals in the dry matter. Microbiology test were conducted on the fresh plants, soil and water samples using standard methods. 8 kilo grams nitrogen per donom was applied as liquid during the growing seasons. Tack filters to deliver herbicides were connected prior to subsurface drippers in order to prevent clogging (Natafim) during the irrigation period. Plant samples were collected

twice, during the season (after flowering) and at the end of the experiment. The samples were dried, weighed and grinded. Standard procedures were employed for the analysis of Na, K, N and P. Four cultivars of chickpea, namely: Bulgarit, wir 32, Jordan and ICC 11293, and cultivar of faba beans (local variety) were tested during the course of this project.

Another important pole studied by partner 5 in Morocco in the frame of this big project, was the **supplemental irrigation** of wheat crop, in order to stabilize the yield.
Wheat production in arid regions of morocco is very dependent on rainfall. Seasonal rainfall amount and its distribution have profound impact on wheat production, environmental rehabilitation and economies of these regions. Frequent droughts took place during the spring that corresponds to flowering or grain filling stage depending on the planting date. Supplemental irrigation is widely practiced to stabilize and to improve crop yield (Oweis et al., 1998). However with the scarcity of high quality water resources, the use of marginal waters (saline water and treated wastewater) is not only a necessity, but also an inevitable option to alleviate the water crisis in these regions. The acceptability of wastewater to replace conventional water resources is highly dependent whether the health risks and the environmental impacts (salinity, nitrate pollution) are within acceptable levels. The needs for improving wastewater-use efficiency (WUE) in wheat production and sustainable reuse of treated wastewater are clearly urgent. The objectives was to optimise the use of wastewater for maximum crop yield or profit, but taking into account the cost of the irrigation water and minimizing the risks for soil salinity and deep percolation of nitrate. Several experiments were undertaken during the last four years to define the most critical stages of wheat; to determine the optimum water depth under supplementary irrigation practice; to evaluate the effects of supplementary irrigation on the crop development, flowering, and grain yield; to determine the impacts of applying treated effluent on the soil characteristics and the plant nutrition; and to test the suitability of the modern irrigation technique "Mini-sprinklers" , using treated wastewater. For cereal's crops (maize, durum wheat, bread wheat, barley) during the first year were applied increasing regime of irrigation water (100, 110, 120%ETM) and compared two type of water (sand filter treated wastewater, well water to which we added nutrients). Also was a control treatment for which plants were irrigated at the germination stage and for the rest of the cycle they were under rainfed conditions. The second year was applied increasing dose of treated wastewater (100, 200, 300, 400 mm) using micro-sprinklers. The third year were compared five irrigation doses (250, 275, 300, 350, 400 mm) to rainfed treatments. The fourth year were tested two doses of irrigation water (200, 350 mm) throughout all the crop growth stages. The entire field has received the same amount of water, which was equal to 100 mm in the vegetative stage (germination + tillering). Starting from the flowering stage the irrigation amount was allocated according to the schedule between the flowering stage (F) and the grain filling stage (G) as following: 50% at (F) and 50% at (G); 70% at (F) and 30% at (G); 30% at (F) and 70% at (G). The control plants received also the same amount of water (100mm) up to the flowering stage, after which no irrigation was added, and the plants water requirements depended on the rainfall. The experiment design adopted for the experiment was a split plot with six repetitions. The cultivars of the bread wheat used was *Marchouch.* In this trail, were used the mini-sprinkler irrigation system which known as *micro jet sprinkler*. Its discharge ranges between 40-50 l/h, according to the water pressure, and each sprinkler covers (1 $m^2$).

**Nitrogen management** as fertilizer when wastewater is used for irrigation was investigated by partner 6 in Cyprus and by the co-ordinator in Belgium.

Rational use of the nutrients in recycled water could increase crop production and reduce environmental pollution. In addition to water benefit to the irrigated land, treated municipal wastewater can provide significant amounts of plant nutrients, especially nitrogen and phosphorous, which can improve the fertility of soils, benefit plant growth, improve crop production and reduce

the total requirements of commercial fertilizers needed to be applied, increasing the total economic return to the farmers. However with the treated effluent as an irrigation source, the additional fertilizer N may create conditions of $NO_3$ percolation and pollute groundwater (Papadopoulos and Stylianou, 1987, 1988a,b). The aim of the experiments, conducted in 2000-2002 in **Cyprus**, was to present yield results obtained from sudax, eggplant and sweet pepper irrigated with wastewater and freshwater with the addition of N fertilizer in order to investigate the N requirements of these crops and evaluate the treated wastewater as a source of Nitrogen. Three separate experiments were carried out from 2000-2002, on sudax (hybrid "Trudan"), eggplants ( *Solanum melongena*) of the variety "Bonica", and sweet pepper (*Capsicum annuum*) of the variety "Gedeon". The treatments included two sources of irrigation water, (borehole and secondary treated wastewater) with four levels of nitrogen, 0, 50, 100 and 150ppm. The field experimental layout for all three experimental plots was a split plot design with four replications with the two sources of water assigned to the main plots and N levels to the subplots. In the sudax experiment each plot consisted of 3 rows 30m long, spaced 60cm apart and irrigated with 10L drippers spaced 30cm apart on the irrigation line. In the sweet pepper experiment, each plot consisted of three rows 1m apart with 42 plants in each row, having each plant planted 60 cm apart whereas in the eggplant experiment the rows were 80cm apart. Plants of eggplant and sweet pepper were watered by drip irrigation using 10L drippers and in all experiments the amount of water applied was based on Epan evaporation. The field studies were conducted on a calcaric cambisol soil with 20% $CaCO_3$. The secondary treated wastewater used in this experiment is a product of an activated sludge treatment plant from a residential community with no industrial inputs. The quality of the treated wastewater was monitored every week during the investigation period. The analysis included electrical conductivity ($EC_w$), pH, Ca, Mg, Na, K, $HCO_3$, Cl, $SO_4$, $NO_3$-N and B. Nitrate-N was determined by using a specific $NO_3$-N electrode (Kent, EIL model 8006.2). All other analyses were performed according to standard procedures. The mean biological oxygen demand ($BOD_5$), the chemical oxygen demand (COD) and the suspended solids (SS) of the treated wastewater were during the irrigation season 76, 45 and 38 mg/lt respectively.

The experiments performed over the four years of project duration in **Belgium** have tested five cultivations. Two experimentations were achieved on the same field site and with the collaboration of research partners. The experimental site was located inside an irrigated perimeter around the agro-food industry Hesbaye Frost, producing frozen vegetables, in Belgium. The water used by the factory to wash, peel and cook the vegetables is poured into an aerated storage basin (110000 $m^3$). Its functions are to accommodate the factory wastewater production with the seasonal agricultural water demand and to neutralize the pH of the water. Its aeration avoids sedimentation, and thus periodical cleaning of the basin and fermentation, which produces undesirable odours in the residential neighbourhood of the industry. When the vegetable crops cultivated inside the irrigated perimeter request water, wastewater is pumped from the storage basin and sent under pressure into the underground canalisation network (18Km long). The farmers connect winders to one of the 160 hydrants, the nearest to their field edge and irrigation by means of sprinkler aspersor canon can occur. Depending on the crops rotation adopted by the farmer, whose field was under experiments, four vegetables cultivations (spinach, beans, carrots and broad beans) and one cereal (winter wheat) were tested. Because of time required for implementation the experiment and meteorological conditions, the irrigation factor was not tested for spinach (1999) and wheat (2000) cultivations. The purposes of the experiment were first, to adapt the nitrogen fertilization to ensure, for the five vegetables cultivations tested the best yields and second, to guaranty the admitted level defined by EU standard (50 Kg N/ha on 60 cm depth) of nitrogen residue in the soil after cultivation when irrigation with industrial wastewater occurs. The tested crops depend on the rotation culture determined by the farmer. Four vegetables cultivations were tested (spinach, beans, carrots and broad beans) and one cereal (winter wheat). The experimental factors were irrigation factor :

irrigation or no-irrigation of the cultivation with wastewater from the network; and, fertilization factor : three fertilisation levels of mineral nitrogen next to a reference without any nitrogen supply The experiment plan was a split plot design with non random irrigation factor and randomised fertilization rate, with 4 replications. The irrigation factor consists of wastewater irrigation by sprinkler cannons and no irrigation. No irrigation is obtained by setting plastic cover sheets over the plots during irrigation. The plots under the plastic sheets do not receive water from irrigation, but do receive natural rainfalls as the sheets are taken off after irrigation. All the plots are implemented on the same pedological unit. The establishment of the plots in the field is made by means of a theodolite, taking fixed reference marks outside the field to insure reproducibility of the localization for further cultivation. The optimum nitrogen fertilization is defined by a French software, named AZOBIL, based on the mineral nitrogen soil reserve measured just before implantation of the cultivation and on the mineralisation release that occurs during the crop. Four different quantities of nitrogen supply are tested : Azobil recommended optimum quantity N, N/2, 3N/2 and 0N as reference. The studied parameters were the yields are calculated for each plot; the mineral nitrogen content in the soil on 1,5m depth : soil is sampled in all 32 plots, first before sowing to determinate the optimum nitrogen quantity to add and a second time just after harvest to establish the nitrogen balance; wastewater composition is analysed for content in nitrogen, phosphorus and potassium for every irrigation; and moisture profile : weekly measured by TDR probes.

