



UTILIZATION OF AGRICULTURAL DRAINAGE WATER FOR LETTUCE PRODUCTION IN NFT HYDROPONIC SYSTEM

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ABSTRACT

Using alternative water resources such as agricultural drainage water is considered very important to produce crops (e.g., lettuce plant) due to fresh irrigation water shortage, especially in arid and semiarid regions like Egypt. Moreover, production of lettuce hydroponically in economical scale is becoming popular in drought prone areas with less water consumption. This study aimed to explore the effects of irrigation with different combinations of Agricultural Drainage Water (ADW) and fresh water on lettuce (*Lactuca sativa* L.) yield, quality, and water use efficiency (WUE) under hydroponic conditions. Three combinations were applied as: T1, (100% agricultural drainage water), T2, (50% agricultural drainage water + 50% fresh water), T3, (100% fresh water). Nutrient Film Technique (NFT) hydroponic system was developed with three pipes and nutrient solution added in rates of 12.5%, 50%, and 100% from standard nutrient solution for T1, T2, and T3, respectively. It seems that lettuce plant can be produced in 50 days from planting to harvest the entire system. T2 treatment was effective in increasing the green and dry matter yields, where the green yields accounted for 2.330, 10.587, and 7.090 kg/m² for T1, T2, and T3, respectively. The highest lettuce yields as affected by water treatments could be ranked as follow T2 > T3 > T1. This may be attributed to nutritive value of ADW especially at 50% treatment. Moreover, plants irrigated with T2 have ability to use irrigation water more efficiently than those irrigated with other water treatments. Water Use Efficiency values (WUE) were 8.96, 39.215, and 24.451 kg/m³ for T1, T2 and T3, respectively. Mineral nutrient contents of N, P, K, and Ca in dry matter were obviously higher in plants irrigated with T3 than other water treatments. This may be due to nutrient solution concentration rates. Heavy metals (Cd, Ni, Cr and Pb) contents in lettuce shoots were higher in plants irrigated with T2 than those irrigated with other water treatments, but their levels did not exceeds the critical levels noted by FAO for edible crops. In conclusion, the NFT hydroponic lettuce could be irrigated safely with agricultural drainage water (ADW) mixed with fresh water in ratio of (50%: 50%) (T2) to produce remarkable economical yield with less water requirement. Moreover, use of agricultural drainage water (ADW) in irrigation of lettuce in hydroponic system could be considered as useful alternative source of wastewater without environmental risk of heavy metals accumulation in soil.

Key words: Agricultural drainage water, heavy metals, lettuce plant, NFT hydroponic system, water use efficiency.

INTRODUCTION

Egypt is an arid country, which covers an area of about 1,001,450 km² of which only 4%

is occupied by its population. The population has tripled during the last 50 years from 19 million in 1947 to about 83.5 million in 2012 and expected to be about 100 million by the year

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2025 (Abdel-Lateef *et al.*, 2011). About 99% of the Egyptian population is concentrated within 5.5% of the area of the Nile Valley and Delta region. They are extremely dependent on the River Nile for agriculture, drinking water and energy. Where, the actual water resources currently available for use in Egypt are 55.5 BCM/yr from river Nile, and 1.3 BCM/yr effective rainfalls on the northern strip of the Delta, non-renewable groundwater for western desert and Sinai, while water requirements for different sectors are in the order of 79.5 BCM/yr. The gap between the needs and availability of water is about 20 BCM/yr. This gap is overcome by wastewater recycling.

On the other hand, the agricultural sector is utilizing about 86% of the available water supplies; however, this amount of water that returns to drains from irrigated lands is relatively high (about 25 to 30%). Generally, the drainage water from agriculture is collected, by an extensive drainage network. Currently about 5.5 BCM of drainage water are being reused after mixing with fresh water. This amount is expected to increase up to 9.6 BCM by the year 2017. In general, the utilization of agricultural drainage water (ADW) and marginal quality surface water is an emerging necessity to deal with severe water shortage in arid and semi-arid land. Upgrading of ADW may enable appropriate schemes for controlled application depending on treated ADW or *via* mixing with other sources of surface water. Its reuse in Egypt for agriculture could bridge the gap between the expected (74 milliard m³) and required (85 milliard m³) water demand. In addition, agriculture drainage water can be considered as a nutrient-rich resource that can be used for food production and thus help alleviate food shortages with minimum use of chemical fertilizers. However, whatever its application, and whatever the type and level of treatment technologies, they must meet the recommended microbiological and chemical quality guidelines. These presume low cost and minimal operational and maintenance requirements.

