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Environmental Effects of Wastewater Use in Agricultural Irrigation at Dhamar City, Republic of Yemen

Ameen Yahya Rageh[1], Maged Ahmed Al-Garadi[2], Mohammed Hezam Al-Mashreki[1]

[1]Renewable Natural Resources Research Center (RNRRC), Agricultural Research and Extension Authority (AREA) Dhamar, Yemen

[2]Department of Veterinary medicine, Faculty of Agriculture and Veterinary Medicine, Thamar University, Dhamar, Yemen

Abstract

The current research is designed to assess the impact of wastewater use on the soils, water resources and public health comparing with chemical, biological and physical analysis with local and international standards. One sample was collected from outlet of wastewater treatment system, ten ground water samples and eight soil samples were collected at 0-60m depth for physical and chemical laboratory analysis. The wastewater is relatively saline (1.7 dS/m), contain BOD and COD, 89.4 and 106 mg/l, respectively. The EC is relatively low (1711 μS/cm), TDS amounts is moderate (1112 mg/l) and the total coli form is very high (up to 78×10^{6} CFU/100 ml). The groundwater and surface water analytical results showed that NO_3 concentration and *F. coli* are higher than the WHO recommended and the soils are highly saline (>15 dS/m). In conclusion, the wastewater is considered unsuitable for irrigation use due to it's a high risk on the surrounding environmental resources.

Keywords: Agriculture, Groundwater, Irrigation, Soils, Wastewater

1. Introduction

Yemen still faces an acute problem in the shortage of water resources where there are no water resources except for rain water and groundwater stored for hundreds of years. About 93% of water is consumed by the agriculture sector while 7% by for domestic purposes and 3% for industry (Atroosh, 2010). Regarding the increase in water demand and the scarcity of renewable resources in mountain heights in recent years, many farmers have tended to search for other water resources such as wastewater to be used for forage production. Yemen is a water-scarce country with a rich natural environment and agricultural diversity due to its varied terrain and climatic conditions(Naji Abu-Hatim, 2009). The natural resources are the basis of the national economy but the depletion and degradation of these is undermining sustainable development and Yemen is facing a water crisis (Bazza, 2000). Treated effluent should be regarded as valuable resource for crop irrigation and soil fertilisation, and the water-scarce conditions in Yemen emphasise the need and urgency of reusing all treated wastewater, as far as practicable. However, there is a lack of clear means of implementing policy as institutional responsibilities are poorly defined. Existing effluent reuse standards are not widely known and there are no standards on sludge use in Yemen. Furthermore, there is limited practical knowledge of the ways and means of realising the resource value of effluent and sludge in a sustainable and safe manner (Essafi, 2000). In fact, wastewater reuse was actually defined as “the use of treated wastewater” in activities such as agricultural irrigation (Metcalf & Eddy, 2003). However, in many parts of the world wastewater in general and sewage in particular are not treated at all, and direct discharge of raw or poorly treated sewage into the environment is one of the main sources of pollution (Gijzen, 2002). In arid and semi-arid regions, wastewater reclamation and reuse has become an important element in water resources planning (Abedi-Koupai and Bakhtiarifar, 2003). This has occurred as a result of increasing fresh water scarcity, the high cost of chemical fertilizers, high nutrients in wastewater, the high cost of advanced treatment required for other applications and the availability of wastewater near agricultural lands. Wastewater possesses different biological, physical and chemical effects on the environment (Al-Nabhani, 2000).

Irrigation with treated municipal wastewater is considered an environmentally sound wastewater disposal practice compared to its direct disposal to the surface or ground water bodies (Rageh,2014). In addition, wastewater is a valuable source of plant nutrients and organic matter needed for maintaining fertility and productivity levels of the soil (Rusan *et al*., 2007). Human activities are modifying chemicals and element concentrations especially trace elements (Montgomery,1997), which enter environment, cause pollution, influence health and cause disease. Inadequate treatment and improper disposal of sewage effluents pose serious threat on surface and groundwater pollution and soil contamination (Adepelumi *et al.*, 2005).

