Performance of Hydroponic System as Decentralized Wastewater Treatment and Reuse for Rural Communities

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1. Introduction

Wastewater collection and disposal continues to be one of the most public health and environmental problems in Palestine (the West Bank and Gaza Strip). However, the status of wastewater treatment and collection services varies from one locality to another. Wastewater collection systems are available in most of the cities of the West Bank and Gaza Strip. Few wastewater treatment plants have been constructed in the past ten years for a number of cities in the West Bank and Gaza while untreated wastewater still flows in the wadis from many other cities including major urban centres as the city of Nablus. However, more than half of the population of the West Bank live in more than 500 villages. Most of these village lack wastewater collection systems and rarely have wastewater treatment systems. In most of these villages, wastewater is disposed through cesspools. Existing data for wastewater quality in the West Bank shows BOD values ranging between 400 mg/l to 1400 mg/l with an average of about 600 mg/l.

Decentralized wastewater treatment plants are small scale plants that serve one house, few neighboring houses, or small village. Due to (a) the low and high fluctuations of wastewater flow rates from decentralized, small communities, (b) the availability of agricultural lands in rural communities, (c) the spread of the rural population in the West Bank in a large number of villages, and (d) the high cost of wastewater conveyance system, it was recommended to test the use of hydroponics as decentralized wastewater treatment and reuse.

Hydroponics has the advantages of requiring small space, could operate with any size of flow, greatly reduces or eliminates soil borne weeds, diseases and parasites, doesn't require special drainage system, and grows almost any plant and in various spaces as available around the house (various containers, channels, pipes, etc). Hydroponic systems are proved to have several advantages over soil gardening. The growth rate on a hydroponic plant is 30-50 percent faster than a soil plant, grown under the same conditions. In addition, in hydroponics wastewater treatment and reuse systems there is no land used for crop production or soil damaged by salts and solids accumulations due to effluent reuse. However some constraints are associated with hydroponics such as having relatively high set up cost and being not that simple for small scale systems.

It should be noted that plant production in hydroponics and soilless culture and due to its many advantages is rapidly expanding throughout the world, raising a great interest in the commercial as well as scientific community (Papadopoulos, et. Al., 2008).

In this paper, the performance and feasibility of using hydroponics as decentralized wastewater treatment plants in the rural areas of the West Bank will be presented and discussed.

2. Hydroponics: Key Elements and Considerations

2.1 Definition

Hydroponics comes from a Latin word: hydro meaning water and ponos meaning labor which literally means “Working Water”. Hydroponics is systems in which plants are grown in a nutrient solution without soil. The plant is usually provided with structural support which called media (Wikipedia 2009). The media is mostly made of inert material such as gravel. The nutrient solution, is composed of water and fertilizers. In our case are applied to the plant according to its needs. It is possible to apply treated or partially treated wastewater to the root system of the plant. Nutrients are added to the water to satisfy plant nutrient requirements. Wastewater moving through plant roots will either be utilized by the plant or will flow through the rooting system receive additional treatment which makes it suitable for other reuse options. The type of structural support and the method of water application provide many options for hydroponics.

2.2 History

Hydroponics is not a new idea; it is deep rooted in history. Egyptians, Chinees and Indians used it almost 4000 years ago. Hanging gardens of Babilons about 660 B C (Jones 1982, Raviv et. al., 2002, and Raviv and Leith 2007).

The earliest published work on growing terrestrial plants without soil was the 1627 book, Sylva Sylvarum by Sir Francis Bacon, printed a year after his death. In 1699, John Woodward published his water culture experiments with spearmint. He found that plants in less pure water sources grew better than plants in distilled water. The discoveries of the German botanists, Julius von Sachs and Wilhelm Knop, in the years 1859-65, resulted in a development of the technique of soilless cultivation.[1] In 1929, Professor William Frederick Gericke of the University of California at Berkeley began publicly promoting that solution culture be used for agricultural crop production. Gericke introduced the term hydroponics in 1937 (Wikipedia 2009).

One of the early successes of hydroponics occurred on Wake Island, a rocky atoll in the Pacific Ocean used as a refueling stop for Pan American Airlines. Hydroponics was used there in the 1930s to grow vegetables for the passengers.

In the 1960s, Allen Cooper of England developed the Nutrient film technique. The Land Pavilion at Walt Disney World's EPCOT Center opened in 1982 and prominently features a variety of hydroponic techniques. In recent decades, NASA has done extensive hydroponic research for their Controlled Ecological Life Support System or CELSS. In 1978, hydroponics pioneer Dr. Howard Resh published the first edition of his book "Hydroponics Food Production." This book (now updated) spurred what has become known as the 3-part base nutrients formula that is still a major component of today's hydroponics gardening (Wikipedia 2009).

