International Journal of Plant & Soil Science
3(6): 644-658, 2014; Article no. IJPSS.2014.6.009

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Reuse of Drainage Water of Fish Ponds in Soybean Cultivation under Sprinkler Irrigation System

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Conference Proceeding Full Paper

Received 13th December 2013
Accepted 22nd February 2014
Published 19th March 2014

ABSTRACT

Nowadays the limited water resources in Egypt lead to use the drainage water effluent in agriculture, particularly in reclaimed desert land which inherently deficient in organic matter, nutrient and trace elements. Therefore the aim of this study is maximizing benefits from drainage water of fish ponds in irrigation of soybean crop and using it as new water recourse. Two field experiments were carried out during growing seasons 2012 and 2013, in research farm of National Research Center (NRC), Nubaryia province, Egypt to study the effect of fertigation rates and using drainage water of fish ponds in irrigation of soybean. Study factors were water quality (traditional irrigation water "TW" and drainage water of fish ponds "DWFP") and fertigation rate "FR" (25%, 50%, 75% and 100% from recommended dose from NPK).The following parameters were studied to evaluate the effect of study factors :(1) Calculating the lost amount of wastewater of fish ponds per season without any benefit. (2) Growth characters (3) Yield (4) Irrigation water use efficiency of soybean "$IWUE_{soybean}$" and (5) Oil and protein content. Statistical analysis of the effect of the interaction between study factors on growth, yield, irrigation water use efficiency of soybean and oil and protein content indicated that, maximum values were obtained for yield, IWUE, oil and protein content of soybean under DWFP x $FR_{100\%\ NPK}$, also indicated that, there were no significant differences under DWFP x $FR_{100\%\ NPK}$ >

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Note: Full paper submitted at the First International Conference on "Food and Agriculture: New Approaches" held in the National Research Centre, Cairo, Egypt from December 2 to 4, 2013.

DWFP x $FR_{75\%\ NPK}$ this means that, using drainage water of fish ponds as a new source for irrigation will save traditional irrigation water and save 25% from minerals fertilizers under sprinkler irrigation system.

Keywords: Drainage water of fish ponds, fertigation rates, soybean crop, sprinkler irrigation system, oil and protein content of soybean.

1. INTRODUCTION

Many countries have included wastewater reuse as an important dimension of water resources planning. In the more arid areas of the world, wastewater is used in agriculture, releasing high quality water supplies for potable use. Recycling the drainage water (DW) of fish farming, rich with organic matter for agriculture use can improve soil quality and crops productivity [1], reduce the total costs since it decreases the fertilizers quantity use, which demand became affected by the prices and the framer's education [2]. Meanwhile, organic matter content of DW of fish supports the cation exchange process in soils, which is important to the nutrition of plants [3]. Aquaponics is the combined culture of fish and plants in recirculating systems. Nutrients, which are excreted directly by the fish or generated by the microbial breakdown of organic wastes, are absorbed by plants cultured hydroponically (without soil). Fish feed provides most of the nutrients required for plant growth. As the aquaculture effluent flows through the hydroponic component of the recirculating system, fish waste metabolites such as ammonia is removed by nitrification and direct uptake by the plants, thereby treating the water, which flows back to the fish-rearing component for reuse. [4]. Minimizing water exchange reduces the costs of operating aquaponic systems in arid climates and heated greenhouses where water or heated water is a significant expense. Having a secondary plant crop that receives most of its required nutrients at no cost improves a system's profit potential. The daily application of fish feed provides a steady supply of nutrients to plants and thereby eliminates the need to discharge and replace depleted nutrient solutions or adjust nutrient solutions as in hydroponics. The plants remove nutrients from the culture water and eliminate the need for separate and expensive bio-filters. There is a growing body of evidence that healthy plant development relies on a wide range of organic compounds in the root environment. These compounds, generated by complex biological processes involving microbial decomposition of organic matter, include vitamins, auxins, gibberellins, antibiotics, enzymes, coenzymes, amino acids, organic acids, hormones and other metabolites. Directly absorbed and assimilated by plants, these compounds stimulate growth, enhance yields, increase vitamin and mineral content, improve fruit flavor and hinder the development of pathogens. Various fractions of dissolved organic matter (e.g., humic acid) form organo-metallic complexes with Fe, Mn and Zn, thereby increasing the availability of these micronutrients to plants [5]. Studying the effect of irrigation systems, fertigation rates and using the wastewater of fish farms to irrigate potato. Study factors were irrigation systems (sprinkler irrigation system "SIS" and trickle irrigation system "TIS), water quality (traditional irrigation water "TIW" and wastewater of fish farms "WWFF") and fertigation rates "FR" (20%, 40%, 60%, 80% and 100% from recommended dose from NPK). Statistical analysis of the effect of the interaction between study factors on yield, irrigation water use efficiency indicated that, maximum values of yield were obtained under SIS x $FR_{100\%\ NPK}$ x WWFF, also indicated that, there were no significant differences for yield values under the following conditions: SIS x $FR_{100\%\ NPK}$ x WWFF > SIS x $FR_{80\%\ NPK}$ x WWFF > SIS x $FR_{60\%\ NPK}$ x WWFF > TIS x $FR_{100\%\ NPK}$ x TIW this means that, using wastewater of fish farms in the irrigation can save at least 40% from mineral fertilizers and irrigation water under sprinkler irrigation system. They mentioned also, yield of potato was decreased under