Finally, the **impact of wastewater reuse on soil characteristics** was tested in Tunisia (partner 4) and Belgium (partner 1, co-ordinator).

An experimental test has been treated since 1999 on a period of 4 years in **Tunisia**. The main objective was to study the treated wastewater impacts on soil physical characteristics especially on surface structural stability. This study was conducted on a field of olive trees planted on sand-clayey to clay-sandy soil. This field plot is irrigated by two qualities of water: treated wastewater and underground water. The method used to analyse of soil samples is HENIN methods, determining the indicator of soil structural instability (IS) including parameters as percentages of aggregates between 0.2 and 2 mm equilibrated with water after treatments with alcohol and cyclohexane and the and the average percentage of different aggregation, rate of clay and silt and rate of gravel sand. Dates for taking samples was considered as the first factor with 4 levels (12/08/1999, 22/02/2000, 28/02/2001 and 04/04/2002). The second factor was the nature of water used: treated wastewater and underground water. It is considered that these factors and their interactions could influence the measured parameters. The device of the test is in total randomisation with two repetitions. The statistical treatments of data have been realised with the STATITCF software. Variance analysis for the controlled factors with limit of risk of 5% was studied. This analysis has been completed by a multiple comparison by the test of Newman and Keuls (limit of 5%) according to methods of Steel Robert (1980), Dagnelie (1986) and Thomas and al (1990).

The objective of the experiment led in **Belgium** was to determine the impact of irrigation and soil cover factors on yields and soil structure. The experimental plan was a split plot design with 4 replications, non random irrigation factor, and randomised soil cover factor. The irrigation factor consists of irrigation by aspersion canon, with wastewater or clear water, and no irrigation. Wastewater is again coming from the agro-food industry Hesbaye-Frost. The two types of soil covers are bare ground, obtained by destruction of sowing, and soil covered by the cultivation. Pedologic and hydrodynamic measurements are studied. Yields are calculated per plots.

The goal of the **third part** of this study is the **economical analysis** of 8 WWT plants located in the different countries of the INCO project (i.e. Belgium, Greece-Creta and Skyros islands- Cyprus, Israel, Palestine, Tunisia and Morocco). The consultant from 1999 up to 2001 has visited the main plants in Belgium, Greece, Cyprus, Israel, Palestine and Tunisia. During these travels economical data were collected in each country on each partner's plant site. Then the study was a survey of existing literature regarding the economical aspects of wastewater treatment and its reuse in agriculture. The different types of WWT studied are: waste water recycling directly by irrigation, free water system, epuvalisation, long term storage and activated sludge/extended aeration. For each plant the total investment cost includes engineering study, cost of the land, civil works, construction materials and labour. Operating cost have been obtained by summing the energy, maintenance, depreciation and operating labour costs. To compare the different WWT the investment and operating cost have been calculated per $^{3}$m and per equivalent inhabitant per year. Finally, the study is a survey of the WWT economy in the 7 countries of the project. Data's have been collected in the literature regarding secondary, tertiary and desalinated seawater. Different scenarios using secondary and tertiary WWT were compared to river disposal to assess the total benefit for the state/the municipalities and for the farmer. An attempt to fix a fair and attractive price for treated waste water to the farmer, have been suggested.

## ***RESULTS ACHIEVED***

The main results achieved, by the Free Water System as wastewater treatment, of the 2nd and 3d year of the main experiment could be summarized as a removal efficiency of BOD of 77.00% with recycling and 51.25% without. Due to those encouraging results, researches are continued, financed by other cooperation and projects.

The main results achieved with the Long Term Storage proved that the storage of wastewater brings a significant improvement of its microbiological quality. According to the duration and conditions of retention, the bacteriological quality of the water could be sufficient for unrestricted crop irrigation. In basins with a depth of less than 150 cm, a reduction of Faecal coliforms in the order of 3 log units was achieved within three days under an ambient temperature of 25 °C. The same reduction takes 8 days with an average temperature of 31°C. The elimination of the faecal indicators basically depends on retention time, depth of storage basins, ambient temperature and level of initial contamination of the water. The faecal coliform die-off coefficient can be expressed as a function of retention time by the following relationship :
$K_b = 9476.6 \times t^{-2.175}$. The seasonal storage lasting 7 months does not affect water quality. After decontamination, the number of indicators keeps to a level that is close to the detection limit of the analytical method used; no proliferation happens during the duration of the storage. The degree of water salinity does not undergo any significant change in test conditions. The pathogens (Salmonella ) were sometimes found in the bottom sludge. A particular attention should be given to the management of these wastes. To avoid health and environmental risks a proper treatment of these sludge should be established prior to their elimination or recycling. They also found that storage basin with small capacity working in batch mode can provide water with quality A at least once a week during the irrigation period (may - September). This nearly equals the periodicity of irrigation under the climatic conditions of the study area. Thus, small storage reservoir established by farmer can play the double role of a regulation tool and a complementary treatment system.

Epuvalisation in Greece shown that virtually, when the wastewater has sufficient dissolved oxygen, every terrestrial plant appears to be capable of growing in some form in the epuvalisation system. The wastewater did not involve modification of the total growth of *Setaria viridis*, but growth of the other plant species was inhibited and the plants wither in one, two or three months, mainly due to lack of oxygen in the root system. In the lack of oxygen the roots stop to grow and finally die. When fresh water or wastewater rich in oxygen was used the plants recover forming new roots and starting sprout. The lack of oxygen might be due to a lot of organic mater that was in the wastewater. *Setaria viridis* adapted better to the lack of oxygen in the root system. The dissolved oxygen determined in the inflow was in average 0.51 $mg.l^{-1}$. Dissolved oxygen concentrations, at the exit of the channels were significantly higher, in average about 2.0 $mgl^{-1}$. Nitrate and ammonium are the major sources of inorganic nitrogen taken up by the roots of higher plants. The wastewater brings on average about 81.9 $mg.l^{-1}$ of total N (mainly in form of $NH_4^+$). Potassium is the mineral nutrient required in the largest amount by plant after nitrogen, potassium concentration was on average seven times less concentrated in wastewater than in the nutritive solution of a normal hydroponic system for commercial production. The sewage composition for $BOD_5$, in the entrance of the epuvalisation system, varied widely: from 80$mg.l^{-1}$ to 440 $mg.l^{-1}$. The reduction of the value of $BOD_5$ was significant in average 47.4% for the channels with live plants, 30.6% for the channels with dead plants, and 11.1% for the channels without plants. The system with plants shows a tendency to remove $P_2O_5$ in average 3.5%. The $P_2O_5$ removal was a little modified by plant mortality. The total nitrogen decrease in the presence of plants shows a trend for reduction of about 13% in average. In the channel with dead plants the average reduction was 9.4% and in the unplanted channel the average reduction was 5.2%. In the absent of oxygen no significant amount of $NO_3^-$ was appeared in the solution. Only in some cases that wastewater was well oxygenised was observed the appearance of $NO_3^-$. Significant nitrification began to take place in the wastewater when the $BOD_5$ is reduced to less than 45 $mg.l^{-1}$. The removal of total phosphorus and total nitrogen from the system as it is now is not sufficient to allow the rejection of the effluent into the sea. Adding a new shallow basing, after the maturation basing, in order to improve the oxygenation of the wastewater, it is very likely that will increase the aeration of the wastewater and thus the performance of the system. Although the wastewater in most cases contains in a lower concentration the mineral nutrients, comparing with a nutrient solution of a commercial hydroponic cultivation, it can provide the necessary elements for a normal growth. The oxygen dissolved in the wastewater entering to the epuvalisaton system was very low. The root systems were saturated with organic material. That shows the need of a better aeration of the wastewater before that comes into the epuvalisation system. For most of the tested plants (except *Setaria viridis*), the lack of oxygen leads to a premature death of the plants, for the *Arudo donax* the root system remains in place for a significant period after death, providing a large surface area for microbial growth, thus permitting a continuation in reduction of $BOD_5$ parameters. The system of wastewater purification with anaerobic treatment, maturation basin and epuvalisation (as it is now) reduced significantly the $BOD_5$ but didn't made it possible to achieve the permitted levels for discharge wastewater, defined by the European directive 21/05/1991, in eutrophically sensitive areas. Adding a new shallow basin, after the maturation basin, to improve the aeration of the wastewater, is very probable that will increase the performance of the system and make it possible to achieve the permitted levels for discharge.