Hydroponics is a method of growing plants in a soilless environment. The nutrient source is provided directly to the plant roots in solution. Recent studies have indicated that nutrients from treated wastewater could be purified by using some plant species in a hydroponic system

(Vaillant *et al.*, 2004; Yang *et al.*, 2008; Snow and Ghaly, 2008; Rababah and Ashbolt, 2000; Rababah and Al-Shuha, 2009). Moreover, hydroponics (soilless) culture could lead to solve the global issues such as the shortage of water, environmental pollution, and instability of ecological system in various ways. Constituting high values for agricultural crops by using low water inputs and high fertilizer efficiencies is one of the methods used in addressing the environmental and resource problems (Sezen *et al.*, 2010). Hydroponic culture could be arranged with optimum environmental medium for crop growth in order to gain maximum yield and high quality products. However, there are few studies on the nutrient availability in agriculture drainage water for optimum plant growth, pathogen contamination in edible parts of the plant and nutritional quality of vegetables grown in agriculture drainage water using the hydroponics system. One of the most important aspects of fresh food is its nutritional quality; however, it is not clear whether agriculture drainage water is able to provide necessary nutrients to food crops as well as adequate nutritional quality of the product. The current study aimed to investigate lettuce yield and quality, water use efficiency, and heavy metal contents using agricultural drainage water (ADW) for irrigation in hydroponic system in comparison with fresh water irrigation.

MATERIALS AND METHODS

Hydroponic NFT system was constructed during 2014 at the greenhouse of Soil and Water Research Department, Nuclear Research Center, Atomic Energy Authority, Inshas, Egypt. Experimental site is located at 30°24' N latitude, 31° 35' E longitude while the altitude is 20m above the sea level.

The Hydroponic System

Lettuce (*Lactuca sativa* L.) seeds were sown on 1st Sept., 2014 in Rockwool and transplanted 3 week later into rockwool blocks. On 21st Sept., 2014, at the four- to five-leaf stage, transplants were placed in net cubes and inserted in the NFT hydroponic system. The NFT system was made of plastic PVC Pipes (3 m long × 4 inch diameter) set on a flat surface with a 0.1% slope.

Each experimental bloc had twelve plants. Each effluent was complemented with appropriate nutrient solution. Blocs with three treatments and four repetitions of each treatment were applied. After seeding, lettuces were transferred to the experimental units. The irrigation of plants was programmed with a timer to put on the pumps 4 times every day for 5 minutes per time. Nutrient solution was delivered at 2L. Min⁻¹, monitored and adjusted daily for pH and electrical conductivity (EC). In the NFT system, solution was recycled not replaced but adjusted based on pH and EC measurements.

Plant Material

Plant seeds were provided by Agricultural Research Centre, Dokki, Cairo, Egypt. Lettuce (*Lactuca sativa* L.) seeds were subjected to a germination test to check for their viability before being used; where the results indicated 97% germination percentage.

Treatment of Seeds and Planting

Seeds of lettuce were cleaned from debris and other foreign materials, and then the cleaned seeds were surface sterilized by soaking for 30 minutes in a 20% sodium hypochlorite solution (Clorox bleach) to prevent the formation of mould. Planting tubes and the growing net cubes also were cleaned and disinfected. The seeds were washed well from residues of bleach and re-soaked in tap water overnight (about 12 hours) before sowing. Seeds were sown in the polystyrene trays lined with black plastic sheets and have holes at the bottom to allow drainage of excess water from irrigation.

Irrigation Treatments

Tubes were irrigated by programming a timer to put on the pumps four times every day for five minutes with three water treatments: three concentrations of agricultural drainage water (ADW) were used, i.e. T1: (100% agricultural drainage water), T2: (50% agricultural drainage water +50% fresh water), and T3: (100% fresh water). The agricultural drainage water (ADW) was harvested from the outlet of drain system of minayer region with a capacity of 2,500 m³/day. Adequate nutrient solution was added in each treatment with rates of 12.5%, 50%, and 100% from standard nutrient solution for T1, T2, and T3, respectively to enhance plant growth and its contents of the nutritional elements.

