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TREATED WASTEWATER REUSE IN AGRICULTURE

PART I: HUSSEIN MEDICAL CENTER PROJECT

THE WATER RESEARCH AND STUDY CENTER

THE UNIVERSITY OF JORDAN

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PREFACE

Jordan is a semi-arid country suffering continuous shortages in water supply for domestic, industrial and agricultural purposes. Since its water resources are scarce, Jordan is resorting to the use of nonconvintional water resources, the most eminent of which is the reuse of recycled wastewater in agriculture and industry. Although this practice is now common in many parts of the world, it is still by no means acceptable in Jordan. Hence, The University of Jordan is conducting field experiments with a view to exploring the feasibility of using recycled wastewater and sewage sludge for agricultural-related projects without posing environmental hazards or threatening public health. In fact, this study is part of a series of studies which aim at reflecting positive interaction between The University of Jordan and the local community. Ever since its establishment, the University has encouraged such an interaction and has even linked its scientific research with aspects of economic development in Jordan in an attempt to support community avtivities and to meet its immediate demands. It is indeed hoped that this cooperation with the local community would contribute effectively to enriching and promoting scientific research.

This project would not have been possible without the full cooperation of both The Civil Aviation Authority and The Directorship of The Hussein Medical Center.

The University of Jordan conveys its deep appreciation and gratitude to its faculty and staff members who are carrying out this study in cooperation with their collegues from The Water Research and Studies Center. Thanks are also due to The Ministry of Planning for its financial support of this project.

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ABSTRACT

TREATED WASTEWATER REUSE IN AGRICULTURE

PART I: HUSSEIN MEDICAL CENTER PROJECT

Treated wastewater generated at Hussein Medical Center was used in irrigation of sweet corn, tomato and water melon in an attempt to study the effect of this water on soil composition, soil characteristics, and crop yield. Of particular interest also was the distribution of bacteria among the environmental components involved which were soil, water and plant material.

The results showed that the treated wastewater did not drastically affect soil composition and soil content of nutrients and trace elements when compared with those of soil irrigated with fresh water. In addition, crop yield increased appreciably under both drip and furrow irrigation systems; this was due to the fertilizing nature of the treated wastewater which contains higher levels of nutrients than fresh water. However, the bacterial counts of the soil and crop material were higher when treated wastewater was used in irrigation as compared with fresh water. Also, bacterial contamination was higher when furrow irrigation was employed as compared with drip irrigation.

Consequently, treated wastewater used in irrigation to increase crop yield, save fresh water and decrease the use of chemical fertilizers must be strictly monitored for its bacteriological quality in order to avoid high levels of bacterial contamination of soil and crop, a matter hazardous to human health. Also, the use of treated wastewater in irrigation renders this water useful instead of being allowed to run into neighbouring Wadis thereby leading to their pollution.

TREATED WASTEWATER REUSE IN AGRICULTURE

PART I: HUSSEIN MEDICAL CENTER PROJECT

INTRODUCTION

Wastewater effluent irrigation is becoming an increasingly popular practice in several countries of the world, especially in arid and semi-arid areas (1,2). There are several encouraging advantages in the recycling of human and animal wastes especially when used in agriculture and aquaculture. Following is a list of the benefits of the reuse of wastewater in agriculture (3).

1. Increase in water supplies for productive agricultural use which leads to the conservation of fresh water normally used in agriculture.
2. Control of surface water pollution.
3. Reclamation of soil and maintenance of soil fertility by the addition of macro and micronutrients.
4. Decrease in the use of synthetic fertilizers which reduces:
    a) The cost of soil fertilization, and
    b) The chemical pollution of soil and water resourses.
5. Recharge of groundwater aquifer system.

However, uncontrolled wastewater irrigation practices may have major detrimental effects on the health of people who consume the irrigated edible crops, or to farmers who are directly exposed to wastewater irrigation (3,4,5). Also, soil properties such as salinity might be gravely effected if the concentration of salts in the wastewater exceeds certain limits (6,7). Wastewater used in irrigation should not include industrial wastewater which may contain elevated concentrations of trace elements and heavy metals. If untreated wastewater is used in irrigation then the major threat to human health comes from microbiological contamination of such water (4,8-12). The empirical evidence and the model developed by several studies supported by the World Bank, the World Health Organization, United Nations Environmental Program and Food and Agriculture Organization, to mention a few, suggest that the highest risk of pathogen transmission, infection and sickness is associated with the helminths, followed in order by bacterial infections and last by viral infection (3). Based on this, the Engelberg Report, 1985, suggested new guidelines for the use of wastewater in agriculture (5). These include for the first time a guideline for nematodes which is one or less than one nematode egg per liter. The bacteriological guidelines, a geometric mean fecal coliform concentration of 1000 per liter of irrigation water, were less restrictive than the previous ones (5).

Due to geography, climate and population pressure, Jordan has a need to conserve its water resourses. This includes the recycling of wastewater along with nutrient recovery to prevent eutrophication of receiving surface waters. Several studies were carried out in several parts of the world dealing with wastewater reuse (1). However, since social activities vary from one part of the world to another, and since waste composition differs accordingly, reuse of wastewater in agriculture in Jordan should be given seperate consideration.

The Water Research and Study Center, in collaboration with the Biology Department and the Faculty of Agriculture at the University of Jordan, conducted over a period of three years two experiments in a study on the reuse of wastewater effluents in irrigation. The two sites were Hussein Medical Center (HMC) and Queen Alia International Airport (QAA). The main objective of the study was to evaluate the feasibility of wastewater reuse in irrigation in Jordan.

The specific objectives were the following:

1. To study the physical, chemical and microbiological characteristics of the treated wastewater.
2. To study sludge characteristics used as a fertilizer (In QAA site).
3. To evaluate the effects of irrigating selected crops using the treated wastewater in terms of crop yield, and the modification of soil characteristics.

Part I of this article deals with the experiment conducted at Hussein Medical Center using the treated wastewater generated at the hospital.