From the results obtained from epuvalisation in Cyprus, it is evident that the system can reduce nitrates up to 30-40% in the water and also suspended solids up to 45%, depending on the season, rate of flow of water and the effluent quality. There was no significant reduction of $BOD_5$, pH and electrical conductivity in the water. Reduction of nitrates in the water facilitates safe water disposal whereas reduction of suspended solids helps to reduce clogging of the irrigation systems if the water is to be used for irrigation purposes. Further work should be done to investigate the effect of

the length of the channels, the rate of flow of water in the channels during the different seasons and the use of other plants or combination of several plants, in the purification efficiency of the system.

The experimentation testing the impact of WW reuse on irrigation system showed that performance of micro irrigation systems depend on the screen system. Their sensitivities to the clogging problems were evaluated. Tests showed that there is an important link between the irrigation uniformity and yields of potatoes. The integrated emitters presenting a weak sensitivity to the clogging problems gave the most important yields with the two qualities of water. With the two qualities of irrigation water, the mini-sprinkler and derived emitters PC gave the worst emission uniformities of irrigation and the bad yields. These results converge well with those gotten at the laboratory. The mini-sprinkler emitters and pressure compensations drippers are the most sensitive to clogging, and the integrated dripper system being the less affected by the quality of water. With the some filter conditions, physical, chemical and biological clogging problems are very notable with treated wastewater for all type of emitters then with conventional water. The optimal operating duration of these emitters using treated wastewater with 100 µm of screening is about 5 years (7 years with conventional water) in Tunisian conditions. To promote these techniques, it proved necessary to have a screening station that assures a level of 100 µm. All tested emitter's present a variability of sensitivity to the clogging problems with different qualities of water. The relation between this phenomenon and the irrigation uniformity is very important. The human intervening, that consists in emitters cleaning and manual maintenance can be an important recourse for the improvement of the hydraulic performances of these emitters and therefore the improvement of the emission uniformity.

The irrigation with WW on olive trees proved that the irrigation uniformity, the clogging sensitivity and the yield are depending on the emitters used. Bubbler system is the most sensitive to the clogging problems, this explain that's why because of the bad irrigation uniformity more less than 60% the yield of clementine trees were the lowest with treated wastewater. The nozzle emitting holes could be used with treated wastewater without clogging problems. The Bubbler system needs high level of screening (80 µm) than emitting holes (200 µm) to be used with this type of water. The last one fathers a high irrigation uniformity (average 85%). After 4 years of operating, the ageing of integrated drippers on the orchard of olive trees was more marked with the treated wastewater then conventional water. The behavior of olive trees depend on variety, on quality of irrigation water and on irrigation system: Manzanille and chemlali varieties had an optimal agronomic development with treated waste water. On the other hand, Meski includes better with the conventional water. Picholine variety is indifferent for the quality of water as well as the system of irrigation. Chetoui variety gave the best agronomic parameters: diameter and volume with emitters with 50 cm spacing. Concerning the root systems of all olive trees develop their roots in the first 60 cm of soil and more then 70% are in the first 30 cm. The tensiometric method of irrigation scheduling needs some knowledge of the hydrodynamic characteristics of soil to irrigate while giving precisely water needs of crops and with treated wastewater to prevent all contamination with underground water. These results show that the treated wastewater can be valorized as well as conventional water using the adequate micro irrigation systems.

The bacterial contamination of soil and plant study demonstrated that soils irrigated with secondary effluents were significantly more contaminated by the faecal indicators than the control soils irrigated with ground water. The level of bacterial contamination was higher at the end of the irrigation season than at the beginning. Accumulation in the soil of microorganisms brought by wastewater is thus possible. In the soils irrigated with secondary effluents, the concentration of micro organisms decreased with depth. This drop appears between 20 and 50 centimetres down; at

surface level, the bacterial contents are often low because of the rapid death of germs exposed to heat and solar radiation. A comparison of the results obtained on soils irrigated with secondary effluents by different irrigation systems reveals a trend whereby bacterial concentrations are increased with furrow irrigation. The lowest level of contamination corresponds to the plots irrigated with micro-sprinkler. But this system's performance is reduced because of its extreme vulnerability to clogging and because of the negative effect on the yield due to water-plant contact. The study of the hygienic quality of the potatoes grown revealed a significant increase in the number of total and faecal coliforms on tubers from plots using furrow irrigation with secondary effluents compared with tubers from the controls using the same technique. Through the various results obtained, drip irrigation appears to be the best irrigation system when using treated wastewater. This would enable the management of this resource to be optimised, while limiting the harmful effects due to salinity and the microbial load.

The conclusions resulting from the studies of salts accumulation and nitrates leaching in the Moroccan soils demonstrate the height value of the reuse of treated wastewater when appropriate practices are adopted. Treated wastewater resulted in similar to better growth and yield as well as the same quality of crop irrigated with reclaimed waste water in comparison to the control.The use of drip irrigation and plastic mulch eliminated the risk of coliforms contamination of the harvested products.

In the case of vegetable and flower control correspond to well water with added fertilizers and for cereals control correspond to rainfed conditions. The nitrogen mass balance for the tested crops receiving treated wastewater indicates the high risk of nitrate ground water table. In fact the texture, the high infiltration rate and the high nitrate concentration in the treated effluent contribute to high nitrate leaching potential the amount of nitrogen lost to the underground water are 346 and 343 kg of N/ha respectively for melon and carnation, considering all the components related to nitrogen budget. Regarding the water effeciency, the results show two mean tendencies. On one hand, the amount of water corresponding to 120% ETM induced high nitrogen leaching and reduced salt accumulation in the root zone. Even though, the obtained yield was significantly increased for this water regime. On the other hand, the application of an equal amount of the crop requirement induces salt accumulation and reduces the nitrogen leaching and yields. Additional experiments for selected crops showed that water application of 100% ETM during the two first stages characterized by low water requirement and 120% ETM during the last stage of the crop growth reduce the nitrate leaching by 67% and increased the soil salinity by only 25%. Two others recommendations should be emphasized from these studies for the reuse of treated wastewaters : conjunctive use of treated wastewater and conventional water to dilute the salt level and nitrate concentration; and improve the treatment process by adding a denitrification phase.

Comparison of water type for irrigation in Cyprus showed that in the experiment of irrigation of Gerbera plants, with secondary treated wastewater, borehole water and fresh water with and without additional fertilization, freshwater produced significantly more flowers per plant than the other water qualities. Fertilization had a significant effect on flower production for both freshwater and borehole water, but no significant effect on wastewater irrigated plants. There was a significant difference in flower number between wastewater and borehole water treatments compared to the freshwater irrigated plants as a result of the high electrical conductivity and chloride concentration of both waters as Gerbera plants are sensitive to high salt concentrations. In general freshwater produced better quality flowers in terms of flower height, weight and diameter even without the application of fertilisers. In the case of wastewater better quality flowers were

produced with the addition of fertiliser, whereas in the case of freshwater there was no significant difference with or without the addition of fertiliser. In the case of borehole water there was only a significant increase in flower weight with the application of fertiliser but no significant effect on flower height or diameter. In the second year all treatments gave better results in terms of flower production and flower quality because the plants were shaded from the beginning of the experiment whereas in the first year the experiment was not shaded from the beginning and the plants were more stressed due to the high temperatures at the time. The results indicate that high salt concentration in wastewater can be a limiting factor for the production of sensitive plants such as ***Gerbera jasmesonii*** probably due to the slower uptake of water and fertilizer by the plant. Mixing of wastewater with freshwater could give good results by lowering the salt concentration of the water and also providing some nutrients to the plants.