WIT more than WWFF this may be due to available dissolved elements and increasing of bio-components in WWFF than in WIT [6]. Objective of this study is reuse of drainage water of fish ponds in cultivation of soybean and use it as a new source for irrigation and a bio-source for fertilizing under sprinkler irrigation system.

2. MATERIALS AND METHODS

2.1. Site Description

Field experiments were conducted during two growing seasons from May to Sep. of 2012–2013 at the experimental farm of National Research Center, El-Nubaria, Egypt (latitude 30.8667N and longitude 31.1667E and mean altitude 21 m above sea level). The experimental area has an arid climate with cool winters and hot dry summers prevailing in the experimental area. The monthly mean climatic data for the two growing seasons 2012 and 2013, for El-Nubaria city, are nearly the same. The data of maximum and minimum temperature, relative humidity and wind speed were obtained from "Central Laboratory for Agricultural Climate (CLAC)" as shown in Table 1.

Table 1. Summarizes the monthly mean climatic data for the two growing seasons 2010 and 2011, for El-Nubaria city

Date	Precipitation [mm]	Air temperature [°C]			Relative humidity [%]
	Sum	Average	Minimum	Maximum	Average
May/2012	0.0	21.4	15.4	28.8	66.1
Jun/2012	0.0	26.3	19.7	30.5	68.6
Jul/2012	0.18	26.63	20.62	33.19	73.17
Aug/2012	0.11	26.4	20.5	32.8	72.5
Sep/2012	0.16	26.06	18.05	32.22	75.13
May/2013	0.05	22.46	15.65	30.72	74.81
Jun/2013	0.0	25.3	19.6	31.9	80.6
Jul/2013	0.12	28.7	21.1	33.8	80.1
Aug/2013	0.0	27.5	21.7	34.1	78.7
Sep/2013	0.00	24.99	19.34	31.51	81.24

2.2 Estimation of the Seasonal Irrigation Water for Soybean

Seasonal irrigation water was estimated according to the meteorological data of Central Laboratory for Agricultural Climate (CLAC) according to Penman-Monteith equation shown in Fig. 1 the volume of applied water increased with the growth of soybean (Giza 111) then declined at the end of the growth season. The seasonal irrigation water applied was found to be 3536 m^3/fed./season for sprinkler irrigation system.