PART I: HUSSEIN MEDICAL CENTER PROJECT

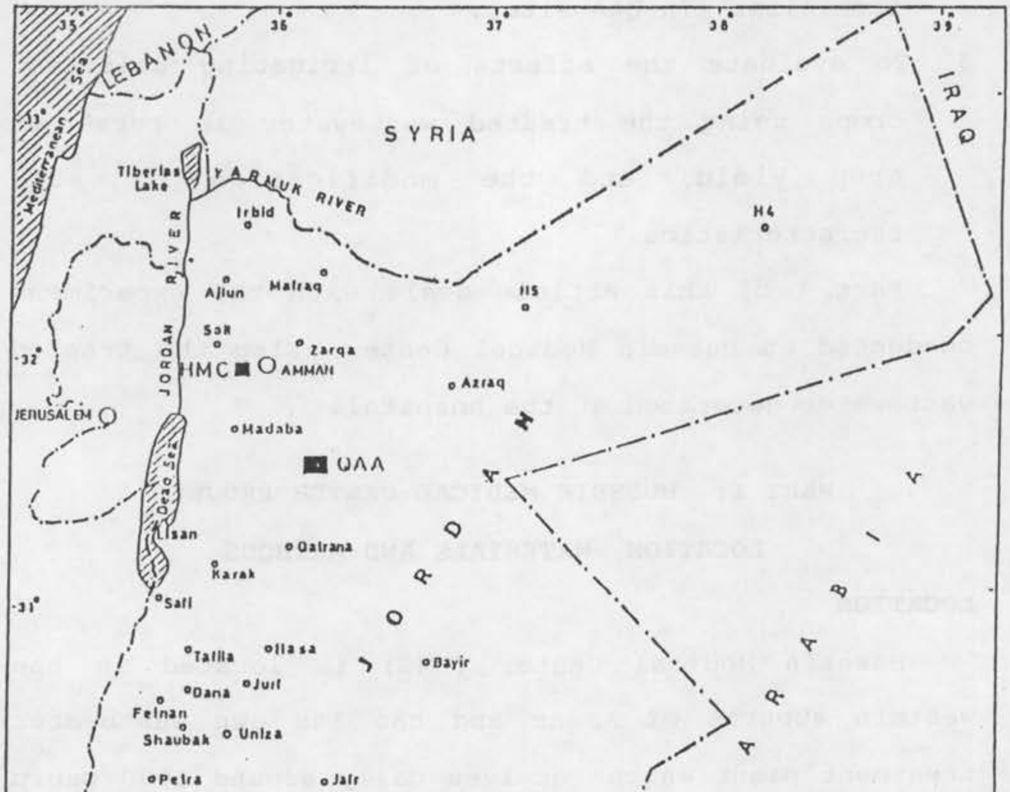
LOCATION, MATERIALS AND METHODS

LOCATION

Hussein Medical Center (HMC) is located in the western suburbs of Amman and has its own wastewater treatment plant which receives daily around 1000 cubic meters of wastewater effluent from the hospital (Figure 1). The treatment plant is of the trickling filters type. The wastewater treated includes laboratory wastes, human tissues, drugs and the patient care waste. The average annual rainfall in the area is about 450 mm and the monthly mean temperatures during summer and winter are 17 C and 8 C, respectively.

FIGURE 1.

LOCATION OF EXPERIMENTAL SITES AT HUSSEIN MEDICAL CENTER AND QUEEN ALIA INTERNATIONAL AIRPORT



EXPERIMENTAL LAYOUT

Two types of irrigation methods were employed, drip and furrow, as discussed below separately.

Drip Irrigation: The experimenta layout was randomised complete block design. One group was irrigated with municipality-piped water that will be referred to as fresh water in this article and the other with treated wastewater. In each group, there were four replicates of each crop planted (Figure 2). The detailed layout of each group is shown in Figure 3. The trickling laterals, each 5.15 m long, were 0.5 m apart with 4 L/hr- emitters. Manual volumetric valves were used to control the quantity of water to each plot. The schedule of planting was as follows:

1985: sweet corn, tomato and water melon.

1986: sweet corn.

1987: sweet corn.

Sweet corn (Zea Mais, "Jubilee" hybrid variety) was sprayed once with Dorospan (2 ml/L water), one month after planting, to protect the plant from aphids. No fertilizers were used during the experiment. Emitter clogging (13), distribution efficiency (14) and uniformity coefficient (14) were also evaluated.

Furrow Irrigation: The experimental layout was a randomised complete block design. Each group was run

FIGURE 2.

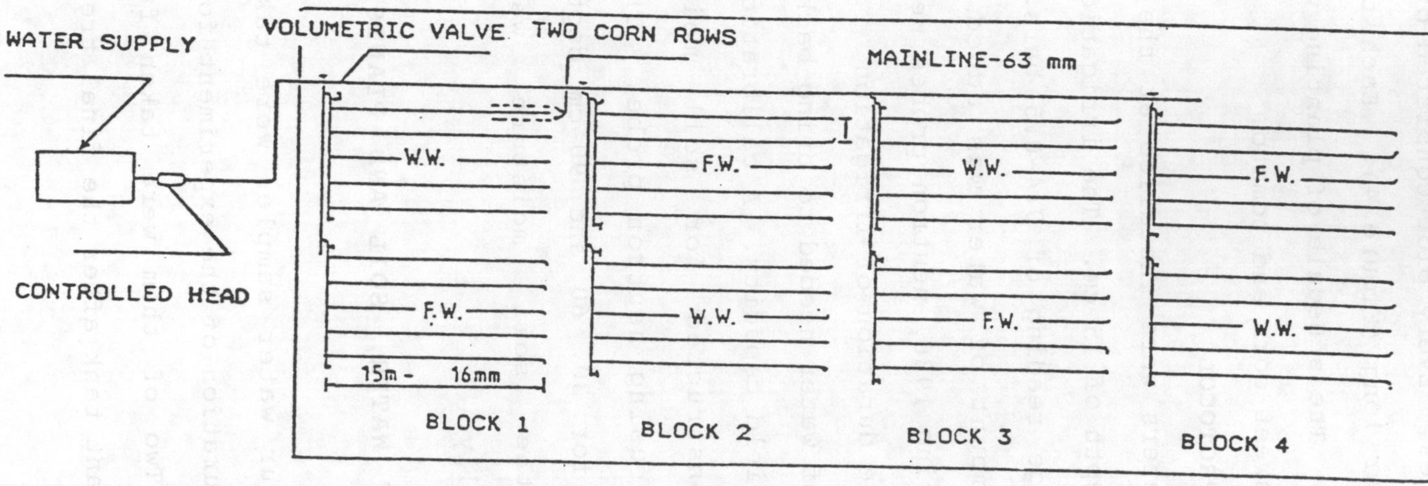
CROP DISTRIBUTION IN HUSSEIN MEDICAL CENTER FOR DRIP IRRIGATION SYSTEM

1 TOMATO	4 CORN	7 TOMATO	10 WATER MELON
2 WATER MELON	5 WATER MELON	8 CORN	11 TOMATO
3 CORN	6 TOMATO	9 WATER MELON	12 CORN
13 WATER MELON	16 CORN	19 TOMATO	22 WATER MELON
14 TOMATO	17 WATER MELON	20 CORN	23 TOMATO
15 CORN	18 TOMATO	21 WATER MELON	24 CORN

PLOTS 1-12 = FRESH WATER IRRIGATION

PLOTS 13-24 = TREATED WASTEWATER IRRIGATION

FIGURE 3. DETAILED OUTLINE OF EXPERIMENTAL LAYOUT OF THE DRIP IRRIGATION AT HUSSEIN MEDICAL CENTER



F.W. = PLOTS IRRIGATED WITH FRESH WATER

W.W. = PLOTS IRRIGATED WITH TREATED WASTEWATER in triplicates. Every plot consisted of 6 furrows, each 45 meter long (Figure 4). Each two furrows were 0.7 m apart. The schedule of planting was as follows:

1985: sweet corn and tomato.