The conclusions of supplemental irrigation of wheat in Morocco demonstrate that supplemental irrigation stabilize the cereals crops yield under arid condition of morocco. There is an increase of grain yield of wheat crop from 9.5 qx /ha to 32 qx/hat when the amount of water increase from 100 mm to 300 mm. Plants growing under rain fed condition yielded almost zero production. The findings demonstrate that flowering stage is the most critical growth stage, in fact, the units that received the highest amounts of water at flowering stage produce the largest yield (48.1q/ha with dose 363 mm and 34.9 q/ha with dose 230 mm). One of the important observations at this trial is that the units that receive less than 50 mm at flowering stage have a critical impact on its grain yield. Furthermore, the units that received the highest amounts of water at flowering stage produce the highest number of spikes per $m^2$. This high yield obtained using treated wastewater as supplementary irrigation source, compared with adjacent rainfed wheat field, which received 107 mm yielded almost zero tonnage. This result indicates the high value of the treated wastewater reuse as supplementary irrigation. If water is the limiting factor, and land is available, it appears more effective to use lower dose on large acreage. In fact, if the same amount of water (363 mm) which produced the highest yield, is applied at the rate of (230 mm), this will cover 1.58 ha which will produce 55.1 q/ha (based on the yield produced at a rate of 230 mm), and the Water Use Efficiency will increases from 132.4 to 151.8 g grain /$m^3$. The most important soil parameters are nitrate $NO_3$, the largest yield obtained by the upper amount of water is at the expense of environment, particularly the groundwater aquifer The other components that must be taken into consideration are the concentration of sodium and chloride, which are presented in high concentration in treated wastewater, as the accumulation of these salts lead to salinity problem on the long run. For example the soil chloride concentration before sowing was 0.28 g/kg, at the end of trial it became between 0.6-0.8 g/kg, the sodium was 0.3 g/kg it became between 0.5-0.6g/kg. In other investigation, tertiary treated wastewater is applied ( using reed bed), so the quantities of $NO_3$ and P levels were low and did not meet the plant nutrition requirement with dose (200mm), and induced soil nitrate reduction. Therefore tertiary wastewater treatment could meet the environmental goals, but didn't match the crop nutrition requirement. The high purification level of treated wastewater, and the installation of disc-filter upstream in the field, protects the mini-sprinklers system from clogging, but the disc-filter has to be washed frequently after each three applications. Using 2410 $m^3$ per hectare for wheat production can save 30-35% of the nitrogen fertilizer, 10% of P fertilizer, and 70-82% of K fertilizer, of the whole plant exported nutrients and increase the farmer income.

From the results of Nitrogen management when wastewater is used for irrigation, it is demonstrated that the yield of sudax, in all years, are better with wastewater than freshwater at all nitrogen concentrations and without N application. Application of N in wastewater had no significant effect on yield at all concentrations  From the results of yield of eggplant and sweet

pepper, it is demonstrated that wastewater gave better yield and fruit number than freshwater at all nitrogen concentrations and without N application. I all cases, application of N in wastewater had no significant effect on yield, and fruit number at all concentrations. In all treatments yield and fruit number for both sweet pepper and aubergine, followed a similar trend showing that the increase of yield was due to the increase of number of fruits and not to the increase in fruit size.With all crops, higher yield was obtained with the treated wastewater than with the borehole water indicating the superiority of the treated wastewater and the possibility of producing high yields without additional N fertilizers (Papadopoulos and Stylianou, 1987,1988a, 1988b, 1991). It is therefore, imperative that recommendations to the farmers concerning fertilisation should be different for the effluent and fresh water, in order to improve the efficient use of water and of nutrients present in wastewater. This will also minimize the risk of pollution, especially in cases where water table is shallow and pollution by nitrate-N could easily happen (Papadopoulos and Stylianou, 1987, 1988a,b). Properly planned use of wastewater can be of economic importance to crop production as it could substitute for fertilizer application and, therefore, reduce cost of production, which can be an important factor to the agricultural economy of developing countries where fertilizer cost is a major constrain to improve production. The yield results indicate the superiority of the treated wastewater and the possibility of producing high yields without additional N fertilizers. In this case yield might not be the highest but with no additional N, pollution problems are minimised. The plant nutrients load in the wastewater can be an important factor in saving costs of fertilizers needed for crop production. It is therefore advisable that recommendations to the farmers concerning fertilisation be different for the effluent and freshwater.

The experimentation on nitrogen management in Belgium tested the impact of three fertilisation levels on yields and nitrogen residues in the soil after harvest, with a reference without any nitrogen fertilisation supply, on four vegetables crops (spinach, beans, carrots and broad beans) and one cereal (winter wheat). All the irrigated cultivation present significant higher yields in comparison with no irrigation. Broad beans and carrots are the lonely cultivations whose yields are not significantly influenced by the fertilisation level. The increase of fertilisation levels increase the amount found in the plant for spinach, beans and carrots cultivation, without any increase of dry matter rate. Irrigation engenders a lower nitrogen accumulation in different parts of the plant, with a lower dry matter rate in comparison with no irrigation. The tested nitrogen levels let residues in the soil after harvest acceptable till the optimum recommended, but are excessive for the maximum level apllied. Globally, irrigation allows better yields and decreases nitrogen residues in the soil after harvest. The wastewater composition spread by irrigation has to be regularly analysed for its supplementary nutritive elements load. The following of moisture profile demonstrates the decrease of moisture content, due to the plants uptakes within the roots system depth. Below this zone, the moisture content stay high and equal all the cultivations seasons long. The impact of irrigation is noticeable with higher moisture contents in the upper soil horizon layers, within various depths according to the delay between the irrigation and the measurement. Thus, irrigation management, sustainable fertilisation and adequate inset cultivations allows high yields production and avoid pollution with nitrates leaching of the underground water reserves.

The analysis of the variance, on structural soil stability in Tunisia, with two factors showed that irrigation improved all studied parameters. This improvement is especially notable in the last sample. Although the type of soil, analyses of results showed that the treated wastewater compared with the underground water improved the studied parameters and notably the indicator of soil structural instability especially at the superficial layers.

To determine the impact of factors on soil structure, the experimental field in Belgium was sampled for pedelogical analyses at the beginning and at the end of the experimentation. Experimental plots have been implemented on loamy soil, with good drainage ability, with textural b horizon, classified as a Aba according to Belgian map pedology. The analyses and topographic data indicate that the experimental field presents a gradient of clay according to topography; this gradient is conditioning the capacity level of cationic exchange and the content in exchangeable calcium, main cation on the exchange complex. The complex is globally supersaturated due to regular amendments of the field. The variation of the other parameters can be considered as unpredictable at the experiment scale; no spatial tendency has been identified. Analyses of structural soil stability (by Henin methodology) does not reveal any significant difference for the soil cover factor, even if superior values seem to be concentrated on bare ground soil. There is a significant difference for the irrigation factor, with higher index values for the non irrigated strip by comparison with the two others, irrigated with clear and wastewater. But comparison to values obtained at the beginning of the project experimentations shows that we already had this difference between irrigation strips. We observe then, that the soil structural index does not suffer any evolution from 1998 till 2002. It demonstrates that, even before the experimentation, there was an heterogeneity of soil factor in the field. The four years of experimentations testing irrigation and water type factors on cultivated or bare ground soils have no impact on soil structural stability. Yields obtained for the tested cultivation present a significant effect of irrigation and water type factors, only for years where water stress occurs and cultivations have really needed irrigation, to achieve a good development of the cultivation. For those crops only, irrigation induces better yields than without. No difference is pointed out for the water type factor. For the other years, when temperature and natural rainfalls have induced no water stress for the cultivations, yields are not related to irrigation and water type factors, but well to pedological soil quality, topographic localisation in the filed and soil drainage ability of the experimental plots. Infiltration velocity measurements give good indications on the impact of the different cultivation on soil infiltration capacity. The development of root system, the type of roots, the soil coverage according to the type of leaves are some of the specific factors having influence on infiltration velocity along the cultivation season. At least, penetrability measurements give visual appreciation of effects such as cultural works, rainfall, cultivation development, ...

## ***PROBLEMS ENCOUNTERED***

No serious problems were encountered, no results were not achieved. The two partners testing the epuvalisation system as tertiary treatment were delayed a little during the first years. As well as Free Water System that have to be constructed before beginning the experiment. For this reason, the beginning of experiments were sometimes delayed.

All the partners encountered at least one year some problems of agenda, deadlines for reports were not necessary corresponding to the tested crop harvests and thus results interpretations and reports.

Due to the events in the Middle East, partner 8 (Palestine) was not able to continue the experiment as easily as during the first year. However, results were achieved for the last two years, what must be received with respect.

Hereafter followed some technical problems encountered with the epuvalisation system in Cyprus first, then in Greece.