Lettuce Yield

At the end of experiment (50 days after seeding), the produced fresh lettuce was ready for harvest (Plate 1), and green plants with their root mats in the tubes were harvested and the following data were recorded: total fresh and dry lettuce yields, seedling height, and leaves number.

Water Use Efficiency

Planting tubes were irrigated four times every day for five minutes for each water treatments to provide enough water that keeps seedlings moist. Daily amounts of water used in irrigation were recorded to compute the total amounts used in irrigation throughout the experiment duration. Drained water was recycled in the plastic tanks which were placed under each planting tube. Water consumption (m³/m²) was computed as the following:

$$\text{Water consumption (m}^3\text{/m}^2\text{)} = \frac{\text{total irrigation water in tank at the beginning of the experiment} - \text{total irrigation water in tank at the end of the experiment}}{\text{area of the experiment}}$$

Water use was computed according to:

$$\text{Water use} = \frac{\text{m}^3 \text{ water used}}{\text{kg fresh lettuce produced}}$$

Water use efficiency (WUE) was computed according to:

$$\text{WUE} = \frac{\text{kg fresh lettuce produced}}{\text{m}^3 \text{ water used}}$$

Chemical Analyses

Mineral nutrient analysis

Representative fresh green lettuce samples (150 g) from each treatment were taken in four replicates at harvest, oven-dried at 70°C for 48 hours, ground to pass through a 0.5 mm sieve, prepared for wet digestion using H₂SO₄ and H₂O₂ and then subjected to chemical analyses. The nitrogen content was determined using Kjeldahl's method. Samples were prepared for determination of mineral nutrients using dry ashing method (Schouwenberg and Walinge, 1973). Phosphorus was determined using spectrophotometer (Watanabe and Olsen, 1965); potassium and sodium by flame photometer (Ryan *et al.*, 2001), Ca, Mg, Mn, Zn and B by Atomic Absorption Spectrometer (Buck type 210). Some nutritional elements (N, P, K, Ca, Mg, Zn, Na, and B) in various irrigation waters were also analyzed.



Plate 1. Lettuce plant view at harvest time

Heavy metals analysis

Dried and ground plant samples as well as various irrigation waters were analyzed for heavy metals Cd, Ni, Cr, and Pb.

RESULTS AND DISCUSSION

Irrigation Water Quality

Chemical and biological characteristics of irrigation water used for the various treatments are listed in Table 1. The salinity of irrigation water was 0.89 dS/m (fresh water) and 2.63 dS/m (ADW). The pH values were 7.42 for the fresh water and 7.95 for the ADW.

Concentrations of N, K, Na, Cl and Zn in ADW were higher as compared to fresh water (Table 1). However, similar amounts of P, Mg, and B were recorded in both ADW and fresh water. The concentrations of these elements are considered lower than those recommended for nutrient solutions in crop production (e.g., vegetables) under hydroponic systems according to Benton (2005).

To know the potential risk of heavy metals in irrigation water to plants and hence human beings, it is necessary to evaluate their concentrations in ADW. The heavy metal concentrations of ADW and freshwater used in this study are presented in Table 2. Although the chromium, cadmium, nickel, and lead contents in ADW are much higher than those in fresh water, the levels of these elements in ADW are lower than the acceptable levels set for irrigation water for crop production

according to FAO guidelines (FAO, 1992).

Lettuce Yield

Lettuce yields (on fresh green and dry weight basis), plant height and leaves number at harvest are presented in Table 3. Higher yields of fresh and dry matter were recorded in plants irrigated with T2 than for others. Fresh yield was 2.330, 10.587, and 7.090 kg/m² under irrigation with T1, T2, and T3, respectively. Consequently, performance of different irrigation water treatments could rank as following: T2>T3>T1. Similar trend was observed with dry matter yield. On line with these results, Gonnella *et al.* (2003) found that fresh leaf yield of lettuce was on average near to 6 kg/m² and leaf dry matter content was on average 5 g/100 g of fresh weight. In addition, Keller *et al.* (2005) observed healthy lettuce plants irrigated with secondary effluent diluted 50% where it achieved high production. Leafy plant production has been reported to highly correlate to N content of irrigation water (Azevedo *et al.*, 2006). These results confirmed the results we have since the analysis of mixed water or ADW solely (Table 1) used in this study indicated that ADW contains higher N than fresh water.