IRRIGATION PROTOCOL

Tensiometers were installed at the center of each plot at a depth of 15 cm. The irrigation was scheduled at an average reading of 0.4-0.5 bars. During 1985, the same amount of water was added to all plots; however, during 1986, neutron probes were installed to determine the duration of irrigation, i.e. to determine the amount of water needed to bring back the soil water content to field capacity. A calibration curve (Figure 5) was constructed for soil moisture content measurement using neutron probe. The curves were constructed for 30, 60 and 90-cm depths. For this purpose, the soil moisture was determined gravimetrically.

SAMPLING OF WATER, SOIL AND PLANTS FOR CHEMICAL ANALYSIS

Water: Four water samples were taken every week during the duration of the experiment for chemical analysis. Two of them were taken from the sewage treatment plant tank after the final treatment of the

FIGURE 4. CROP DISTRIBUTION AND EXPERIMENTAL LAYOUT FOR FURROW IRRIGATION AT HUSSEIN MEDICAL CENTER

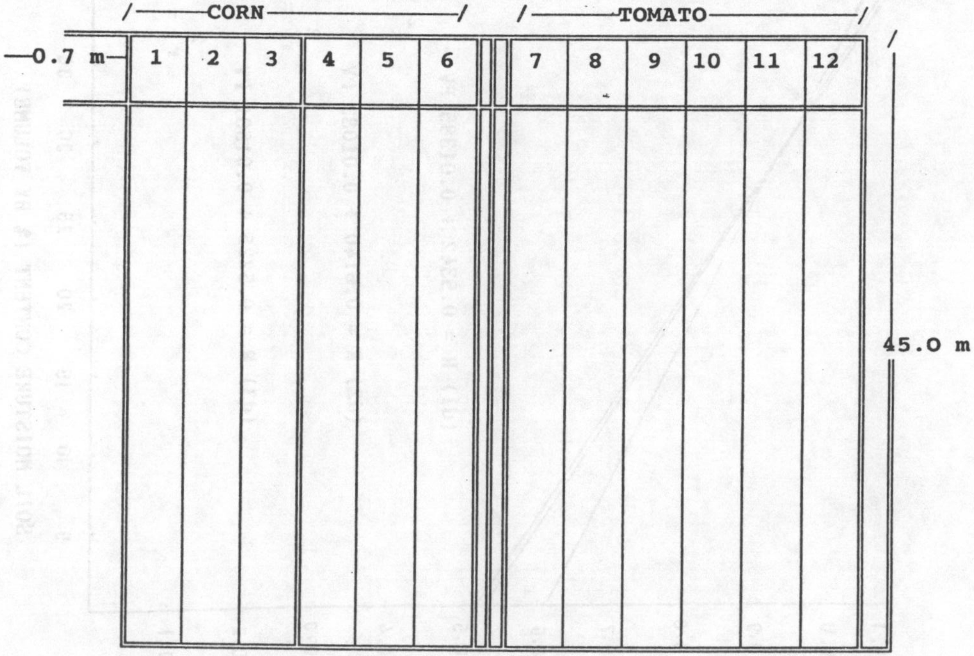
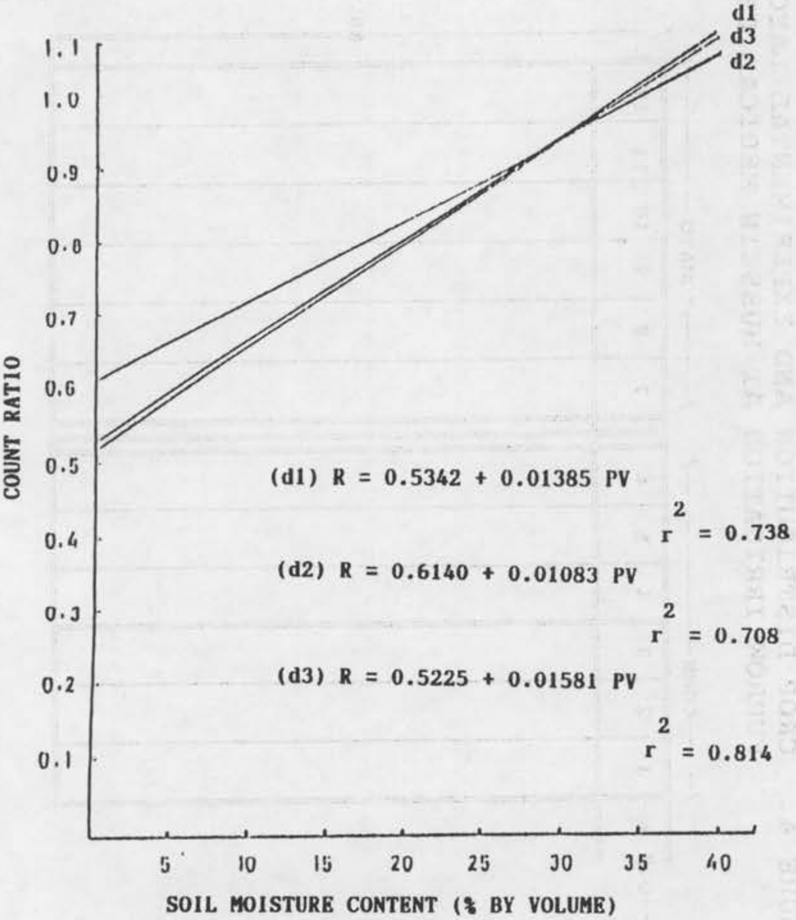


FIGURE 5.

NEUTRON PROBE CALIBRATION CURVES FOR SOIL AT HUSSEIN MEDICAL CENTER



d1 = 30 cm depth
d2 = 60 cm depth
d3 = 90 cm depth

wastewater; this will be referred to as treated wastewater. The other two samples were fresh water.

Soil: Samples were taken from two layers (0-20 cm and 20-40 cm) for both experiments one before planting and another after harvest for drip irrigation and only once after harvest for furrow irrigation. Soil samples were air-dried, ground, allowed to pass through a 2-mm sieve and stored in plastic bags for chemical analysis.

Leaves: Representative leaf samples from 20-30 plants were taken from each plot of the two experiments at tasselling to silk stage. The leaves were washed with distilled water and detergent, then rinsed with distilled water. Plant samples were oven-dried at 56-70 C to a constant weight, ground with Wiley mill and stored in paper bags for chemical analysis.

BACTERIOLOGICAL ANALYSIS OF SAMPLES

Plant, soil and water samples were collected aseptically and transported in ice box to the laboratory in propylene sterile bags within two hours of collection. Samples were collected, once a week, for six weeks from July 3 through August 24, 1985. Soil samples were composited and collected from the surface and at a depth of 8-10 cm. Vegetation samples were also composited. For studying bacterial persistence in soil in furrow irrigation experiment, samples were collected daily for seven days from the surface and from a depth of 8-10 cm.