Because the epuvalisation system was constructed in open air and was not protected from the adverse environmental conditions of the different seasons several changes had to be made in the construction of the experimental channels during the four years of the project in order to increase the dissolved oxygen in the water and decrease the water temperature in the channels to create optimum conditions for the survival of the plants and the micro organisms in the channel. Shading of the channels helps to decrease the temperature of the water and of the air providing better conditions for the establishment of the plants in the system. It also helps to reduce evaporation of the water. In winter if the system is to be installed at areas of high altitude where the temperatures are very low, the whole system will have to be constructed in a greenhouse. The channels should be constructed from concrete or other material, which will provide insulation keeping the water temperature at acceptable levels. From several plants used in the channels mentha was the easiest plant to be established. It grows vigorously and is not greatly affected by the environmental conditions either by the very high summer temperatures or by the low temperatures (below $0^oC$) during winter. It can also grow satisfactory at low dissolved oxygen conditions. Also being a perennial plant once established it needs replacement in the channels only once or twice a year, making the maintenance of the system easier. It can also be cut in order to reduce evapotranspiration during summer and can easily re-grow back. Plant establishment was easy and fast during spring and autumn, but because the system was constructed in open-air, establishment of plants during winter or summer when the temperatures were low or very high, was difficult therefore the plants in the channels should be grown early in spring or late summer in order to be already well established during summer or winter.

Seawater entrance in the sewage system of the village in some periods, during the two fist years, had distractive consequences to the plants of the epuvalisation system. The wastewater analysis shows a very high concentration of $Cl^-$ and $Na^+$. Actions were taken with help of the municipality authorities to solve this problem. After the correction of the problem new plantations took place. Cold weather during the winter of 1999 and 2000, damaged celery plants, The damage of plants could not be avoided, because the system is on the open air. New plants were planted. The last year two pump systems in the sewage collector at the village, got out of order for two months. It was difficult to solve this problem quickly, because some parts of the systems (belonging to the municipality) should have come from another country.

## ***TECHNOLOGY IMPLEMENTATION PLAN***

(Contract number : IC18-CT98-0272)

Table 1 : Overview of results

| No | Title of exploitable results | Category (A, B or C) | Partners of the project involved (results owner) or third parties to exploit results | Exploitation/dissemination intention | Type of IPR |
|---|---|---|---|---|---|
| **1** | Wastewater treatment<br>Free Water System | C | Partner 3 : Greece-Iraklio | - Presentations in conferences<br>- Through meetings and visits by the scientists involved in the project<br>- Through a seminar organised at the end of the project<br>- Publication to relevant scientific reviews | - |
| **2** | Wastewater treatment<br>Long Term Storage | C | Partner 4 : Tunisia | - Presentations in conferences<br>- Through meetings and visits by the scientists involved in the project<br>- Through a seminar organised at the end of the project<br>- Publication to relevant scientific reviews | - |
| **3** | Wastewater treatment<br>Epuvalisation | C | Partner 1 : Belgium<br>Partner 2 : Greece-Athens | - Presentations in conferences<br>- Through meetings and visits by the | Patent obtained |

| | | | | | |
|---|---|---|---|---|---|
| | | | Partner 6 : Cyprus | scientists involved in the project<br>- Through a seminar organised at the end of the project<br>- Publication to relevant scientific reviews | |
| **4** | Irrigation technics compatible with sustainable agriculture<br>Effect of wastewater on irrigation system | C | Partner 4 : Tunisia<br>Partner 7 : Israel<br>Partner 8 : Palestine | - Presentations in conferences<br>- Through meetings and visits by the scientists involved in the project<br>- Through a seminar organised at the end of the project | - |
| **5** | Irrigation technics compatible with sustainable agriculture<br>Effect of wastewater on soil | C | Partner 2 : Greece-Iraklio<br>Partner 4 : Tunisia<br>Partner 5 : Morocco<br>Partner 7 : Israel<br>Partner 8 : Palestine | - Presentations in conferences<br>- Through meetings and visits by the scientists involved in the project<br>- Through a seminar organised at the end of the project<br>- Publication to relevant scientific reviews | - |
| **6** | Irrigation technics compatible with sustainable agriculture<br>Effect of wastewater on plant | C | Partner 2 : Greece-Iraklio<br>Partner 3 : Greece-Athens<br>Partner 4 : Tunisia<br>Partner 5 : Morocco<br>Partner 6 : Cyprus<br>Partner 7 : Israel<br>Partner 8 : Palestine | - Presentations in conferences<br>- Through meetings and visits by the scientists involved in the project<br>- Through a seminar organised at the end of the project<br>- Publication to relevant scientific reviews | - |

Table 2 : Timetable for exploitation and dissemination activities

| Activity | Partners involved | Start date | End date |
|---|---|---|---|
| **Conference**<br>Presentation of a conference at the first World Congress of the International Water Association (IWA)<br><br>Presentation of conferences and poster at the Regional Symposium on *Water recycling in Mediterranean region*. (IWA) | Partner 1 : Belgium / Partner 2 : Greece-Iraklio / Partner 3 : Greece-Athens / Partner 4 : Tunisia / Partner 5 : Morocco / Partner 6 : Cyprus / Partner 7 : Israel / Partner 8 : Palestine | 3rd July 2000<br><br>26th September 2002 | 7th July 2000<br><br>29th September 2002 |
| **Meetings of scientists involved in the project**<br>- 1st co-ordination meeting (Cyprus)<br>- 2nd co-ordination meeting (France)<br>- 3rd co-ordination meeting (Greece)<br>- 4th co-ordination meeting (Greece) | Partners 1 / 2 / 3 / 4 / 5 / 6 / 7 / 8 | - January 1999<br>- 3rd July 2000<br>- 9th July 2001<br>- 24th September 2002 | - 3rd february 1999<br>- 7th july 2000<br>- 12th July 2001<br>- 25th September 2002 |
| **Visits of the scientist involved in the project** | - Visit of Mr Savvides (Partner 6) in Belgium (Partner 1)<br>- Visit of Mr Dumont (Partner 1) in Athens (Partner 3)<br>- Visits of Mr Xanthoulis (Partner 1) in Tunisia (Partner 4), Morocco (Partner 5), Greece (Partners 2 and 3) and Cyprus (Partner 6)<br>- Collaboration and visits between Partner 7 and Partner 8<br>- Visits of Mr Xanthoulis (Partner 1) in Israel (Partner 7) and Palestine (Partner 8)<br>- Visit of all the partners in Belgium | - 08/99<br>- 07/99<br>- 99, 2000, 2001, 2002<br>- 99, 2000<br>- 99, 2000<br>- 2000 | - 08/99<br>- 07/99<br>- 99, 2000, 2001, 2002<br>- 99, 2000, 2001, 2002<br>- 99, 2000, 2001, 2002<br>- 99, 2000<br>- 2000 |
| **Publication to relevant scientific reviews** | See publication list | | |
| **Final seminar** | All the partners | 2002 | 2002 |

## ***PUBLICATIONS AND PAPERS***

**Partner 1 (Belgium)**
**Xanthoulis D., Fonder N.**, Participation à la première réunion à Barcelone Espagne, décembre 2002. Projet MED-REUNET : Mediterranean network on wastewater reclamation and reuse**.** First meeting Barcelona, Spain, December 2002.

**Conferences and presentation**s of researches results about INCO-DC project , for trainings (nov.2002), students (May 2002), foreign visitors (2002, 2003)

**Xanthoulis D., Fonder N**. « 4th International Symposium on Wastewater Reclamation and Reuse, México », IWA (International Water association). Paper submitted "Optimisation of the use of nitrogen fertilisation under irrigation with industrial wastewater"

**Xanthoulis D., Fonder N.** Center of Excellence of Cyprus Conference on Integrated Water Management ¨Policy Aspects. Conference and paper presented : "Sustainable water management practices for agriculture », Lefkosia Chypre, April 2003.

**Xanthoulis D., Fonder N.**, **Wauthelet M**. "ecosan – closing the loop". 2nd International Symposium on ecological sanitation. Paper and poster presented "Optimisation of wastewater purification and reuse in Mediterranean countries". Lübeck, April 7-11, 2002

**Partner 3 (Greece Iraklio)**
**Dialynas, G.E., N. Kefalakis, M.G. Dialynas, and A.N. Angelakis** (2002). Performance of the First Free Water Surface Constructed Wetland in Crete, Greece. Wat. Sci. Tech. 46 (4-5): 355-360.