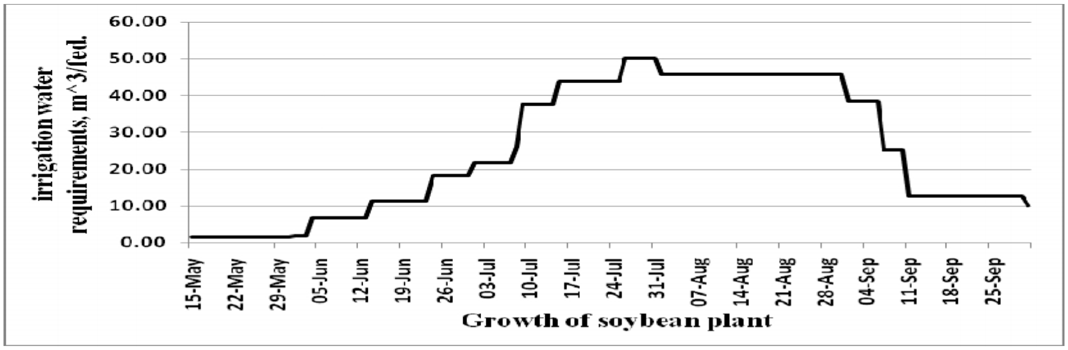


Fig. 1. The relation between growth of soybean plant and irrigation water requirements

Hectare =2.4 fed. fed. =4200 m^2

2.3 Some Physical and Chemical Properties of Soil and Irrigation Water

Some Properties of soil and irrigation water for experimental site are presented in (Tables 2,3 and 4).

Table 2. Some chemical and mechanical analyses of soil study site

Depth	Chemical analysis				Mechanical analysis, %			Texture
	OM (%)	pH (1:2.5)	EC (dSm^{-1})	$CaCO_3$ %	Course sand	Fine sand	Clay +Silt	
0-20	0.65	8.7	0.35	7.02	47.76	49.75	2.49	Sandy
20-40	0.40	8.8	0.32	2.34	56.72	39.56	3.72	
40-60	0.25	9.3	0.44	4.68	36.76	59.40	3.84	

OM= organic matter. pH= power of hydrogen EC= Electrical Conductivity

Table 3. Characteristics of soil study site

Depth	SP (%)	F.C (%)	W.P (%)	A.W (%)	Hydraulic conductivity (cm/hr)
0-20	21.0	10.1	4.7	5.4	22.5
20-40	19.0	13.5	5.6	7.9	19.0
40-60	22.0	12.5	4.6	7.9	21.0

S.P. = saturation point, F.C. = field capacity, W.P. = wilting point and A.W. = available water.

Table 4. Some chemical characteristics of used irrigation water in the open channel at farm study site

pH	EC (dSm^{-1})	Cations and anions (m. equivalent /L)								SAR%
		Cations				Anions				
		Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	CO^{-}_3	HCO^{-}_3	Cl^{-}	SO^{-}_4	
7.35	0.41	1	0.5	2.4	0.2	--	0.1	2.7	1.3	2.8

pH= power of hydrogen EC= Electrical Conductivity SAR= Sodium Adsorption Ratio,

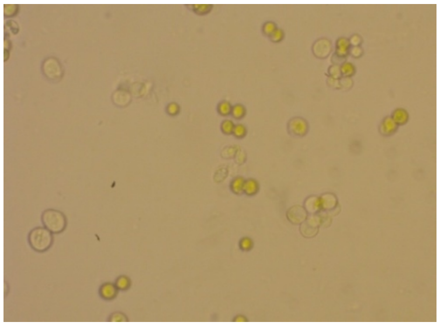
2.4 Chemical and Biological Description of Drainage Water of Fish Farm