Jorda ́n et al., (2004) indicated that under arid or semi-arid conditions and in regions of poor natural drainage, there is increased potential for hazardous accumulation of salts in soils. The processes by which soluble salts enter the soil solution and cause salinity and sodicity include, the application of water containing salts; weathering of primary and secondary minerals in soils and organic matter decay. The importance of each source depends on the type of soil, the climate conditions, and the agricultural management. The overall objective of the current research is to contribute to the saving of scarce water resources through the reuse of effluent whilst minimizing potential impacts on the environment and public health. In addition, to achieve sustainable improvements to the environment and human health through the development of practicable and feasible concepts which will increase the efficiency and control of the reuse of treated effluent. Furthermore, its importance as focused on Almawaheb Wastewater Treatment Plant in Dhamar City to evaluates the wastewater quality and its validity for agricultural irrigation use and exposes the problems and constraints that affect the soil type, the fodder crops productivity and damages on livestock health.

2. Material and Methods

2.1 The study area

Almawaheb Valley is located in Dhamar plain, which is part of the Central Highlands’ plain, flat to undulating area, with hills and depressions, surrounded in the west and the east by volcanic mountains (Figure 1). According to a recent study Bruggeman, (1997) survey area which is located in agro-climatic zone 6a, which has two representative rainfall stations, viz. Dhamar at. 2100m and Risaba at 2300m in altitude. In this zone (6a), the first rainy period starts around mid-March - beginning of April. The second rainy period begins mid-July - beginning of August and stops abruptly at the end of August. The months September through to February are generally dry, although occasional thunderstorms may bring some rain during these months. The number of rainy days with precipitation amounts above 5 mm/day varies between 15 and 25. The average amount of rainfall per rain day is about 16 mm. The potential evapotranspiration (PET) for an average year varies depending on altitude and wind exposure. The PET is 3-4 mm/day during the dry, cold period and around 5 mm/day during the months May and June. The average annual evapotranspiration is about 1500 mm. The mean monthly maximum temperature varies between 21-22 ℃ during the cold months or November through February, and 25-28 ℃ during the warm months or June to September, while the mean monthly minimum temperature varies between 2-4 ℃ during the cold months of November through January, and 12"C during the wet month or July. Night frost may occur between October and February. The mean monthly relative humidity ranges between 51 and 53% during the cool and dry period, between 56 and 62% during the wet months of July and August, and between 43 and 50% during (the hot, dry months of May and June.

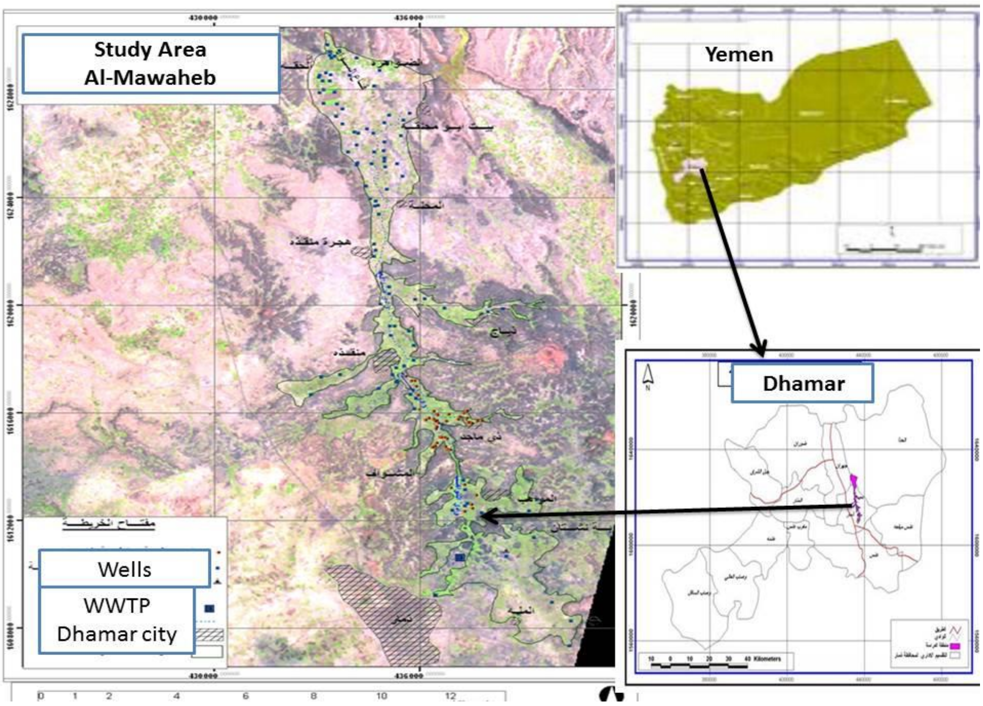

Figure: 1. Map of the study area located in Al-Maahib area at Dhamar Governorate, Yemen

2.2 A General Description of wastewater treatment plant (WWTP)

The WWTP is located in agricultural area about 2 km northeast of the Dhamar City, at elevation of 2400 meter above the sea level (Figure 2). The design horizon of the WWTP is refer to year 1991 for the treatment of an average flow of 5,000 m^3/d (57.9 l/s) generated from an estimated population of 90,000. Treatment is provided by three stage stabilisation pond system.