Total Bacterial Count: This was determined using agar plates, in duplicates for each sample, incubated at 28 C for 43 hours.

Total Coliforms Count : This was determined using decimal dilution samples grown on Eosin-Methylene-Blue (EMB; Difco) medium. The plates were incubated at 37 C for 43 hours.

Salmonella spp.: Samples suspected to have *Salmonella spp.* were checked using SS-agar (Difco) plates incubated at 37 C for 43 hours.

For sample dilution, sterile saline solution was used. For plant and soil samples, vortex mixer was used to dislodge the bacteria into the dilution water.

TEMPERATURE, pH AND DISSOLVED OXYGEN MEASUREMENTS

Air and water temperatures were measured in the field using regular laboratory thermometer. Water and soil pH values (sediment:deionized water in 1:2.5 ratio) were measured using digital pH meter. Dissolved oxygen (DO) and pH were measured in the laboratory using dissolved oxygen and pH meters.

CHEMICAL ANALYSES OF WATER, SOIL AND PLANT

Parameter	Analytical Method
pH	pH digital meter
Temperature (C)	Laboratory thermometer
Dissolved Oxygen (DO)	DO-meter
Electrical conductivity (EC)	EC meter
Na^+ and K^+	Flame photometer and atomic absorption
Ca^{2+} and Mg^{2+}	Titration with Titriplex III
CO_2 gas and HCO_3^-	Titration with HCl
Cl^-	Titration with $Hg(NO_3)^-.2H_2O$
NO_3^-	UV-spectrophotometer, 206 nm
SO_4^{2-}	Spectrophotometer, 491nm

All parameters were analyzed according to Standard Methods for the Analysis of Water and Wastewater (15).

SAMPLE TREATMENT

1. Soil: Some physical and chemical properties of soil profile in the area of the experiment were

determined as follows:

a) Soil texture was determined by pipette method as described by Day (16).

b) Organic matter content was determined by potassium dichromate according to Walkley-Black methode as described by Allison (17).

c) Elements content was determined by wet oxidation methods using HNO_3 and $HClO_4$ after being extracted by diethylene triamine penta acetic acid .

d) Total nitrogen was determined by H_2SO_4-salicylic acid mixture.

e) Total $CaCO_3$ was measured by calometric methods and Cation Exchange Capacity (CEC) as was described by Allison (17).

f) Electrical conductivity was measured using a soil:water mixture in 1:2 ratio at 25 C as described by USDA Handbook No. 60 (7).

g) pH was measured using a soil:water mixture in 1:1 ratio as described by USDA Handbook No. 60 (7).

h) The infiltration rate was measured for each plot of drip and furrow experiments before planting and after harvesting using double ring infiltrometer (18).

2. Plant: Corn plant leaves and seeds were wet-digested using H_2SO_4 and $HClO_4$ for the determination of total elements; these were P, K, Na, Ca, Mg, Fe, Zn, Mn, Cu, Pb, Co, Cd, Cr, Ni and Mo. Nitrogen was determined by Kjeldahl method.

CLIMATIC DATA

These were obtained from the Meteorological Department/ Ministry of Transportation in Amman.

RESULTS

1.SOIL PROPERTIES

Table 1 shows soil properties at HMC. The values presented are each the mean of four samples. The effect of irrigation using wastewater on these properties is shown in Table 2.

2.EVALUATION OF DRIP IRRIGATION SYSTEM

Table 3 shows the distribution efficiency (Ed) and the uniformity coefficient (Uc) of this type of irrigation. The two values are calculated as follows (14):

$$Ed = \frac{\text{Average low quarter depth infiltrated}}{\text{Average depth of water infiltrated}} * 100$$

$$Uc = \frac{\text{Average catch} - \text{Average deviation from average catch}}{\text{Average catch}} * 100$$

TABLE 1.

SOIL ANALYSIS BEFORE PLANTING AT HUSSEIN MEDICAL CENTER

SOIL DEPTH (cm)	BLUK DENSITY (gm/cm^3)	E.C. (uS/cm)	pH	ORGANIC MATTER (%)	ACTIVE $CaCO_3$ (% TOTAL)	N (%)	CLAY (%)
0 - 30	1.56	0.75	7.20	3.37	1.8	0.32	37.0
30 - 60	1.58	0.15	7.01	3.02	2.0	0.15	62.0
60 - 90	1.48	0.42	7.85	2.32	1.2	0.11	59.5

TABLE 2.

SOIL ANALYSIS AFTER HARVEST AT HUSSEIN MEDICAL CENTER

SOIL DEPTH (cm)	WATER TYPE	BULK DENSITY (gm/cm^3)	E.C. (uS/cm)	pH	ORGANIC MATTER (%)	ACTIVE $CaCO_3$ (% TOTAL)	N (%)
0 - 20	FRESH	1.14	0.4	7.0	2.86	6.4	0.32
	TREATED	1.12	0.8	7.2	3.57	6.6	0.32
20 - 40	FRESH	1.19	0.3	7.3	3.52	7.6	0.37
	TREATED	1.10	0.9	7.2	3.64	8.3	0.42

TABLE 3.

DISTRIBUTION EFFICIENCY (Ed) AND UNIFORMITY COEFFICIENT (Uc) FOR DRIP IRRIGATION AT HUSSEIN MEDICAL CENTER

PARAMETER	TEST 1	TEST 2	TEST 3	MEAN	STD. DEV.
Ed	88.0	86.2	87.9	87.4	1.0
Uc	90.3	88.5	92.8	90.5	2.2

3.HYDROCHEMISTRY OF IRRIGATION WATER

The hydrochemistry of fresh water and wastewater used in irrigation are presented in Table 4 and Table 5, respectively.

4.TRACE METAL, HEAVY METAL AND NUTRIENT CONTENT OF IRRIGATION WATER

Table 6 shows the content of elements of public health significance in water used in irrigation at HMC.

5.EFFECT OF IRRIGATION WITH TREATED WASTEWATER ON SOIL CONTENT OF ELEMENTS

Table 7 and Table 8 show the concentration of certain elements in soil samples taken from two layers, 0-20 and 20-40 cm, at midseason and after harvest, respectively, for drip and furrow irrigation.

6.EFFECT OF IRRIGATION WITH TREATED WASTEWATER ON CROP PRODUCTION

Table 9 and Table 10 show the effect of using treated wastewater on corn production for furrow and drip irrigation, respectively, for the year 1985.

Table 11 and Table 12 show the effect of using treated wastewater on production of water melon and tomato, respectively, using drip irrigation during 1985.

TABLE 4.