The data aforementioned in Table 5 showed that, the EC was 1.82 ds/m, pH was 7.02. Also, the results in Table 5 showed that Chromium, Copper, Nickel, Zinc, total Nitrogen as N, Phophorus as P, Potassium and Sodium reached 0.0, 0.33, 0.0, 1.1, 4.79, 10.2, 35 and 205 ppm respectively. The data mentioned above showed quantitative fertigation capacity of the drainage water of fish farm under study to be used as irrigation water. Drainage water of fish farm could supply the soil seasonally with 13.637 kg of nitrogen/Fed of the whole quantities of irrigation water used by sprinkling method, that are equivalent to 80.65 kg of ammonium sulphate fertilizer (21% N). Also, fish drainage water under search could supply seasonally the soil with 29.039 kg of phosphorus that are equivalent to 435.95 kg of superphosphate fertilizer (8.25% P). Quantitative estimation of bacteria and fungi: The data aforementioned in Table 6 showed that, the total counts of bacteria reached $1.5X10^4$ CFU/ ml; also total counts of free N_2 bacterial fixers determined by Ashby's medium [7] were 600 CFU/ml however the total count of faecal coliform was $3X10^2$ CFU/ ml. On the other hand, total counts of fungi reached 500 CFU/ ml. The possible counts of total counts of bacteria in domestic drainage water reached between 10^3 to 10^5 CFU/ml and also, the Coliform group of bacteria comprises mainly species of the genera Citrobacter, Enterobacter, Escherichia and Klebsiella and includes Faecal Coliforms, of which Escherichia coli is the predominant species were 10^2. Several of the coliforms are able to grow outside the intestine, especially in hot climates; hence their enumeration is unsuitable as a parameter for monitoring drainage water reuse systems. The Faecal Coliform test may also include some non-faecal organisms which can grow at 44°C, so the E. coli count is the most satisfactory indicator parameter for wastewater used in agriculture. Quantitative estimation of phytoplankton: The morphological studies using a light microscope were done on the water samples under estimation. Water samples showed various phytoplankton structures belonging to two main groups, namely, Chlorophyceae (Green Algae) and Cyanophyceae (Blue-Green Algae). The general distribution of phytoplankton is demonstrated in Table 6. It may be important to note that genera, chlorella, Pediastrum and Scenedesmus as green algae were detected, whereas, Oscillatoria and Nostoc represented the most abundant genera of cyanobacteria in the investigated samples. The algal biomass contains nutrients such as C, N, P, k and some trace elements essential for microorganism development. The general microalgae biochemical structure has been successfully utilized as feedstock for digesters and as nutrient supplements in dairy farming. Algae biomass components such as protein, carbohydrates, poly-unsaturated fatty acids, are rich in nutrients vital for development of fish and shellfish consumption and other aquatic microorganisms as shown in Fig. 4.

Table 5. Some physical and chemical determinations of drainage water of fish farm study site

Physical Determinant		Value
EC		1.82 dsm^{-1}
pH		7.02
Chemical elements:		
Chromium	Cr	0.0 ppm
Copper	Cu	0.33 ppm
Nickel	Ni	0.0 ppm
Zinc	Zn	1.1 ppm
Nitrogen	N	4.79 ppm
Phosphorus	P	10.2 ppm
Potassium	K	35 ppm
Sodium	Na	205 ppm

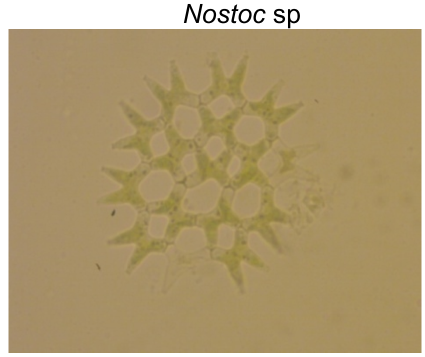
pH= power of hydrogen EC= Electrical Conductivity



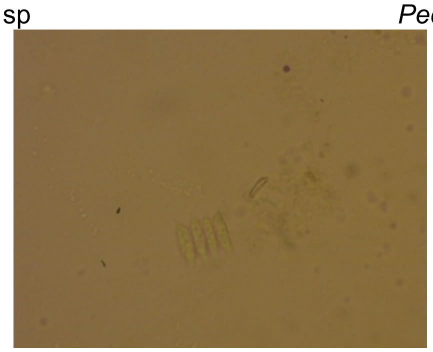
Chlorella sp

Nostoc sp

Oscillatoria sp



Pediastrum sp



Scenedesmus sp

Fig. 4. Types of algae found in the drainage water of fish ponds such as *Chlorella* sp, *Nostoc* sp, *Oscillatoria* sp, *Pediastrum* sp and *Scenedesmus* sp