The design capacity of the existing treatment plant is about 5,000 m^3/d but is currently receiving about 7,150 m^3/d. The current flow represent 43% and 115% hydraulic and organic overloading, respectively. The overloading of these magnitudes is the main cause behind the poor quality effluent produced by the plant. The quantities of effluent produced are less than the inflows to the WWTP with stabilization ponds due to the significant amounts of water lost by evaporation from the large surface areas of the ponds and the extended retention times in these WWTP.Effluent reuse on the large area of agricultural land surrounding the WWTP is considered a practicable option. The majority of crops grown in the area are predominantly cereals (mostly sorghum), although some vegetables are grown (mostly potatoes). Supplementary irrigation is currently given to high value crops, but also to sorghum if the rains are light. The provision of a continuous and free source of effluent would allow farmers to intensify cropping and reduce reliance on groundwater for irrigation, saving pumping costs. At the design capacity of the WWTP, there would be sufficient effluent to irrigate 30 ha, assuming an annual irrigation duty of 20,000 m^3/ha for two crops per year. Peak irrigation demand is in June when there would be sufficient effluent to irrigate only 50 ha. The valley is well defined for only about one kilometer with no continuous drainage channel.

Figure 2. Design of the WWTPs components

2.3 Methodology

All basic material and data were prepared and collected including all secondary information related to the study area, confirmatory review of available previously documents including thematic maps (topography, vegetation, geology, water resources etc.) and analyzing and evaluating all these data.

2.3.1. Field work and visits

Fieldwork was conducted for identifying the reality and the mechanism and the energy absorption capacity and compilation of initial information and carrying out the necessary measurements such as measuring the drain rate inside and outside of the WWTP. These field work including visits to Water and Sanitation Authority office, WWTP place and its laboratory at Dhamar Governorate.

2.3.2 Samples and data collection

Wastewater and ground water samples

Total eleven samples were collected one samples from outlet wastewater and ten samples from different ground water sources all samples were subjected for standard laboratory analysis according to FAO (1988).

Soil samples

Numerous ground observations of soils were carried out through augers, mini pits and natural cuts to identify the main soils properties and their distributions. Eight soil samples were collected at 0-60 depth for physical and chemical laboratory analysis according to FAO, (1988).

Farmer questionnaire

The direct interview among the farmers individually was done and it was focused to ensure wastewater resource importance, management, acceptance, satisfaction, problems and suggested solutions. Moreover the interview including the kinds of forage crops that irrigated by wastewater, irrigation ways and practices, problems arising and suggested solutions. The result was analyzed and compared with international and local indicators.

2.3.3 Soils and water sampling and laboratory analysis

Analyses of soils, groundwater water and wastewater samples collected from the study area were deliver to the laboratory of Renewable Natural Resources Research Center at Yemeni

Agricultural Research and Extension Authority. The methods used for the analysis of water extracts of soil obtained at saturation are similar to (FAO, 1988). The parameters used to determine the quality of wastewater samples were BOD, COD,TDS, EC, pH, SO_4, Mg, Ca, NO_3, Na, HCO_3, K, and Cl concentrations. The parameters used to determine the quality of water samples were the contents of electrical conductivity (EC), pH, sodium, calcium, magnesium, potassium, carbonates, bicarbonates, chlorides, sulphates, nitrates. In order to quantify the various water quality hazards, the sodium adsorption ratio (SAR), total dissolved solids (TDS) and residual sodium carbonate (RSC) parameters were calculated. The soil samples were analyzed for Soil Reaction (pH), Organic carbon content (OC), Cation Exchange Capacity (CEC), Electrical Conductivity (EC), Calcium carbonate ($CaCO_3$), Soil Texture or particle size distribution, Exchangeable Cations and Anions as well as Soluble Cations and Anions if the EC >1 mS/cm (milisimins/cm). The soil samples were air dried, passed through a 2 mm sieve and stored in plastic bags ready for laboratory analysis.