STATISTICAL ANALYSIS OF PARAMETERS OF FRESH WATER USED IN IRRIGATION AT HUSSEIN MEDICAL CENTER

PARAMETER	MINIMUM	MAXIMUM	MEAN	STD. DEV	N
pH- value	8.22	8.36	8.28	0.06	4
EC uS/cm	554	669	609.50	60.87	4
Na meq/l	0.93	1.22	1.03	0.13	4
K meq/l	0.00	0.04	0.01	0.02	4
Mg meq/l	1.50	1.60	1.56	0.05	4
Ca meq/l	2.90	3.50	3.19	0.30	4
Cl meq/l	1.25	1.50	1.41	0.12	4
NO_3 meq/l	0.16	0.71	0.34	0.25	4
SO_4 meq/l	0.21	0.39	0.29	0.08	4
HCO_3 meq/l	3.09	3.25	3.17	0.07	4
CO_3 meq/l	0.09	0.26	0.17	0.07	4
pH (equilib)	7.65	7.75	7.70	0.05	4
Sat. Index	0.55	0.63	0.58	0.03	4
TDS mg/l	404.1	417.7	412.06	5.83	4
Ionic Strength (mmole/l)	7.70	8.40	8.08	0.38	4
pCO_2 (%)	0.08	0.12	0.10	0.02	4
Tot. Cat. meq/l	5.39	6.05	5.78	0.31	4
H_2CO_3 mg/l	2.0	2.8	2.38	0.35	4
SI-magnesite	0.23	0.34	0.27	0.05	4
SI-dolomite	1.39	1.56	1.45	0.08	4
SI-calcite	0.83	0.91	0.86	0.04	4
SI-anhydrite	-2.62	-2.30	-2.47	0.15	4
SI-gypsum	-2.52	-2.20	-2.37	0.15	4
SI-brucite	-8.65	-8.35	-8.49	0.13	4
SI-aragonite	-0.58	0.65	0.31	0.59	4
SI-$NaHCO_3$	-15.83	-15.38	-15.7	0.21	4
SI-halite	-7.59	-7.42	-7.5	0.07	4

TABLE 5.

STATISTICAL ANALYSIS OF PARAMETERS OF TREATED WASTE-WATER USED IN IRRIGATION AT HUSSEIN MEDICAL CENTER

PARAMETER	MINIMUM	MAXIMUM	MEAN	STD. DEV.	N
pH- value	7.91	8.63	8.23	0.31	5
EC uS/cm	760	1121	995.20	140.87	5
Na meq/l	1.50	6.47	4.9	1.95	5
K meq/l	0.02	1.04	0.59	0.40	5
Mg meq/l	1.20	1.50	1.36	0.13	5
Ca meq/l	2.78	4.70	3.36	0.79	5
Cl meq/l	2.30	5.10	3.90	1.03	5
NO_3 meq/l	0.64	1.00	0.77	0.15	5
SO_4 meq/l	0.15	0.91	0.56	0.36	5
HCO_3 meq/l	3.61	5.44	4.40	0.76	5
CO_3 meq/l	0.00	0.94	0.39	0.47	5
pH (equilib)	7.35	7.69	7.55	0.14	5
Sat. Index	0.44	0.95	0.68	0.19	5
TDS mg/l	600.70	812.40	730.90	85.05	5
Ionic Strength (mmole/l)	11.10	14.00	12.66	1.05	5
pCO_2 (%)	0.05	0.34	0.19	0.13	5
Tot. Cat. meq/l	7.72	11.41	10.20	1.44	5
H_2CO_3 mg/l	3.4	8.3	5.74	1.91	5
SI-magnesite	-0.02	0.56	0.26	0.25	5
SI-dolomite	0.96	2.06	1.49	0.49	5
SI-calcite	0.67	1.18	0.91	0.19	5
SI-anhydrite	-2.83	-2.06	-2.32	0.33	5
SI-gypsum	-2.73	-1.96	-2.22	0.33	5
SI-brucite	-8.92	-7.79	-8.28	0.50	4
SI-aragonite	0.41	0.92	0.65	0.19	5
SI-$NaHCO_3$	-15.24	-13.08	-13.62	0.92	5
SI-halite	-7.13	-6.16	-6.45	0.39	5

TABLE 6.

CONCENTRATION OF ELEMENTS AND NUTRIENTS IN IRRIGATION WATER AT HUSSEIN MEDICAL CENTER

METAL/ NUTRIENT	FRESH WATER (mg/l)	TREATED WASTEWATER (mg/l)
Fe	0.08	0.044
Cu	BSL	BSL
Zn	0.068	0.298
Mn	0.02	0.019
Sr	0.70	0.512
Cr	BSL	0.096
Cd	0.008	0.003
Pb	0.01	0.022
NO_3	20-30	40-62
NH_4	0.0	6-18
PO_4	0.02	6-12

BSL= Below Sensitivity Limit (0.035 mg/l for Cu and 0.07 mg/l for Cr for Phillips UNICAM SP 9090 Atomic Absorption Spectrophotometer)

TABLE 7. SOIL ANALYSIS AT MID-SEASON OF PLANTING AT HUSSEIN MEDICAL CENTER

CROP-WATER	N (%)		P (ppm)		K (ppm)		Fe (ppm)		Mn (ppm)		Zn (ppm)		Cu (ppm)		Cr (ppm)	
DRIP	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40
C - Tr	0.148	0.168	49.0	47.5	572.9	535.9	12.10	8.7	660.0	396.5	8.25	6.08	3.92	4.09	1.68	1.32
C - Fr	0.150	0.161	56.8	44.8	503.3	496.5	9.67	9.2	593.3	257.5	8.25	7.15	2.5	3.8	1.5	1.56
T - Tr	0.248	0.152	46.4	48.4	575.0	514.4	11.40	6.4	629.2	328.7	6.85	5.75	3.5	3.49	1.5	1.44
T - Fr	0.154	0.157	47.3	51.4	852.5	511.3	10.18	6.8	479.0	408.7	7.34	6.45	3.45	2.82	1.5	1.44
M - Tr	0.171	0.156	50.4	49.3	555.0	538.4	10.25	7.6	671.5	249.5	8.02	7.43	4.6	3.7	1.62	1.5
M - Fr	0.236	0.146	58.0	58.5	582.5	539.6	10.00	6.6	755.5	289.5	8.46	7.25	3.33	2.92	1.5	1.38
FURROW																
C - Tr	0.150	0.154	41.7	39.4	441.0	444.5	11.33	8.9	506.7	302.3	4.70	4.08	2.76	2.88	1.28	1.44
C - Fr	0.158	0.189	34.7	39.0	434.0	427.0	10.60	7.3	562.0	238.0	4.41	3.65	2.6	2.46	1.44	1.36
T - Tr	0.152	0.168	33.4	34.0	420.0	493.5	13.06	10.0	760.0	308.7	8.87	3.48	3.2	2.00	1.36	1.36
T - Fr	0.43	0.159	23.7	33.3	455.0	514.5	11.13	9.3	621.3	374.0	3.41	2.98	2.6	1.84	1.36	1.36

Crop Type:

C = Corn
T = Tomato
M = Water Melon

Water Type:

Tr. = Treated Wastewater
Fr. = Fresh Water

TABLE 8. SOIL ANALYSIS AFTER HARVEST AT HUSSEIN MEDICAL CENTER

CROP-WATER	N (%)		P (ppm)		K (ppm)		Fe (ppm)		Mn (ppm)		Zn (ppm)		Cu (ppm)		Cr (ppm)	
DRIP	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40
C - Tr	0.176	0.170	45.3	46.0	282.5	242.5	6.65	6.0	615.0	217.0	3.05	6.65	5.65	3.35	1.5	1.26
C - Fr	0.157	0.174	34.8	51.3	270.0	320.0	10.45	5.6	288.0	226.0	9.38	7.28	5.8	3.31	1.38	1.5
T - Tr	0.152	0.150	50.8	39.3	260.0	243.0	8.65	4.65	537.0	176.0	8.08	6.33	4.99	3.9	1.32	1.4
T - Fr	0.157	0.166	48.0	45.5	277.5	287.5	6.658	4.55	331.0	176.0	7.60	6.7	4.6	3.62	1.32	1.56
M - Tr	0.168	0.162	42.8	47.3	300.0	277.5	8.625	4.95	656.0	192.0	9.18	7.18	5.1	4.4	1.5	1.38
M - Fr	0.181	0.170	43.8	48.5	292.5	277.5	9.05	4.95	587.0	226.0	9.60	7.14	3.63	5.1	1.38	1.44
FURROW																
C - Tr	0.22	0.149	34.0	42.0	226.6	260.0	7.27	5.20	255.0	174.0	3.65	3.01	3.33	3.53	1.36	1.36
C - Fr	0.148	0.155	36.3	39.7	256.6	233.3	6.20	4.23	319.0	153.0	4.25	3.42	2.89	2.70	1.20	1.44
T - Tr	0.16	0.175	34.3	42.0	276.6	310.0	7.00	2.73	247.0	210.0	3.18	3.23	2.28	2.09	2.16	1.32
T - Fr	0.182	0.161	43.7	41.0	366.6	303.3	6.673	1.99	380.0	203.0	3.82	4.02	1.55	1.51	1.52	1.44

Crop Type:

C = Corn
T = Tomato
M = Water Melon

Water Type:

Tr. = Treated Wastewater
Fr. = Fresh Water

TABLE 9.

SWEET CORN PRODUCTION (Kg/1000 m^2) AT HUSSEIN MEDICAL CENTER UNDER FURROW IRRIGATION

WET WEIGHT	1	2	3	TOTAL
TREATED WASTEWATER	2064	1864	1709	5637
FRESH WATER	1770	1541	1354	4665

DRY WEIGHT	1	2	3	TOTAL
TREATED WASTEWATER	640	578	530	1748
FRESH WATER	549	478	420	1446

STOVER WEIGHT	1	2	3	TOTAL
TREATED WASTEWATER	257	263	260	776
FRESH WATER	192	181	239	612

TABLE 10.

SWEET CORN PRODUCTION (Kg/1000 m^2) AT HUSSEIN MEDICAL CENTER UNDER DRIP IRRIGATION

WET WEIGHT	1	2	3	4	TOTAL
TREATED WASTEWATER	1647	1682	1333	1481	6143
FRESH WATER	1581	1226	1160	1207	5174

DRY WEIGHT	1	2	3	4	TOTAL
TREATED WASTEWATER	613	526	496	551	2285
FRESH WATER	588	456	432	449	1924

STOVER WEIGHT	1	2	3	4	TOTAL
TREATED WASTEWATER	163	212	207	268	850
FRESH WATER	173	169	191	178	711

TABLE 11

WATER MELON PRODUCTION (Kg/1000 m^2) UNDER DRIP IRRIGATION AT HUSSEIN MEDICAL CENTER

WET WEIGHT	1	2	3	4	TOTAL
TREATED WASTEWATER	2296	1703	3259	4140	11400
FRESH WATER	2963	-	2740	3407	9111

TABLE 12.

TOMATO PRODUCTION (Kg/1000 m^2) AT HUSSEIN MEDICAL CENTER UNDER DRIP IRRIGATION

WET WEIGHT	1	2	3	4	TOTAL
TREATED WASTEWATER	559	816	1422	1744	4541
FRESH WATER	1047	927	816	1946	4734

7.BACTERIOLOGY

Table 13 shows air temperature, water temperature, pH and dissolved oxygen content, and soil pH on the same dates that samples were collected for bacteriological analysis between July 3, 1985 and August 24, 1985. Total aerobic bacterial counts, total viable coliform counts and Salmonella spp. counts are presented in Table 14, Table 15 and Table 16, respectively. The distribution of the different types of bacteria in soil, corn and irrigation water is shown in Table 17.

DISCUSSION OF RESULTS

Water management in Jordan is becoming increasingly essential because both water quality and water quantity are threatened. One of the resource recovery activities that are being considered is the reuse of treated wastewater in irrigation of crops planted as animal feeds or for human consumption. Since the practice involves health risks for both humans and the environment (3-12), the first part of an experiment on wastewater reuse in irrigation in agriculture was conducted on a small scale at the Hussein Medical Center (HMC) which has its own wastewater treatment plant. As in the implementation of any land irrigation project, several interconnected variables were studied.

TABLE 13. ENVIRONMENTAL PARAMETERS RECORDED DURING THE STUDY PERIOD AT HUSSEIN MEDICAL CENTER

DATE	Air Temp.	Water Temp.	Water pH	Water DO	Soil pH
July 3, '85	19	21	7.5	5. 6	7. 6
July 14, '85	22	23	7.4	5. 4	7. 6
July 21, '85	16	19	7.3	6. 1	7. 7
July 23, '85	26	28	7.2	5. 9	7. 9
Aug. 7, '85	25	27	7.2	6. 0	7. 8
Aug. 24, '85	33	30	7.7	6. 4	8. 0

Temp. = Temperature, C°

DO = Dissolved Oxygen, mg/l

TABLE 14. AEROBIC TOTAL BACTERIAL COUNTS/ GM (SOIL AND PLANT) AT HUSSEIN MEDICAL CENTER

SAMPLING DATE	DRIP IRRIGATION (WATER MELON)			FURROW IRRIGATION (CORN)			TREATED WASTEWATER (No./ml)
	S. SOIL	8-10 cm. SOIL	PLANT	S. SOIL	8-10 cm. SOIL	PLANT	
July 3/85	2.2×10^{7}	2.9×10^{6}	8.1×10^{3}	2.3×10^{7}	1.6×10^{6}	3.9×10^{4}	7
July 14/85	6.3×10^{6}	1.3×10^{7}	1.0×10^{3}	1.3×10^{7}	1.7×10^{6}	3.0×10^{2}	650
July 21/85	5.2×10^{6}	6.6×10^{6}	1.3×10^{4}	2.6×10^{6}	7.3×10^{5}	1.2×10^{3}	200
July 28/85	5.0×10^{6}	8.3×10^{6}	5.8×10^{4}	1.3×10^{7}	8.8×10^{5}	8.5×10^{3}	1700
Aug. 7/85	4.5×10^{5}	1.1×10^{7}	9.0×10^{2}	6.4×10^{6}	4.7×10^{5}	4.0×10^{4}	400
Aug. 24/85	3.0×10^{6}	1.1×10^{6}	ND	3.8×10^{6}	7.9×10^{5}	ND	2900