2.4 Experimental Design

Irrigation system components consisted of a control head and a pumping unit. It consisted of submersible pump with 45 m^3/h discharge driven by electrical engine back flow prevention device, pressure regulator, pressure gauges, flow-meter and control valves. Main line was of PVC pipes with 110 mm in diameter (OD) to convey the water from the source to the main control points in the field. Sub-main lines were of PVC pipes with 75 mm diameter (OD) connected to the main line. Manifold lines: PE pipes was of 63 mm in diameter (OD) were connected to the sub main line through control valve 2`` and discharge gauge. Layouts of experiment design consisted of two irrigation systems. Sprinkler is a metal impact sprinkler 3/4" diameter with a discharge of 1.17 m^3h^{-1}, wetted radius of 12 m and working pressure of 250 kPa (Kilopascals) and the source of wastewater of fish farm collected from 12 pond (5m *5m *2m depth) are shown in Fig. 2.

Table 6. Determination of total bacterial, fungal and some algal counts in drainage water of fish farm study site

Biological Determinant	Counts as CFU/ml
Total counts of bacteria	$1.5X10^4$
Total count of faecal coliform	$3X10^2$
Total counts of fungi	500
Total counts of free N_2 fixers	600
Green algae:	
Chlorella sp. Count	400
Scenedesmus sp. Count	150
Pediastrum sp. Count	120
Cyanobacteria:	
Oscillatoria sp. Count	100
Nostoc sp. Count	50