**Dialynas, G.E., E.G. Dialynas, T.V. Manios, and A.N. Angelakis. 2002**. Use of Free Water Surface Constructed Wetlands for Treatment of Mixture of Olive-oil Mill and Municipal Wastewater. In: Proc. of IWA-Regional Symposium on Water Recycling in Mediterranean Region, (A.N. Angelakis et al., Eds). Iraklion, Greece, 26-29 September 2002, 2: 127-130.

**Kapellakis, I.E., K.P. Tsagarakis, E.G. Dialynas, and A.N. Angelakis**. (2003). Effective treatment of olive mill wastewater on free water surface constructed wetlands. International Symposium on «The Olive Tree and the Environment», October 1-3, 2003, MAI Ch, Chania, Crete, Greece.

**Partner 4 (Tunisia)**
**Trad-Raïs M. et Xanthoulis D**. 1999. Amélioration de la qualité bactériologique des effluents secondaires par stockage en bassin. Biotechnologie, Agronomie, Société et Environnement. 1999, Vol.3, n°3 , 129-192.

**Trad-Raïs M., Xanthoulis D., and N. Gardin** (2002) – Storage of secondary effluents for safe reuse in agriculture. *International Symposium on Environmental Pollution Control and Waste Management, 7-10 January 2002, Tunis.*

**Trad-Raïs M., Xanthoulis D., and N. Gardin** (2002) – Seasonal storage of reclaimed wastewater in Tunisia: A means of upgrading microbiological quality. *International Conference on*

*Environmental Problems of the Mediterranean Region. 12-15 April 2002, Near East University, Nicosia, North Cyprus.*

**Trad-Raïs M. and Xanthoulis D.** (2002) – Bacterial contamination of a soil-plant system under three irrigation techniques functioning with reclaimed wastewater. *IWA Regional Symposium on Water recycling in Mediterranean Region. Iraklio, Greece, 26-29 Septembre 2002. Preprint Book 2, 165-169.*

**<u>Partner 5 (Morocco)</u>**

*Mémoires*

**Skouri, K. 1998.** Impact de l'irrigation par les eaux usées épurées sur la production du concombre. Thèse de 3ème cycle pour l'obtention du diplôme d'ingénieur d'Etat en Agronomie, Institut Agronomique et Vétérinaire Hassan II – Complexe Horticole d'Agadir. 100 p.

**Bencharki, H. 1998.** Impact de l'irrigation par les eaux usées épurées par infiltration-percolation et par épuvalisation sur une culture de fleur coupée (Statice : Limmonium sinuatum) sous serre. Thèse de 3ème cycle pour l'obtention du diplôme d'ingénieur d'Etat en Agronomie, Institut Agronomique et Vétérinaire Hassan II – Complexe Horticole d'Agadir. 93 p.

**Eddib, M. 1999**. Impact de l'irrigation par des eaux usées épurées par infiltration-percolation et par épuvalisation sur une culture de Pelargonium sous serre. Thèse de 3ème cycle pour l'obtention du diplôme d'ingénieur d'Etat en Agronomie, Institut Agronomique et Vétérinaire Hassan II – Complexe Horticole d'Agadir. 65 p.

**Lahkim Bennani, K. 1999**. Impact de l'irrigation par des eaux usées épurées sur la nutrition minérale de deux variétés d'une culture d'aubergine (Solanum melongena L.) sous serre. Thèse de 3ème cycle pour l'obtention du diplôme d'ingénieur d'Etat en Agronomie, Institut Agronomique et Vétérinaire Hassan II – Complexe Horticole d'Agadir. 77 p.

**Maqas M. 1999**. Impact de l'irrigation par des eaux usées épurées sur la croissance, la consommation en eau et la production d'une culture d'aubergine (Solanum melongena L.) sous serre. Thèse de 3ème cycle pour l'obtention du diplôme d'ingénieur d'Etat en Agronomie, Institut Agronomique et Vétérinaire Hassan II – Complexe Horticole d'Agadir. 79 p.

**Alem, S. 1999**. Impact d'une irrigation de complément avec une eau usée épurée sur une culture de mais doux. Thèse de 3ème cycle pour l'obtention du diplôme d'ingénieur d'Etat en Agronomie, Institut Agronomique et Vétérinaire Hassan II – Complexe Horticole d'Agadir. 53 p.

**Majidi A. 2000.** L'irrigation d'une culture de courgette sous serre par les eaux usées épurées par infiltration-percolation : Impact sur la croissance et le rendement. Thèse de 3ème cycle pour l'obtention du diplôme d'ingénieur d'Etat en Agronomie, Institut Agronomique et Vétérinaire Hassan II – Complexe Horticole d'Agadir. 72 p.

**Kriem A. 2000**. Irrigation d'une culture de chrysanthème par une eau usée épurée: effet de différentes doses d'irrigation sur le rendement et la croissance. Thèse de 3ème cycle pour l'obtention du diplôme d'ingénieur d'Etat en Agronomie, Institut Agronomique et Vétérinaire Hassan II – Complexe Horticole d'Agadir. 83 p

**Benhoummane B. 2001**. Optimisation des apports d'azote et de l'irrigation pour une culture de chrysanthème (*Chrysanthemum coronarium*) sous abri serre irriguée par les eaux usées épurées par

infiltration-percolation dans le Souss Massa. Thèse de 3ème cycle pour l'obtention du diplôme d'ingénieur d'Etat en Agronomie, Institut Agronomique et Vétérinaire Hassan II – Complexe Horticole d'Agadir. 93 p.

**Mojtahid A. et Lamiri M.** 2001. Optimisation des apports d'azote et de l'irrigation pour une culture de poivron irriguée par les eaux usées épurées par infiltration-percolation dans le Souss-Massa. Thèse de 3ème cycle pour l'obtention du diplôme d'ingénieur d'Etat en Agronomie, Institut Agronomique et Vétérinaire Hassan II – Complexe Horticole d'Agadir. 103 p

**Zerrak T.** 2002 Impact de l'irrigation par les eaux usées traitées sur la productivité d'une culture d'Haricot vert de plein champs, sur la salinité du sol et le bilan d'azote. Thèse de 3ème cycle pour l'obtention du diplôme d'ingénieur d'Etat en Agronomie, Institut Agronomique et Vétérinaire Hassan II – Complexe Horticole d'Agadir. 90 p.

**Aghai O.** 2002. Impact de l'irrigation par les eaux usées épurées sur la productivité d'une culture de tomate de plein champ, la salinité du sol et le bilan d'azote. Thèse de 3ème cycle pour l'obtention du diplôme d'ingénieur d'Etat en Agronomie, Institut Agronomique et Vétérinaire Hassan II – Complexe Horticole d'Agadir. 79 p.

*Publications*

**Benhoummane B., Choukr-Allah R., Hamdy A. and El Omari H**. Optimization of nitrogen use for the production of chrysanthemum crop irrigated with treated wastewater. ICID-CIID International Workshop on Wastewater Reuse Management, September 2001, Seoul, Korea. p: 119-126. Editors: Ragab Ragab; Geoff Pearce ; Ju-Chang Kim ; Saeed Narizi and Atef Hamdy.

**Mojtahid A., Lamiri M., Choukr-Allah R., Hamdy A. and El Omari H**. Best management of reducing nitrogen pollution under irrigated sweet paper with treated wastewater. ICID-CIID International Workshop on Wastewater Reuse Management, September 2001, Seoul, Korea. p: 55-62. Editors: Ragab Ragab; Geoff Pearce ; Ju-Chang Kim ; Saeed Narizi and Atef Hamdy.

**Partner 7 (Israel)**

**U. Kafkafi, S. Abbo and G. Tavori** Nitrate and sodium chloride influence on P and Mo uptake by Faba bean and 2 chickpea cultivars. The Hebrew University of Jerusalem, Faculty of Agricaultural, Food and Envirinmental Quality Sciences, Department of Field Crops, Vegetables and Genetics, PO Box 12, Rehovot 76100, Israel

## ***CONCLUSION***

The success of this initiative resulted from the close collaboration of the Mediterranean countries' research teams and the European Union laboratories. Meetings, exchange and reports all along the project duration has allowed the partners to share their experiments and establish long term solutions to common problems relative to the two chosen fields, even if each participant has specific needs and environmental conditions. All the partners investigated studies and experiments corresponding to proper request or particular interest, in order to find solutions to specific problems encountered in their countries, to find and test new and innovative ways for wastewater management, developing sustainable practices for agriculture. This study gave us detailed information on the best way for WW treatment and exact amount of water nutrients needed to safe use effluents in producing human edible and non edible crops. A continuous use of effluent year round by agriculture crop help in effluent storage pool management and increase the fresh water available to the growing human population in the area.
This study allowed us to develop good management practices aimed at minimising environmental and health impacts of the WW reuse.