S. SOIL = **Surface Soil, 1-3 cm.**

PLANT = **Plant Material (Leaves and Fruits)**

ND = **Not Determined**

TABLE 15. TOTAL VIABLE COLIFORM BACTERIAL COUNTS/ GM (SOIL AND PLANT) AT HUSSEIN MEDICAL CENTER

SAMPLING DATE	DRIP IRRIGATION (WATER MELON)			FURROW IRRIGATION (CORN)			TREATED WASTEWATER (No./ml)
	S. SOIL	8-10 cm. SOIL	PLANT	S. SOIL	8-10 cm. SOIL	PLANT	
July/3/85	1.9×10^{6}	6.9×10^{5}	2.0×10^{3}	7.5×10^{5}	2.2×10^{4}	0.0	1.5
July/14/85	1.0×10^{4}	2.0×10^{5}	0.0	1.0×10^{5}	2.5×10^{4}	0.0	2.7
July/21/85	1.5×10^{5}	9.9×10^{4}	4.6×10^{3}	1.2×10^{5}	3.8×10^{4}	3.0×10^{2}	50
July/28/85	1.1×10^{5}	1.5×10^{5}	3.5×10^{2}	4.0×10^{3}	2.0×10^{3}	1.6×10^{3}	10
Aug./7/85	1.7×10^{5}	1.2×10^{5}	2.0×10^{2}	1.1×10^{5}	7.0×10^{3}	4.0×10^{2}	1.4 x 10
Aug./24/85	1.2×10^{4}	1.0×10^{2}	ND	1.0×10^{4}	5.0×10^{2}	ND	2.8

S. SOIL = Surface Soil, 1-3 cm.

PLANT = Plant Material (Leaves and Fruits)

ND = Not Determined

TABLE 16. SALMONELLA SSP. TOTAL COUNTS/ GM (SOIL AND PLANT) AT HUSSEIN MEDICAL CENTER

SAMPLING DATE	DRIP IRRIGATION (WATER MELON)			FURROW IRRIGATION (CORN)			TREATED WASTEWATER (No./ml)
	S. SOIL	8-10 cm. SOIL	PLANT	S. SOIL	8-10 cm. SOIL	PLANT	
July/7/85	4.7×10^{4}	3.5×10^{4}	1.0×10^{2}	6.4×10^{5}	1.1×10^{4}	0.0	0.72
July/14/85	5.0×10^{2}	6.0×10^{4}	0.0	1.5×10^{4}	3.5×10^{3}	0.0	5.0
July/21/85	6.0×10^{3}	3.0×10^{3}	5.0×10^{2}	8.0×10^{3}	5.0×10^{3}	100	2.4
July/28/85	7.6×10^{3}	1.3×10^{5}	0.0	1.0×10^{3}	0.0	0.0	20.0
Aug./7/85	7.1×10^{4}	9.9×10^{4}	1.0×10^{2}	1.3×10^{4}	2.0×10^{2}	0.0	0.06
Aug./24/85	2.0×10^{2}	1.0×10^{2}	ND	1.0×10^{2}	1.0×10^{2}	ND	0.06

S. SOIL = Surface Soil, 1-3 cm.

PLANT = Plant Material (Leaves and Fruits)

ND = Not Determined

TABLE 17.

DISTRIBUTION OF DIFFERENT TYPES OF BACTERIA (LOG GFU/GM) IN SURFACE SOIL, PLANT (CORN) AND IRRIGATION WATER AT HUSSEIN MEDICAL CENTER UNDER DRIP IRRIGATION

SAMPLING DATE	SOIL				PLANT		WATER	
	P2		P18		P2	P18	FW	TW
	* 7.79	7.55	7.5	7.95	4.23	3.4	10	50
11/6/87	(6.21)				(0.0)		(0.0)	(30)
	[0.0]				[0.0]			[10]
	* 6.96	8.36	6.66	6.86	2.74	3.6	160	6230
20/6/87	(6.16)				(0.0)		(120)	(4130)
	[4.3]				[0.0]		[0.0]	[0.0]
	* 8.35	8.05	8.08	8.45	4.45	6.15	700	1210
4/7/87	(6.4)				(4.16)		(320)	(190)
	[5.45]				[3.34]		[0.0]	[0.0]
	* 7.59	7.3	8.19	7.82	6.04	4.66	125	2.5
18/7/87	(5.86)				(0.0)		(1.3)	(1.95)
	[4.21]				[0.0]		[20]	[0.0]
	* 5.57	5.41	5.52	5.81	3.61	3.88	-	550
8/8/87	(5.12)				(3.52)		-	-
	[0.0]				[0.0]		-	-

* = Values in this line are for total bacterial counts

( ) = Total coliforms

[ ] = Total growth on SS medium

FW = Fresh Water

TW = Treated Wastewater

These were the hydrochemistry of the water, soil characteristics, crop production, content of elements in crop leaves, and bacteriological analysis of the water, soil and plants. Also, these parameters were studied with respect to two types of irrigation systems which were drip and furrow. The composition of fresh water used in irrigation (Table 4) shows small fluctuations in the concentrations of Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, NO_3^-, SO_4^{2-} and HCO_3^- and as reflected also by the small fluctuations in the electrical conductivity. The pH-value and its dependent parameters of the carbonate system and the saturation indices of carbonate minerals were stable. The hydrochemistry of the treated wastewater varied slightly from that of fresh water except for the E.C., total cations, H_2CO_3, Na, K, Cl and NO_3 (19). The stability of the treated wastewater is close to that of fresh water as indicated by the saturation indices of the carbonate minerals. In fact, this is the reason behind the high distribution efficiency of the drip system as well as its high uniformity coefficient both of which indicate that clogging of the emitters was minimal (Table 3).

The positively high value for SI-aragonite for treated wastewater as compared with that of fresh water explains the lower concentration of Sr in the treated wastewater. A lower iron concentration is due to the precipitation of iron compounds since the wastewater treatment at HMC involves aeration. It is evident that there are more fluctuations in the composition of the treated wastewater in comparison with that of the fresh water. Of particular interest is the high content of nutrients as shown in Table 6. This, of course, contributes to the soil content of these nutrients and consequently to crop production as shown under Results.