2.3 Types of Hydroponic Systems

There are two main types of hydroponic systems: solution culture and medium culture. The following paragraphs will enlist the various techniques used based on these two systems.

(a) Nutrient Film Techniques

The nutrient film technique (NFT) is a modification of the hydroponic plant growth system in which plants are grown directly on an impermeable surface to which a thin film of wastewater is continuously applied. Root production on the impermeable surface is high and the large surface area traps and accumulates matter. Plant top-growth provides nutrient uptake, shade for protection 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.

(b) Hydroponic plant growth systems

The growth of plants in this system take place with the plant roots immersed in nutrient solution without soil. The plant growth requires a large volume of nutrient solution and frequent monitoring and adjustment. Aeration through bubbling in the root zone may be needed. Plants may be grown in support medium or material such as gravel, sand, vermiculite, and other.

(c) Aeroponic Growth System

Plants in this system are grown with roots suspended in air while being sprayed continuously with a nutrient solution. This system provides easy manipulation of the gaseous environment around the root. It should be noted that this system requires higher levels of nutrients to sustain plant growth.

(d) Flood and Drain System

In this system, nutrient solution rises periodically to immerse plant roots and then recedes exposing the roots to moist atmosphere. It should be noted that this system requires higher levels of nutrients to sustain plant growth

(e) Static Solution Culture System

In static solution culture, plants are grown in containers of nutrient solution, such as glass Mason jars (typically in-home applications), plastic buckets, tubs or tanks. The solution is usually gently aerated but may be un-aerated. A hole is cut in the lid of the reservoir for each plant. There can be one to many plants per reservoir. Reservoir size can be increased as plant size increases.

(f) Passive Sub-Irrigation System

Passive sub-irrigation, is a method where plants are grown in an inert porous medium that transports water and fertilizer to the roots by capillary action from a separate reservoir as necessary, reducing labor and providing a constant supply of water to the roots. In the simplest method, the pot sits in a shallow solution of fertilizer and water or on a capillary mat saturated with nutrient solution.

(g) Top Irrigation System

In Top irrigation, nutrient solution is periodically applied to the medium surface. This may be done manually once per day in large containers of some media, such as sand. Usually, it is automated with a pump, timer and drip irrigation tubing to deliver nutrient solution as frequently as 5 to 10 minutes every hour.

(h) Deep Water Culture System

This system consist of plant production by means of suspending the plant roots in a solution of nutrient rich, oxygenated water. Traditional methods favor the use of plastic buckets and large containers with the plant contained in a net pot suspended from the centre of the lid and the roots suspended in the nutrient solution.

Methods and Materials

1. Pilot Plant Setup

The pilot plant is located in the east-northern corner of An-Najah National University new campus and consists of a primary settling tank ,a model green house hosting the hydroponic system, a final settling tank, and an open area for reuse of effluent (see Figure 1).

The primary settling tank is made of steel and coated with anti corrosion layer, with size of about 13 m^3. It receives raw wastewater from the university collection pit, and has a conical bottom for sludge collection and drainage. The elevation of the settling zone (starting at about 2m above ground) was set to allow gravity flow of settled water to the model green house. Because in small communities, wastewater flow rates vary during the day significantly, the primary settling tank serve as a balancing tank.

The model green house is 8.5 m wide, 36 m long, and 5.5m high, made of galvanized steel pipe frame and covered with plastic layer. The hydroponic system in the green house include two types: barrels and channels. The upper half of the barrels and three channels were filled with media. The media consists of: 2 parts gravel 2cm in size, one part wood saw dust, and one part agricultural sand (0.4 mm).