All the research teams are working in close collaboration with the local farmers groups and thus, all the results achieved with particular interest have been presented and exposed to local farmers meetings. Very technical studies have been transposed into very simple new agricultural practices.

# MANAGEMENT REPORT

## ***ORGANISATION OF THE COLLABORATION***

Collaboration for coordination was excellent with all the partners.

No more cooperation between partners 7 and 8 – Israel and Palestine- is possible since year 2000 due to the events in Middle East. Scientists keep contact from time to time but work no more together; do not meet each other and no exchange visits on site are possible.

All other partners are staying close, even since the project is finished.

## ***MEETINGS***

### PREMIÈRE RÉUNION DE COORDINATION – CHYPRE DU 30 JANVIER AU 3 FÉVRIER 1999.

**Presents :** Angelakis (Greece), Khamis (Palestine), Kafkafi (Israel), Papadopoulos (Cyprus), Mavroyannopoulos (Greece), Natsoulis (Belgian Consultant), Xanthoulis (Belgium).

**Excused :** Choukr Allah (Morocco), Chaabouni (Tunisia).

La réunion a débuté par la présentation et la discussion des protocoles expérimentaux de chaque partenaire. Ceux-ci sont repris en annexe.

#### *A. REPORTS*

1) Periodic reports (3 copies) with maximum one page for each partner outlining the work under way and the problems if any at 31 Mars 1999, 31 Mars 2000, 31 Mars 2001, 31 Mars 2002.

2) Detailled scientific report (3 copies) at 30 September 1999, 30 September 2000, 30 September 2001, including :
    - A summary of the work accomplished during the last 12 months. This summary include any information relating to events (meeting, training, exchange and publishing) and the schedule for the activities planned over the next 12 months.
    - The scientific report.
    - A summary (two pages maximum) of the results which have been achieved since the beginning of the contract.

3) At the end of the contract (at 30 September 2002)
    - Short final report (5 copies) by each partner on the work and results, with comments, possible follow-up (scientific and use of results), training carried out, paper published
    - A synthesis (2 pages maximum) by each partner
    - With all this material, the co-ordinator will write the final report for the commission and a summery of the report (6 to 8 pages).

4) Cost statements (part D) are due at the same date that the detailed scientific report at 30 September 1999, 30 September 2000, 30 September 2001. At the end of the project (30 September 2002) a consolidated cost statement have to be given.

***B. NEXT CO-ORDINATION MEETINGS***

The 2d co-ordination meeting will take place in Paris at the same time of the International Conference organised by the Wastewater Reuse Group of IAWQ (June 2000). It is recommended that each partner present the state of his research in this International Conference.
The 3d co-ordination meeting will take place in Skyros island and the 4th in Crete with the organisation of the final seminar.

**SECOND COORDINATION MEETING , PARIS 2000**

**Program**

**9 h** Welcome to all participants

**10 h** Financial and administrative presentation of the project by Dimitri Xanthoulis, Faculty of Agronomy Science of Gembloux (FUSAGx) – Belgium

**10h25’** Experimentation in Belgium by N.Fonder, FUSAGx

**10h50’** Experimentation in Greece by G.Mavrogianopoulos, Agricultural University of Athens (AUA) – **Partner 2**

**11h15’** Experimentation in Greece by A.Angelakis, National Foundation for Agricultural Research Institute of Iraklio (NFARI), **Partner 3**

**11h40’** Experimentation in Tunisia, by Z.Chaabouni, F.Chenini, M.Trad and S.Rejeb, Institut National de Recherche en Genie Rual, Eaux et Foret (INGREF), **Partner 4**

**12h30 – 14h 30’** LUNCH

**14h30’** Partner 4 , suite

**14h50’** Experimentation in Morocco by R.Choukr-Allah, Institut Agronomique et Veterinaire Hassan II (IAVH II), **Partner 5**

**15h30’** Experimentation in Cyprus by S.Savvides, Agricultural Research Institute (ARI), **Partner 6**

**15h55’** Experimentation in Israel by U.Kafkafi, The Hebrew University of Jerusalem, Faculty of Nutrition and Environment Science (HUJ), **Partner 7**

**16h20’** Experimentation in Palestine by M.Khamis, The Al-Quds University of Jerusalem, **Partner 8**

**16h45’** Economic Evaluation by D.Natsoulis

**17h10’** Workplan and end of the session

(18h closing of the meeting room)

**THIRD COORDINATION MEETING , JULY 9-12 2001 - SKYROS ISLAND, GREECE**

Present to the meeting : all the addresses on annex 1
Coordinator : Pr D.Xanthoulis, N.Fonder, FUSAGx, Belgium
Partner2 : Pr G.Mavrogianopoulos, AUA, Greece
Partner 3 : Dr G.Dialinas, NFRAII, Greece
Partner 4 : Z.Chaabouni, F.Chenini, INGREF, Tunisia
Partner 6 : S.Savvides, ARI, Cyprus
Partner 7 : Pr U.Kafkafi, HUJ, Israel
Economical Study D.Natsoulis, Belgium

Invited :
Pr K.Chartzoulakis, Nagref, Greece
Pr S.Kiritsis, Rector AUA, Greece
Pr J.Schwager, Germany
Pr A.Neskakis, Aachen University, Germany
T.Ngyuen Cong, Viet-Nam

Excused :
Partner 5 : Pr R.Choukr-Allah, IAHII, Morocco
Partner 8 : Pr M.Khamis, Al-QU, Palestine

**A)** Professor Xanthoulis opens the session at 9 o'clock AM.
Professor presents past and future milestones of reports and meetings (Annex 2). **The next annual complete scientific report is asked to each partner of the project, covering the period from October 1 2000 to September 30 2001**. The report has to be sent by post mail (with an electronic copy) or by E-mail for October 30 2001 **DEAD LINE**.

Professor reminds the researches achieved during the year 2000 and what has to be realized during the next year 2002 (last year of the project by theme and by partner).

N.Fonder presents the INCO project to the invited persons, the goals and objectives, the results already obtained by theme and by partners.
She also presents the results of the experiments in Belgium about the optimisation of nitrogen fertilisation under irrigation with wastewater. The last year tested crop was wheat and the main encountered problem was the abundant rainfalls and thus no irrigation was needed.
The observed results lead to the conclusion that good yields are obtained with the optimum fertilisation advice quantity. With a nitrogen fertilisation over the advice, the gain of yields is low compared to the nitrogen residue left in the soil after harvest. This overfertilisation may induce to the pollution groundwater pollution.
The tested crop for 2001 is carrots.

**B)** Professor Mavrogianopoulos presents the epuvalisation system applied as tertiary treatment for the purification and valorization of the wastewater of Linaria Village, harbor of Skyros Island.
The encountered problems are lack of dissolved oxygen and high salinity rate. The system is on the way to improving.

**C)** Prof Dialinas presents the Free Water System tested for the purification of municipal sewage and Olive Oil wastewaters. The system is improved by recycling the effluent. The experiments are going on with different BOD loading rates and plant species.

**D)** Z.Chaabouni and F.Chenini present the Tunisian experiments of about the impact of wastewater on irrigation systems, on the soil/plant complex and also the optimisation of fertilisation with the use of wastewater.

**E)** S.Savvides presents the epuvalisation system used as tertiary treatment of domestic wastewater. The main encountered problems were lack of dissolved oxygen and high temperatures. Solutions were found to improve the system and to adapt it to the Cyprus environmental conditions. The experiment for the next year are to test the treatment efficiency of different plants and to use the treated wastewater for irrigation on agricultural crops.

**F)** Professor Kafkafi examines the differences among irrigation methods with respect to 3 nitrogen levels on some vegetative parameters in the field. He points out the surprising anticipation of the plant to the daily drought.

**G)** D.Natsoulis explains his methodology the evaluate the economical impact of the wastewater reuse with the different systems tested by all the partners.

The session was closed around 4 o'clock PM by the coordinator.

All the participants were invited to visit the Linaria plant, where epuvalisation is used as tertiary treatment, managed by the INCO partner 2, Professor G.Mavrogianopoulos from the Agricultural University of Athens.

#### FOURTH COORDINATION AND FINAL MEETING, SEPTEMBER 24-25TH, CRETE, GREECE

The fourth annual and final meeting was held on September, in Greece, Crete, Iraklio city just before the Regional Symposium on *Water recycling in Mediterranean region*. Coordinator and partner have presented papers and posters about the researches and results achieved with this INCO project at this symposium.