Plant dry matter was reduced with increasing water salinity and this is consistent with Al-Maskri, *et al.* (2010) but this is inconsistent with the results of Ünlükara *et al.* (2008) who found that plant dry matter content increased with increasing salinity.

Regarding to plant height, lettuce height recorded 48.40, 52.55, and 47.75 cm under irrigation with T1, T2, and T3, respectively.

Table 1. The characteristics of fresh water and ADW used for irrigation

Parameter	Fresh water	ADW
EC dS/m	0.89	2.63
pH	7.42	7.95
DO (mg/l)	-	2.8
BOD ₅ (mg/l)	-	40
COD (mg/l)	-	38
NO ₃ -N (mg/l)	14	23
Cl (mg/l)	17	129
PO ₄ -P (mg/l)	4.96	6.58
Ca (mg/l)	48.12	59.32
Mg (mg/l)	15.9	17.3
K (mg/l)	98	118
Na (mg/l)	78.4	389
Zn (mg/l)	0.016	0.15
B (mg/l)	0.038	0.050

Table 2. Toxic elements content (mg/l¹) in water used for irrigation and the maximum concentrations of heavy metals in ADW allowed to be used for irrigation according to FAO (1992)

Metal	ADW	Fresh water	Maximum concentrations
Chromium (Cr)	0.0070	0.0018	0.10
Cadmium (Cd)	0.0023	0.0004	0.01
Nickel (Ni)	0.0082	0.0004	0.20
Lead (Pb)	0.167	0.0029	5.00

Table 3. Lettuce (fresh and dry) yield, plant height, and leaf number produced under (NFT) hydroponic conditions and irrigated with different concentrations of agricultural drainage water (ADW)

Water treatments	Fresh yield kg/m ²	Dry yield kg/m ²	plant height, cm	leaf number
T1	2.330	0.117	48.40	27
T2	10.587	0.628	52.55	29
T3	7.090	0.351	49.75	32

Like those of plant dry matter yield, the tallest plants were obtained with T2. It could be explained that salinity level provides more nutrients availability when compared with other water treatments. In this respect, Al-Maskri *et al.* (2010) reported that plants with control treatment produced highest root and shoot length than plants treated with 50 and 100 mM salt, respectively.

Leaf number doesn't vary significantly as affected by different water treatments. In harmony with that results, Andriolo *et al.* (2005) revealed that number of lettuce leaves was not affected by salinity treatments but this is in contrast to the findings of Ünlükara *et al.* (2008) who found that number of leaves was reduced significantly with increasing salinity levels.

Water Use Efficiency

As shown in Table 4, the highest value of (WUE) was obtained with T2 while the lowest WUE value recorded with T1. Irrigation with T2 was found to be more efficient in producing lettuce plant than irrigation with other water treatments. When used only 1m³ water to produce 39.21 kg of hydroponic lettuce in comparison to 8, 96, and 24.45 kg of produced lettuce in T1, T2, and T3, respectively.

Hydroponic system was found to enhance the efficiency of water use (WUE). In the same direction, Bradley and Marulanda (2000) reported that hydroponic vegetables production technique requires only about 10-20% of the water required to produce the same amount of crop in soil culture. While Al-Karaki (2010) mentioned that, only 3-5% of water is needed to produce the same amount of plants in comparison to those produced under field conditions. Producing lettuce under hydroponic conditions is a highly efficient process in term of water saving when compared to field production. Gonnella *et al.* (2003) found that water consumption was near to 80 L/m² regardless of plant density, while WUE resulted on average 3.5 g of leaf dry matter produced per liter of water consumed.

This is a tremendous improvement in WUE and indicated that hydroponic system could play a significant role in improving water use efficiency in Egypt and other countries in the region with shortage in irrigation water.