3. Results

3.1 Quality of effluent

The analysis of wastewater sample revealed low efficiency of the WWTP and Higher TDS and the total coliform and faecal coliform the obtained data indicate that the treated wastewater in area is very high as in table 1.

Table 1. The analysis results of wastewater compared with FAO standard

Parameter	Unit	Outlet water sample	(FAO, 1985)
BOD_5	mg/l	89.4	30>
COD	mg/l	106	90>
EC	µS/cm	1711	3000>
TDS	mg/l	1112	2000 >
NO_3	mg/l	95	30>
PH	mol/L	7.5	8.4>
Ca	meq/l	2.5	
Mg	meq/l	3.5	30>
SO_4	meq/l	5	3>

Parameter	Unit	Outlet water sample	(FAO, 1985)
K	meq/l	1.0	
Na	meq/l	9.0	9>
Cl	meq/l	5	10>
HCO_3	meq/l	7.0	8.5>
Biological analysis			
T.Coli	CFU/100mL	78 $\times 10^6$	1000 (WHO,1989)
F.Coli	CFU/100mL	77 $\times 10^6$	1000

3.2. Quality of groundwater

The chemical analysis results of groundwater samples indicated that its quality is consider low for potable water in some wells comparing with both the WHO and Yemeni standards, where the TDS value for is 1408 mg/l in one well. The NO_3 is between 50 and 98 mg/l in 6 wells, which consider high. Regarding the total coliform and faecal coliform, the analysis data indicate that these value are very high, where both the faecal and total coliform are exceeded 0 CUF/100 ml. however, it could be concluded that the groundwater have been affected by the wastewater and consider unsuitable for drinking purpose, but it could be used for agricultural irrigation. The result appeared in table 2.

Table 2. The chemical analysis results of wells water samples compared with WHO standard and (GYL) Yemeni standard

Parameter	Unit	Well number										W.H.O mg/l	G.Y.L mg/l
		1	2	3	4	5	6	7	8	9	10		
E.C	µs/cm	550	760	520	730	530	990	290	550	2100	1220	400-1500	450-2500
T.D.S	mg/l	352	486.4	332.8	467.2	339.2	633.6	185.6	352	1408	780	1000	650-1000
pH		7.3	7.1	7.1	7.3	7.8	8.5	7.1	8.1	7.5	8.1	6.5-8.5	6.5-8.5
Ca	meq/l	2.20	2.80	2.60	3.90	2.30	4.60	0.90	1.10	5.50	1.70	75-200	75-200
Mg	meq/l	1.70	1.50	1.20	1.40	1.10	3.40	0.40	0.60	4.50	1.30	30-50	30-150

Parameter	Unit	Well number										W.H.O mg/l	G.Y.L mg/l
		1	2	3	4	5	6	7	8	9	10		
Na	meq/l	2.10	3.20	1.80	2.10	2.00	2.00	1.90	3.80	4.20	5.40	20-175	200-400
K	meq/l	0.10	0.12	0.18	0.10	0.12	0.08	0.05	0.14	0.12	0.16	8-12	8-12
HCO_3	meq/l	2.20	4.00	2.80	3.60	2.40	4.80	0.80	3.40	3.20	4.80	150-500	150-500
Cl	meq/l	2.40	2.80	2.00	2.60	1.80	3.80	1.30	1.20	4.10	2.80	250	200-600
SO_4	meq/l	0.90	0.80	o.5	1.10	1.10	1.30	0.90	0.90	6.10	4.60	25-400	200-400
No_3	mg/l	55	43	30	60	33	50	90	46	59	98	25-50	10-50
T.Coli	cfu/100mL	16	14	12	17	13	15	20	12	13	21	0	0
F. Coli	cfu/100mL	10	8	4	6	4	6	10	5	6	11	0	0

3.3. The soil properties

The results of analyzed soil samples are given in Table 3, which were collected randomly from the study area, show that they are close and that the PH of the samples located within the alkali medium range (7-7.5). As for the degree of Electrical Conductivity (EC), which is a reflection of the level of soil salinity, was at a low level (less than 1 mS/cm) at the two sites. Generally, the value of the calcium carbonates content was low. It was in the first site 2.50 %; however, it increased up to 7.50% in the second one. It should be noted that the impact of the irrigation on this indicator is weak and it may appear in the long term. With regard to the quantity and content of organic matter, its values ranged from 0.80% in non-fertilized treatment (during cultivation), while it reached up to 1.20% in fertilized soil (during harvest) in the first site. On the other hand, the values of the organic matter in the second site reached 0.80% for both fertilized and non-fertilized treatment.