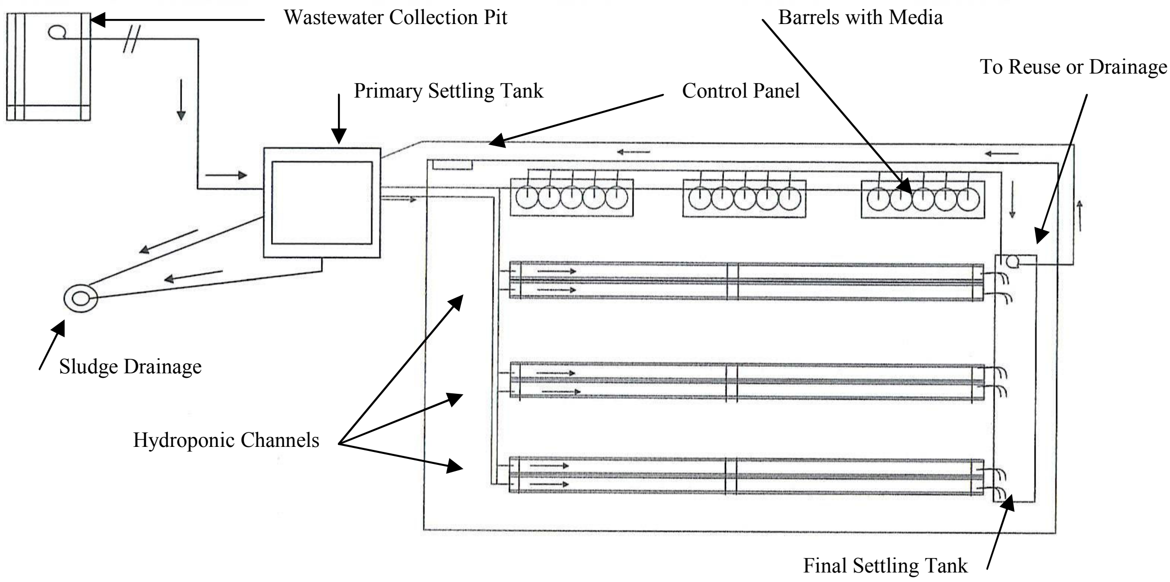

Figure 1 Schematic of Wastewater Pilot Plant

Hydroponic barrels are made of thick plastic, 0.60m in diameter and 0.75m in height. The bottom half of the barrel is without media allowing moist and wetting atmosphere for the roots of the plants (see Figure 1 and 2.a). There are three groups of barrels with five barrels each.

The hydroponic channels are made of steel and coated with anti corrosion layer, with length of 27.1m, width of 20 cm, and height of 35 cm. The channels are made in double and in three lines totalling six channels. Each line, include one channel filled with media and the other without media (see Figure 1 and 2.b).

The open reuse area consists of an area extending from the model green house eastward (width = 8.5 m and length = 150 m) covered with 15-30 cm of agricultural sand. It is intended to cover it with grass.

2. Flow Characteristics:

Two flow regimes were used: vertical for hydroponic barrels and horizontal for the channels:

- Vertical flow (100 l/barrels-day or total of 1.5 m^3/day or a hydraulic loading rate of 98 cm/day)
- Horizontal flow (0.65m^3/channel with media-day and 1.57m^3/channel without media-day or a total of 6.66 m^3/day or a hydraulic loading rate ranging from 24 to 54 cm/day.

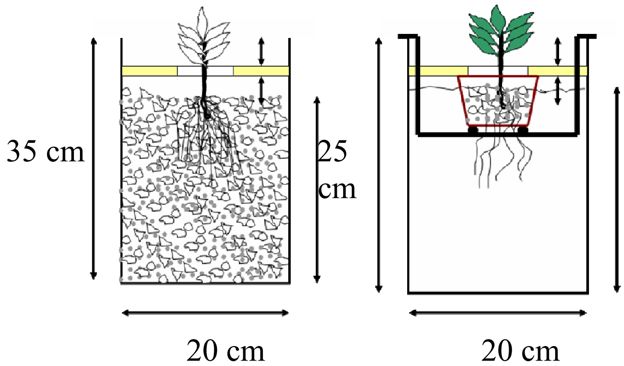

Figure 2.a Schematic of Hydroponic Channels with and Without media

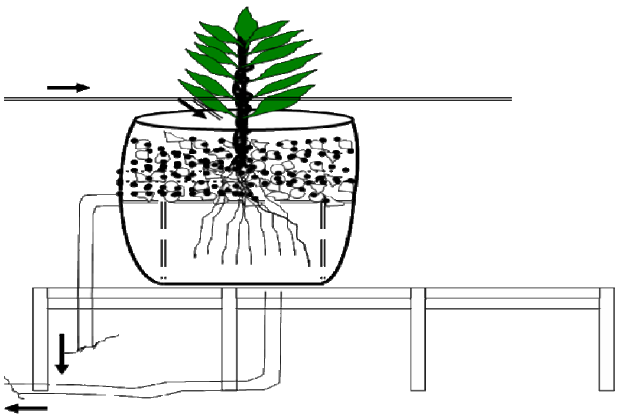

Figure 2.b Schematic of Hydroponic Barrels with media

3. Irrigation System

Two irrigation system were used:

- Flood and drain for the hydroponic channels
- Continuous dripping for the hydroponic barrels

Irrigation frequency and volumes per treatment and plant is given in Table 1, bellow.