Lettuce Quality

Mineral nutrient content in lettuce

Minerals have a major nutritional significance for human beings and feed deficiencies in elements, such as N, P, K, Ca, Cu, Fe, Zn and Mn can lead to a variety of health problems (Liu *et al.*, 2007). Concentration of nutrient elements analyzed in dry lettuce is presented in Table 5. There were obvious differences in concentrations of the analyzed elements (N, P, K, Ca, Cu, Fe, Zn and Mn) between plants irrigated with ADW and those irrigated with fresh water or mixed one. The short growing period of lettuce under hydroponic dependency on its own reserved compounds for the early growing stages may be attributed to the high variations of mineral nutrients in the produced lettuce irrigated with ADW and fresh water. The nutrient requirements of the seedlings after germination are quite low and partially satisfied from the reserved compounds in the seeds (Bewley, 1997).

The high concentrations of macro nutrients N, P, K and Ca in dry matter of lettuce irrigated with T3 might be due to their high nutrient concentrations. This might indicate that the nutrient solution concentrations affected the nutrient uptake by lettuce plant. Samarakoon *et al.* (2006) showed that, increasing nutrient concentration above EC level 2 dS/m, increased nutrients (N, P, K, Ca) uptake by lettuce plant.

On the other hand, all micro nutrient except for Cu, were high in plants irrigated with T2. This may be attributed to high dry weight value induced by T2. Generally, the contents of essential minerals were available in the produced lettuce around their usual level, thus, ADW can be used for irrigation when mixed with fresh water in ratio of (50%:50%) (T2) under hydroponic conditions without any adverse effects.

Heavy metal content in lettuce plant

Crops irrigated with ADW usually contain elevated levels of heavy metals (specifically Cd, Ni, Cr and Pb) which might accumulate in plants and cause toxic effects on human being (Adriano, 2001). In this study, heavy metals (Cd, Ni, Cr and Pb) concentrations in lettuce were higher in plants irrigated with T2 than other water treatments (Table 6). This may be due to dry matter accumulation effect. These are below the limits set by WHO and FAO for leafy vegetables and fresh herb (WHO/FAO, 2007).

Table 4. Total water applied for lettuce and water use efficiency

Water treatments	Water consumption m ³ /m ²	Fresh matter Kg/m ²	Water use m ³ /kg fresh matter	Water use efficiency kg fresh matter/m ³
T1	0.26	2.330	0.112	8,96
T2	0.27	10.587	0.026	39.21
T3	0.29	7.090	0.041	24.45

Table 5. The uptake of mineral nutrients by lettuce plant produced under hydroponic conditions and irrigated with different water treatments (dry matter basis)

Water treatment	N	P	K	Ca	Cu	Fe	Zn	Mn
mg plant ⁻¹								
T1	94.25	11.25	144.64	30.56	0.27	24.99	1.457	1.278
T2	281.42	31.91	507.99	80.77	0.87	56.223	3.338	2.097
T3	479.07	34.53	636.45	172.58	1.11	37.42	2.746	1.378

Table 6. The concentration of heavy metals (mg plant⁻¹) in lettuce plant produced under hydroponic conditions and irrigated with different water treatments

Water Treatment	Cd	Ni	Cr	Pb
mg plant ⁻¹				
T1	0.14908	0.572	0.806	0.12399
T2	0.16615	1.212	2.136	0.14821
T3	0.09189	1.114	1.407	0.10373
Safe limits in plants (vegetative parts)(mg/l)	0.2 [†]	1.5 [†]	20 [†]	5.0 [†]

[†] according to WHO/FAO (2007)

Conclusions

Nutrient Film Technique (NFT) Hydroponic system is a potential technique for lettuce production with less water consumption where water is the main limiting factor for agricultural production. Agricultural drainage water (ADW) is a feasible source for irrigation of hydroponically produced lettuce. The current study shows the superiority of (T2) ADW mixed with fresh water in ratio 0.5/0.5 irrigated lettuce over that irrigated with other water treatments in several aspects related to

production and quality of the produced lettuce crop. This indicated that ADW is a good source of nutrients needed for plant growth to promote optimum yields when mixed with fresh water in ratio of 0.5/0.5. The accumulation of heavy metals in the lettuce plants irrigated with ADW was apparent, yet below FAO accepted limits. The use of ADW in hydroponic systems may reduce the risk of heavy metal accumulation in the soil with prolonged use. It is also considered an environmentally sound waste water disposal practice compared to direct disposal into surface or underground water bodies.