Table 3. The values of chemical analysis of the soil surface in the study area

Soil depth (cm)	pH	EC (mS/cm)	$CaCO_3$ (%)	O M (%)	TN (%)	Avail. P (ppm)	CEC (cmol/kg)	Exch. Na (%)	Exch. Bases (cmol/kg)			
									Na+	K++	Ca++	Mg++
0-30	7.5	0.50	2.50	0.80	0.06	15	17.0	2	0.35	0.14	-	-
0-30	7.0	0.77	2.50	1.20	0.59	25	21.0	4	0.82	1.43	-	-
0-30	7.5	0.88	7,50	0.80	0.36	23	23.5	4	0.84	0.23	-	-
0-30	7.0	0.75	7,50	0.80	0.76	12	23.0	4	0.82	0.20	-	-

3.4. Farmers' Views on Effluent Reuse

A number of local farmers were interviewed to determine the level of acceptance of effluent reuse and their preferred conditions of supply. The interview results that the pipeline was the preferred option for effluent conveyance as the farmers were concerned for the loss of land from a surface channel, but they were also concerned for the disruption to their land from installing a pipeline. They were uncertain of the benefits of effluent and were particularly concerned about the quality of the effluent and the potential to damage their soil. It was a commonly held perception that crop production may be increased for several seasons but then decline to the extent that they may have to rest the land or even abandon their land. They would currently refuse to accept effluent but would reconsider this after seeing how the crops of other farmers responded to effluent. There is little confidence in the agricultural extension service. The concerns over the means of effluent conveyance across the farmers' land have already been acted on by the Local Branch through their own consultation with the farmers. Further detailed discussions will be necessary following site survey when the best line for the pipeline can be determined. The design of the pipeline should facilitate the reuse of the effluent, preferably by gravity flow, to encourage maximum reuse. If the farmer has to purchase a pump to lift the effluent from the pipeline, the uptake of reuse will be slow and more effluent will be discharged to the valley.

4. Discussion

The results of analyzed wastewater samples revealed that the BOD, COD, 89.4 and 106 mg/l, respectively, so that both amounts reflect the low efficiency of the WWTP. The SAR of effluent is relatively low (5.2) but this has to be considered in relation to the salinity. The EC is relatively low (1711 μS/cm), TDS amounts is considered to be moderate (1112 mg/l). Higher TDS contributions are, however, expected during the dry periods when water rationing is practiced. Restriction of its use according to WHO standard (WHO,2006), and FAO standard (FAO,1985). It could be mentioned that the farmers have little or no understanding of crop water requirements or water use efficiency and they are irrigate their lands with the quantity of water available to achieve a fixed water depth on the land. Over-irrigation of some crops, such as alfalfa and potatoes, is common (in fact, measures should be taken to replace alfalfa with more water efficient forage crops as this is a perennial crop with very high water demand). However, it should be borne in mind that the priority of farmers is the efficiency of crop production per unit of land and not water use efficiency as measured by crop production per cubic meter of water.

Regarding the total coliform and faecal coliform the obtained data indicate that the treated wastewater in area is very high, where the faecal coliform numbers in the sample exceeded 77×10^6 CUF/100 ml, and the total coliform in the sample exceeded 78×10^6 CUF/100 ml,). The limit value for unrestricted reuse of effluent is 1,000 FC MPN/100 ml. However, the problem with using treated wastewater for irrigation is that it contains disease causing pathogenic organisms (bacteria, viruses, protozoa and helminthes). The contaminated food can transmit pathogenic micro-organisms to agricultural workers and their families. Referring to table 1 the water quality is not suitable for use in the irrigation of crops that are eaten uncooked, like tomatoes, cucumber, lettuce, carrots, radish, and cabbage. But it can be used to irrigate fodder crops, upon irrigation being stopped two weeks prior to Fodder harvesting . Animals can go to the field for feed after two weeks from the last irrigation. Effluent is likely to pond at the end of the valley, causing permanent flooding of the surrounding agricultural land and creating a disease risk (bilharzia and malaria). These are important issues that need to be taken into consideration for the design and siting of the effluent discharge.