Table 1 Irrigation Frequency and Volumes per Treatment and Plant

System	Plant	Irrigations per week	Water applied each irrigation (m^3)	Weekly volume (m^3/week)
Media channels	Eggplant	3	0.412	1.237
	Cut Flowers		0.358	1.075
	Azalea		0.302	0.906
Barrels	Olives	5	0.892	4.460
	Citrus		0.836	4.178
	Rosemary		1.064	5.319
Without media channels	Cut Flowers	4	1.004	4.017
Total				21.192

4. Plants Used:

A group of plants were tested in the hydroponic system. The cropping started by the start of the second week of June, 2008, and seedlings were bought and brought from a local nursery. The plants were replaced after the growing season. Up to date the following plants were tested:

- Vegetables: Winter squash, Green Beans, corn, eggplants, and Cherry tomatoes
- Various cut flowers including Tagetes erecta , Asarina procumbens, Alonsoa warscewiczii, Calendula officinalis Gitano Mix, Arctotis hybrida
- Trees: Citrus and Olives.

5. Analytical Methods

Samples were collected from the wastewater collection pit, primary settling tank, barrels effluent, and channels effluent and analyzed for their content of Ca, Mg Na, NH_3, BOD, COD, pH, temperature, suspended solids and dissolved oxygen. Analysis of raw and treated wastewater and soil were conducted according to standard methods for the examination of water and wastewater and standard soil analysis (Franson, 1989, Carter 2008, and Page et al 1982).

Results and Discussion

Representative results of the hydroponic system are listed in Tables 2, 3 and 4 bellow. As shown in Table 2 the influent BOD concentration was ranging from 76 mg/l (when there was no activities in the campus) to a maximum of 351 mg/l (mid semester). The removal efficiencies for the hydroponic channels either cropped with cut flower or vegetables or with or without media were better than the hydroponic trees planted in barrel. Dissolved oxygen concentration was very low ranging between 0.2 and 0.6 mg/l affecting the rates of BOD removal and indicating the need for additional aeration. The low dissolved oxygen concentration was attributed to the inhibiting compounds used in Chemistry, pharmaceutical and medical laboratories within the campus.

Total Nitrogen in the influent water was ranging from 102 to 177 mg/l while COD was ranging from 160 to 320 mg/l (see Tables 3 and 4). As BOD and COD concentrations are very closed, it indicated the low wastewater content of non-biodegradable organics. Average COD removal rates for the period assigned and for cut flowers was 34% while it was 47% for the trees and the same period. This result, compared to that of BOD, indicate the variability of system efficiency. However, the sampling dates indicate high strength influent with much inhibiting compounds and does not represent the whole testing period. This explanation is supported by the fact that the biomass produced in hydroponic barrels is much higher than that in channels, an indication of the higher efficiency of the hydroponic barrel system

Table 2 BOD Concentrations and Removal Efficiency for the Various Treatments

	BOD, mg/l				
		Effluent			
Date	**Influent**	**CF with Media**	**CF w/o Media**	**Vegetables**	**Trees**
09-Sep-08	190	116	151	167	116
16-Sep-08	293	186	212	219	193
23-Sep-08	244	170	154	243	170
07-Oct-08	164	109	109	122	116

14-Oct-08	264	141	196	186	157
21-Oct-08	225	148	154	148	112
28-Oct-08	193	125	154	119	109
4-Nov-08	196	163	153	113	96
11-Nov-08	190	182	135	121	248
18-Nov-08	244	336	188	277	154
25-Nov-08	351	315	267	174	206
02-Dec-08	290	283	264	132	257
16-Dec-08	76	42	56	43	183
23-Dec-08	248	112	122	125	184
30-Dec-08	159	22	225	190	116
06-Jan-09	302	259	293	174	293
Average Removal, %		30	27	32	21

CF = Hydroponic Channels Planted with Cut Flower

Table 3 Total Nitrogen and COD Concentrations for Cut Flowers

Date	COD, mg/l		TN, mg/l	
	Influent	Effluent	Influent	Effluent
06-Jan-09	320	218	108	96
13-Jan-09	160	128	102	86
20-Jan-09	184	128	177	118
27-Jan-09	242	112	129	99

Total Nitrogen removal was 23% for cut flowers planted in hydroponic channels and 26% for trees planted in hydroponic barrels (see Tables 3 and 4).

Table 4 Total Nitrogen and COD Concentrations for Trees

Date	COD, mg/l		TN, mg/l	
	Influent	Effluent	Influent	Effluent
07-Jan-09	184	160	108	72
13-Jan-09	160	74	102	70
20-Jan-09	184	60	177	145
27-Jan-09	242	176	129	93

Conclusions

In conclusion, the testing of hydroponic system either in the form of hydroponic barrels or channels and as decentralized wastewater treatment and reuse for rural areas in Palestine is proved to be successful with some limitations due to the fact that the waste quality used is a campus effluent with much inhibiting and oxygen consuming chemicals and not domestic wastewater. As a result it is recommended that further testing of the system is needed with supplementary aeration and lower hydraulic loading rates.

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