Irrigation with treated wastewater modifies soil chemistry due to its constituents as such. As shown in Table 2, the E.C. of the soil increases at both depths due to the higher E.C. and TDS of the treated wastewater. It is also clear from Table 2 that the increase in organic matter content is greater for top soil layer due to the adsorption of the organic matter particles to the soil particles as water perculates into the lower layers. The other parameters did not vary significantly (19).

The effect on soil content of nutrients and elements varies according to the element, crop planted, type of irrigation and date of sample collection i.e. mid-season or after harvest. However, in general there is an increase in soil content of elements and nutrients regardless of the type of irrigation or crop. The effect of using the treated wastewater is more consistent for both seasons for furrow irrigation according to the samples taken from the two layers. No such conclusion could be arrived at for drip irrigation. In this case, soil content of these elements increases or decreases depending on the depth and type of crop. Consequently, the effect of irrigation using treated wastewater on soil content of elements should be considered for each element, depth and type of irrigation on an individual basis (Tables 7 and 8).

Regardless of the effect of treated wastewater on soil content of elements, its effect on crop yield of corn and water melon is positive (Tables 9, 10, and 11). These results agree with previously published data (20-26). However, no effect was observed on tomato production (Table 12). The results (Tables 9 and 10) show that drip irrigation gave higher yield than furrow irrigation for sweet corn. No such comparison could be made for water melon since it was only drip-irrigated.

Of utmost importance in the reuse of treated wastewater are the risks involved to human health. Wastewater contains different types of pathogenic microorganisms which are removed efficiently in waste stabilization ponds constructed in series except for certain types such as Salmonella (Typhoid and paratyphoid) (2,5). Persistence, reduction or removal of wastewater microorganisms depends on their survival which is affected by a series of parameters. These include moisture content, temperature, pH, oxygen (Dissolved or otherwise), soil microflora on one hand and irrigation modalities, soil depth, cultivated crops and climate on the other hand. Table 13 presents the values of a few of these parameters on the dates that samples for bacteriological analyses were collected. The relatively high concentration of dissolved oxygen in water is reflected in the increased aerobic viable bacterial counts in treated wastewater (976/ml). However, these counts did not correlate with counts prevailing in soil and plants. Bacterial counts tended to be higher in soil surface as compared with the plant material (Table 14). The type of irrigation practice showed different effects as well. Furrow-irrigated plants and soil showed elevated bacterial counts compared with drip- irrigated plants and soil (Table 14). Soil samples, whether taken from the surface or from 8-10 cm-depth, affected the bacterial distribution which tended to show lower counts per gram at 8-10 cm-depth (Table 14) (19).

Distribution of coliform and SS-agar (Probably Salmonella spp.) did not correlate with total bacterial counts present either in surface soil, 8-10 cm-deep soil or on plant material tested (Tables 14, 15 and 16). However, the bacterial counts tended to be higher per gram of surface soil and 8-10 cm-deep soil compared with the plant material which harboured fewer bacteria per gram. Ahmad and Muller reported a drop in bacterial counts of one order of magnitude per 20 cm depth down to 75 cm (27). They also found that enterobacteria penetration to 60 cm during the vegetative period and to 135 cm during the non-vegetative period. This was also true regardless of the type of irrigation method employed although furrow-irrigated plants were more contaminated than drip-irrigated ones (Tables 16-17).

The results indicate that furrow irrigation contributes to a wider distribution of contaminating bacteria. There have been several reviews on the subject of land disposal of pathogen-contaminated wastewater and the potential as well as the actual hazards imposed by its use in irrigation (2-5,8-12). Most data in these reviews are concerned with municipal wastewater. The above results were confirmed during the extension of the study in 1987. Table 17 shows that the rate of contamination of both plants and soil is relatively high.

CONCLUSION

Typically, each person produces daily 1.8 L of excreta which comprises 350 gm of dry solids including 90 gm of organic matter and approximately 20 gm of nitrogen together with other nutrients, principally phosphorus and potassium (4). These components along with the pathogenic content of the excreta get modified during the wastewater treatment process. The quality of the effluent and of the properties of soil at a particular location determine the type of crop and the method of irrigation to be employed (28). The reuse of treated wastewater is an attractive practice in arid and semi-arid countries because it improves the environment as a result of several factors. These include avoidance of surface water contamination, conservation of fresh water, reduction of the use of artificial fertilizers, soil conservation through humus build-up and prevention of land erosion, desertification control and desert reclamation. However, soil and groundwater pollution, and the potential health hazards associated with this practice require that it is employed with caution. Consequently, this study was conducted to assess the effects of using treated wastewater in irrigation on physical, chemical and bacteriological qualities of the soil, and on crop yield in an attempt to evaluate the possibility of employing this practice safely on a larger scale in Jordan. When wastewater is treated to meet certain standards, it could be used safely provided that personal hygiene is practiced. Heavy metals and trace elements were not a problem in this study since their levels in the treated wastewater were lower than even the recommended values for surface water used for drinking purposes. However, the relatively higher level of elements require that the groundwater level should be deep enough to guarantee that the wastewater does not reach the groundwater and/or it reaches it after sufficient purification of chemicals and pathogens has taken place. Also, no untreated wastewater must join the treated effluent to avoid increasing the load of chemicals and pathogens of the effluent. Conditioning of the soil was evident in the increased yield of sweet corn and water melon without the application of chemical fertilizers the use of which is costly and could be hazardous to human health and the environment if application is not managed properly. However, the levels of elements in the treated wastewater should be monitored so as not to exceed levels necessary to prevent soil salinization. From the results, it could be concluded that the quality of the treated wastewater at HMC was suitable for irrigation and caused no drastic negative change in soil or plants except from a bacteriological viewpoint. The total and faecal coliform counts in the treated wastewater were consistently higher than those in fresh water due to their survival following chlorination mainly during storage in the water pools.

In general, pathogens removal from water by soil depends upon environmental factors (climate, the soil type and structure, organic matter content, soil chemistry and water velocity, just to mention a few). It is usually the upper few centimeters of the soil that remove human pathogens. The soil profile at HMC was not sufficient to remove bacteria because it has high permeability and contains large aggregates of rocks. The bacteriological results of this study agree with already published studies in the sense that health hazards are due to the persistence of bacteria in the soil, water and on crop parts, especially those which were furrow-irrigated. In this case, the contamination is higher because the plant comes into direct contact with the treated wastewater. The persistence of pathogens in the environment is temporary and should not last for extended periods of time. It depends on environmental factors such as climate, water content of the soil, etc. In conditions similar to those in Jordan, this should not be longer than six months.

Taking into account the previous discussion, it is recommended that treated wastewater should be used in irrigation with caution and restrictions on the type of crop planted and on the irrigation system employed. It is also recommended that the use of each effluent be considered on an individual basis since the composition as well as the quality of the effluent vary from one treatment plant to the other.

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مركز البحوث والدراسات المائية

مجلة علمية متخصصة
ومحكّمة تصدر عن مركز
البحوث والدراسات المائية في الجامعة الأردنية

العدد الثاني عشر ، ١٩٨٩