Ground water that nearby wells are at risk of contamination from leakage from the WWTP and from discharge of the effluent. The discharge channel currently ends at the boundary of the WWTP and no means have been provided to take the effluent to the nearby valley. A potential longer-term concern is for the water quality of the private wells, particularly those located close to the valley where the effluent could be discharged. While this would not have an adverse impact on the irrigation quality of the effluent, these wells are also used as local sources of potable water and so may be considered vulnerable. The wells are deep, up to 90 m, so it is unlikely that there would be contamination of the water by pathogens or heavy metals as these are strongly attenuated within the surface soil layer, but nitrate concentration in the groundwater may increase over time. Selected wells should be regularly monitored, particularly for nitrate, to determine to whether they are affected by effluent reuse and disposal to the valley. Should levels exceed NO3 50 mg /l, the well owners should be notified and advised to secure potable water from another source.

It is noted that the available phosphorus content may have varied in the soil of the first site between 15 and 25 ppm before having irrigated with wastewater (before cultivation) and at harvest, successively. Obviously, the increasing was a direct correlation with the period of wastewater irrigation, which indicates that the content of phosphorus element in wastewater was relatively high or the amount of irrigated water was higher than the crop needs; therefore, there was a cumulative effect. On the other hand, the available phosphorus content in the soil of the second location ranged between 23 and 12 ppm before irrigating with wastewater (during cultivation) and at harvest, successively. As for mutual sodium element, it may have the same character of phosphorus that found in the first location, where it was noted that its quantity increased steadily along with the irrigation period estimated 0.35 and 0.82 cmol/kg in the first location, successively. Therefore, the increased amount of mutual sodium component may have affected the values of mutual sodium ratio where it increased from 2% for the witnessed field (before cultivation) to 4% for the irrigated field during the cultivation period until the harvest. Similar to the available phosphorus, it was also observed that the value of the mutual sodium in the second site was larger than 0.84 cmol/kg before irrigating with wastewater (during cultivation) and at harvest then dropped slightly to 0.82 cmol/kg for the witnessed field (before cultivation). And also the same thing happened for the mutual potassium.

Farmers appeared to be aware of poor experience of effluent reuse elsewhere in Yemen, although they did not necessarily understand the reason. The adverse effects observed elsewhere are almost certainly due to an excessive increase in soil salinity causing loss of crop performance and yield after a few seasons of irrigation. As the salinity of the effluent is greater than that of well water, more water needs to be applied to ensure that an adequate leaching regime is maintained to prevent salt accumulation at the soil surface. This can be done by applying larger amounts of effluent and well water as alternation to maintain an appropriate salt balance. This is essentially an extension issue: farmers should be reassured that this does not cause permanent damage and need to be advised of the appropriate irrigation practice. There is a clear need to establish farmer demonstration trials at the earliest opportunity to convince the local farmers of the benefits to crop yield. This is considered an essential step to achieve a rapid take up of effluent reuse. The trial would provide visible evidence to the farmers of crop performance in comparison and in conjunction with groundwater irrigation. It would also provide training opportunities to instruct farmers on soil salinity control. Within the WWTP, there is an area of about 5 ha which is currently unused and which could be developed for trials or, alternatively, land immediately outside the WWTP could be rented as a demonstration plot. The management and the means of disseminating the resulting information to farmers needs to be considered carefully due to the skeptical response from farmers regarding the extension service.

5. Conclusion

The use of waste water for the irrigation of crops has benefits in using a resource that would otherwise be discarded and wasted. Using waste water also reduces the pressures on the environment by reducing the use of environmental waters. There are factors that need to be considered, including the presence of pathogens and chemical contaminants as well as salinity and impacts on soil structure. These can all be controlled through treatment and effective farm management practices. Ongoing research and development will also improve and increase the use of recycled water for irrigation purposes as well as increasing public confidence. It should be mentioned that farmer opinion is divided as to the advisability of irrigating with effluent as many are concerned that it will damage their land, and would currently refuse to use effluent. This concern is not unfounded because if the farmers are not advised on the appropriate irrigation regime for water more saline than they are accustomed to, the result will be progressive salinization of the soil and crop failure. This must be addressed by establishing demonstration trials and an extension program on how to control salinity by appropriate irrigation rates.

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