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استخدام مياه الصرف الزراعي في إنتاج الخس في نظام الغشاء الرقيق من الزراعة المائية

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يعتبر استخدام مصادر المياه البديلة مثل مياه الصرف الزراعي في إنتاج المحاصيل (مثل الخس) مهما جدا وذلك بسبب نقص مياه الري وخصوصا في المناطق الجافة وشبه الجافة مثل مصر، بالإضافة إلى ذلك أصبح إنتاج الخس بالزراعة المائية شائعا في عدة مناطق من العالم لما لهذه التقنية من أهمية في إنتاج نبات الخس بكميات كبيرة وبأقل استخدام للمياه، يهدف هذا البحث إلى دراسة تأثير الري بمياه الصرف الزراعي على إنتاجية الخس وجودته وكفاءة استخدام الماء بالمقارنة مع الري بالمياه العذبة والمخلوطة، تم استخدام ٣ تركيزات خلط من مياه الصرف الزراعي مع المياه العذبة: م، (١٠٠% مياه صرف زراعي) وم (٥٠% مياه صرف زراعي + ٥٠% مياه عذبة) وم (١٠٠% مياه عذبة)، تم تطوير نظام الغشاء الرقيق من الزراعة المائية ويحتوى على ٣ انابيب بي في سى وأضيف المحلول المغذى بمعدلات: ١٢,٥%، ٥٠%، ١٠٠% من المحلول المغذى القياسى وذلك للمعاملات م^١، م^٢، وم^٣ على الترتيب لاستخدامه في هذه الدراسة. تم حصاد الخس بعد ٥٠ يوم من الزراعة، أظهرت النتائج أن استخدام مياه الصرف الزراعي كان لها تأثير فعال في إنتاج الخس والذي بلغ ٢,٣٣، ١,٥٨٧، ٧,٠٩٠ كجم/م^٢ تحت ظروف الري ب م^١، م^٢، وم^٣ على الترتيب وكان أعلى إنتاج للخس مع م^٢ < م^١ < م^٣ على الترتيب وذلك قد يرجع إلى درجة الملوحة المناسبة والتي أدت إلى إتاحة القيمة العالية من النيتروجين بمياه الصرف الزراعي، وكذلك فإن النتائج أظهرت أن الري بمياه الصرف الزراعي المخلوطة مع المياه العذبة بنسبة ٥٠% : ٥٠% (م^٢) أدت إلى زيادة كفاءة استخدام المياه حيث كانت كفاءة استخدام المياه ٩,٠٤٩، ٣٩,٢١٥، و ٢٤,٤٥١ كجم/م^٢ تحت ظروف الري ب م^١، م^٢، وم^٣ على الترتيب، عند تحليل قيم العناصر المغذية في المادة الجافة للخس (نيتروجين، فسفور بوتاسيوم، كالسيوم) وجدت بتركيز عالى في النباتات المروية ب م^٢ عنها في النباتات المروية بمعدلات المياه الأخرى، ويرجع ذلك إلى تأثير إضافة المحلول المغذى بمعدل ١٠٠% مع م^٣، والعناصر الثقيلة (كاديوم، رصاص، نيكل، كروميوم) كانت أعلى في م^٢ عنها في النباتات المروية بأنواع المياه الأخرى، ولكن لم يتعدى الحدود المسموح بها طبقا لمنظمة الأغذية والزراعة للمحاصيل التي تؤكل، يمكن تلخيص نتائج هذه الدراسة في إمكانية استخدام مياه الصرف الزراعي بخلطها مع المياه العذبة بنسبة ٥٠% : ٥٠% (م^٢) في نظام الغشاء الرقيق من الزراعة المائية بأمان لتحقيق منتج عالى من حيث الكمية والجودة لنبات الخس مع تحقيق أعلى كفاءة لاستخدام المياه باستهلاك أقل للمياه.

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