Those present:

| | |
|---|---|
| Coordinator : | Pr D.Xanthoulis, N.Fonder, FUSAGx, Belgium |
| Partner 2 : | Pr G.Mavrogianopoulos, AUA, Greece |
| Partner 3 : | Dr A.Angelakis, Dr G.Dialynas, NFRAII, Greece |
| Partner 4 : | Z.Chaabouni, F.Chenini, M.Trad, INGREF, Tunisia |
| Partner 5 : | R.Choukr-Allah, Morocco |
| Partner 6 : | S.Savvides, ARI, Cyprus |
| Partner 7 : | Dr M.El-Dakiky, Al-QUDS, East-Jerusalem |
| Economical Study | D.Natsoulis, Belgium |

Invited :
Mrs Bich Thu, Viet-Nam

Excused :
Partner 5 : Dr B.Soudi, Morocco, collaborator of Pr R.Choukr-Allah
Partner 6 : Dr I.Papadopoulos, Cyprus – appointed a representative by S.Savviddes
Partner 7 : Pr U.Kafkafi, HUJ, Israël
Partner 8 : Pr M.Khamis, Al-QUDS, East-Jerusalem, appointed a representative by Dr M.El-Dakiky

## Tuesday 24 September 2002 :

Our INCO group joined the workshop of another INCO group:

European Commission DGXII
Research Project INCO-MED No ICA3-CT-1999-00014
*Water Resources Management under Drought Conditions: Criteria and Tools for Conjunctive Use of Conventional and Marginal Waters in Mediterranean Regions*
Coordinating Institution: Department of Civil and Environmental Engineering, University of Catania, Italy

**WORKSHOP : "MARGINAL WATER TREATMENT AND REUSE UNDER DROUGHT CONDITIONS: EXPERIENCES AND PERSPECTIVES"**

On the second part of afternoon, we joined another workshop :
EUREAU 2 meeting and workshop
**"SMALL WATER TREATMENTS SYSTEMS"**
Lectures by G.Tchobanoglous and T.Gardner

## Wednesday 25 September 2002

Professor Xanthoulis opens the session at 10 o'clock AM.
Dr Angelakis comes a few minutes later to wish every one welcome, as local partner of the project and also as the coordination and final meeting is organised in the frame of the Regional symposium on Water Recycling in Mediterranean Region, organized by his staff.

Successively, all the partners present the results of the last experiments and also a global overview of the researches and results achieved during the fourth years of the duration project.
Every presentation is followed by a small session of 5 to 10 minutes long for questions and discussions.

Partner 1 : N.Fonder, collaborator of Pr D.Xanthoulis, presents the experiment conducted in Belgium
*Optimisation of nitrogen fertilisation under wastewater reuse and the impact of irrigation on soil structure*

Partner 2: Pr Mavrogianopoulos presents the results of the *epuvalisation system applied as tertiary treatment for the purification and valorisation of wastewater* coming from Linaria Village, harbour of Skyros Island, Greece

Partner 3 (Greece, Crete) is held back at the workshops organised for the symposium and will present his work later.

(15 minutes coffee break)

Partner 4 : Mr Chaabouni presents the staff of Tunisian partner and the topics investigated.

*A. Optimisation of irrigation with treated wastewater and their impacts:*
Presented by F.Chenini
•*on irrigation systems and microbial contamination* (experimented by F.Chenini)
•*on crops development and water needs* (managed by Z.Chaabouni)
•*on soil physical characteristics* (managed by Z.Chaabouni)

*B. Study of efficiency of nitrogen in case of irrigation using treated wastewater.*
managed by S.Rejeb and presented by M.Trad

*C. Study of treated wastewater storage in basin.*
managed and presented by M.Trad

Partner 5 : Pr R.Chouk-Allah introduces the results of the 2 research subjects lead in Morocco

*A. Best management practices for reducing nitrogen pollution and salt accumulation under irrigated vegetables and flowers using treated wastewater*
*B. Stabilizing rain fed wheat yield with supplemental irrigation using treated wastewater*

Partner 6 has PC problems and will present his subject later

Partner 7 form Israel is absent. His works are summarised by partner 8.

Partner 8 : Dr M.El-Dakiky, collaborator of Dr M.Khamis, presents the researches and results obtained in East Jerusalem (Palestine).

*A. Test the performance of a small-scale treatment plant (50 $m^3$/day) which can be used to treat wastewater generated from areas were sewage connections and treatment are not available.*
*B. Reuse the treated water (effluent) on the irrigation of chickpea (Humous) as one of the most popular crops in Palestine.*

(short break for lunch)

Partner 6 : S.Savvides, collaborator of Pr I.Papadopoulos, explains us the experiments and the results achieved in Cyprus.

*Epuvalisation system*
*Optimisation of use of nitrogen in the wastewater on Sudax, Aubergines and Sweet pepper crops*
*Optimization of irrigation with treated wastewater on Gerbera jasmesonii culture and Hydroponic culture of cut flowers*

Partner 3 : E.G. Dialynas, collaborator of Dr A.Angelakis, presents the *Use of Free Water Surface constructed wetlands for treatment of mixture of olive oil mill and municipal wastewaters*.

Economical study is presented by D.Natsoulis. He exposes his methodology to evaluate the economical impact and cost of wastewater reuse, following the different systems tested by the partners.

The session was closed around 5 o'clock PM by the coordinator.

## ***EXCHANGE***

For the Coordinator,

- One scientist came from Morocco and presented a PhD master in the frame of the researches occurring in Morocco;
- One training was given on Epuvalisation in Belgium for the partner coming from Cyprus
- One also for the Greek partner from the University of Athens.

All the partners were visited by the coordinator at the beginning of the project, within the first year. Than, they were all visited at least a second time. Scientific visits regularly occurred within the frame of other projects with those countries, especially Greece, Tunisia, Morocco and Cyprus.

## ***PROBLEMS***

Scientific reports were sent on time by all the partners.
Financial report takes a longer time to collect as scientific partners have to reefer to their administration department, before sending it us.
No management problem was encountered.

# COMPLETED CATALOGUE PAGE

This study gave us detailed information on the best way for WW treatment and exact amount of water nutrients needed to safe use effluents in producing human edible and non edible crops. A continuous use of effluent year round by agriculture crop help in effluent storage pool management and increase the fresh water available to the growing human population in the area.

This study allowed us to develop good management practices aimed at minimising environmental and health impacts of the WW reuse.

Results achieved :

- water use efficiency of the tested crops determined
- nutrient uptake from TWW source quantified
- leaching depth of TWW component determined
- degree of contamination of crop and soil determined
- nutrient balance in soil and plants determined
- effect of TWW on structural soil stability determined
- high value crops produced
- optimal water regime for cereals determined
- optimal yields achieved adopting optimal water regime applied
- required quality of the cultivation production, following the WHO guidelines is achieved
- rationalised the supplementary irrigation taking account of the impact of TWW on soil quality, groundwater contamination and crop qualitative and quantitative yields
- installation of WW treatment systems well adapted to their region
- development of decentralised systems for WW management

# DATA SHEET FOR FINAL REPORT

Annexe 2

| **Contract number : ERBIC18CT** | **Year** : |
|---|---|
| **Data sheet for final report** (to be completed by the co-ordinator for the whole project) | |

***1. Dissemination activities***

| | Published | Submitted |
|---|---|---|
| Number of communications in conferences | 27 | |
| Number of communications in other media (internet, video, ...) | 1 | |
| Number of publications in refereed journals | 1 | |
| Number of articles/books | 1 | |
| Number of other publications | 3 | |

***2. Training***

| | |
|---|---|
| Number of PhDs | |
| Number of MScs | 4 |
| Number of visiting scientists | 54 |
| Number of exchanges of scientists (stay longer than 3 months) | |

***3. Achieved results***

| | |
|---|---|
| Number of patent applications | |
| Number of patents granted | |
| Number of companies created | |
| Number of new prototypes/products developed | |
| Number of new tests/methods developed | 2 |
| Number of new norms/standards developed | 1 |
| Number of new softwares/codes developed | |
| Number of production processes | |
| Number of new services | |
| Number of licenses issued | |

***4. Industrial aspects***

| | yes | no |
|---|---|---|
| Industrial contacts | ☒ | ☐ |
| Financial contribution by industry | ☐ | ☐ |
| Industrial partners : - Large | ☐ | ☐ |
| - SME[1] | ☒ | ☐ |

***5. Comments :*** Other achievements (use separate page if necessary)

[1] Less than 500 employees.