CFU= Colony Forming Units

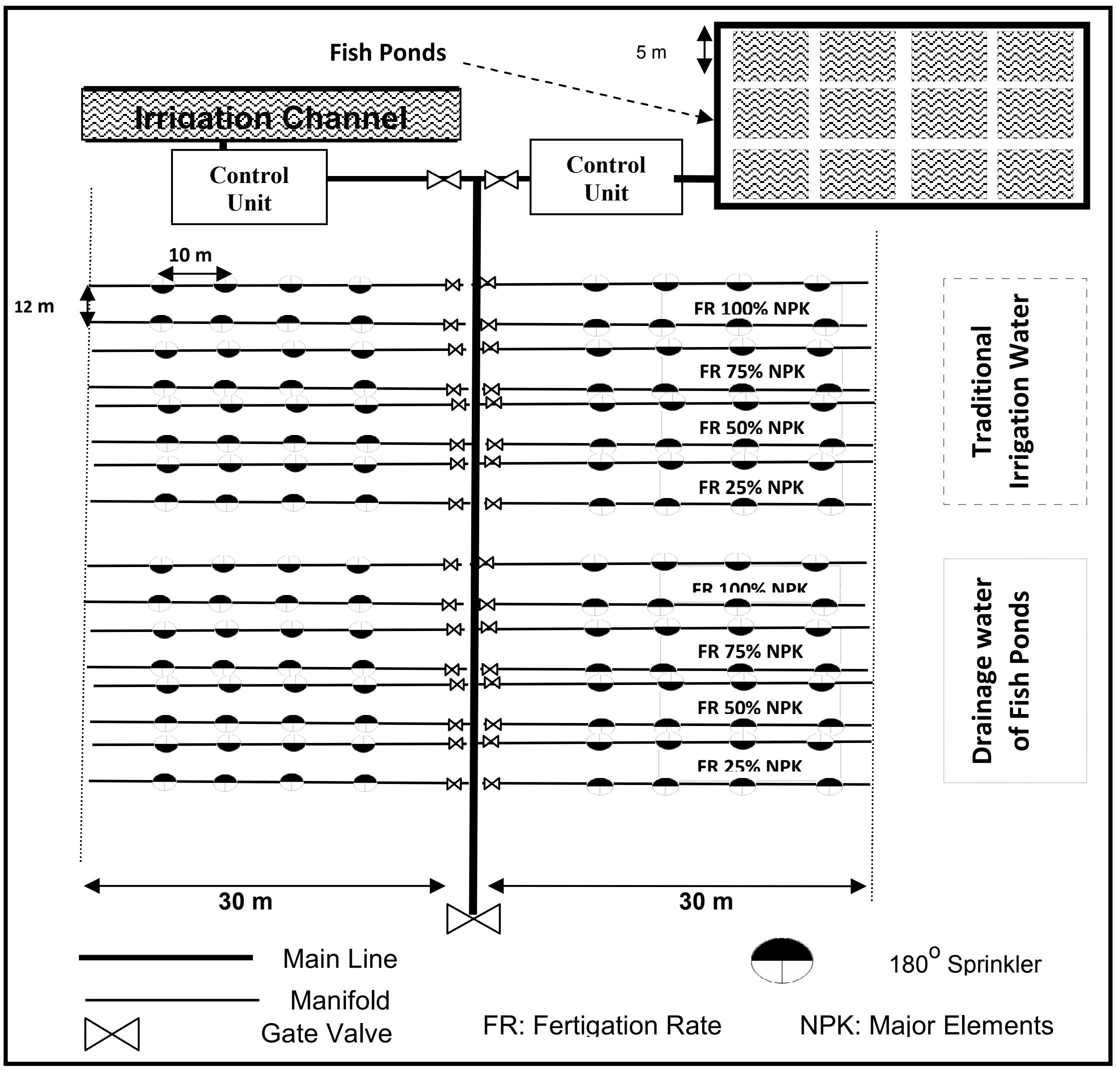


Fig. 2. Layout of Experiment Design

2.5 Fertigation Method

Phosphate fertilizer was added before planting (during processing) and during plantation services at a rate of 300 kg super phosphate monobasic 15% $P_2 O_5$. 20 units nitrogen per fed. As a booster dose of nitrogen fertilizer was added at planting time. Also, a dose of 50 kg of potassium sulfate per fed. was added before planting (info-unit@caae-eg.com, 2011).

2.6 Methods

Sampling Site Description: wastewater for fish farm samples were collected at the outlet of water basin used for fish breeding and production. Physico Chemical Characters of wastewater for fish farm: The physicochemical characteristics were carried out according to [8] and [10] pH, EC, N, P, K and potential toxic elements (Cu, Zn, Pb… etc.).

Biological Parameters**:** All microorganisms were counted on their specific count media and incubation temperature of 30ºC except faecal coliform group that was incubated on 44º C (1) Total Viable Count of Bacteria: TVCB was determined using the standard plate count method and nutrient agar culture medium according to APHA 1998 [9]. (2) Total count of fungi: was determined using the standard plate count method and Rose-bengal agar culture medium according to [10] (3) Faecal coliform bacteria were counted using MacConkey broth and incubated at 44ºC [11] using most probable number method [12]. (4) Total counts of free N_2 fixers using Ashby's medium [13]. (5) Algae enumeration: The grouping of green algae and blue-green algae were accomplished and counted depending on morphological shape under light microscope using the Sedgwick-Rafter (S-R) cell count chamber according to [9] and then calculated algae counts from the following equation:

$$No./mL= (C*1000\ mm^3) / (L*D*W*S)$$

Where: C = number of organisms counted, L = length of each strip (S-R cell length), mm, D = depth of a strip (S-R cell depth), mm, W = width of a strip (Whipple grid image width), mm, and S = number of strips counted.

Irrigation water use efficiency of Soybean crop ($IWUE_{\text{Soybean crop}}$) was calculated according to [14] as follows: $IWUE_{\textbf{Soybean crop}}$ (kg_{grain} /m^3_{water}) = Total yield, (kg_{grain} /fed.) / Total applied irrigation water, (m^3_{water} /fed./season).

Leaf area = leaf length x maximum leaf width x 0.75 according to [15] and chlorophyll content was estimated by Span device.

Seed oil %: was determined by Soxhelt apparatus using petroleum ether (40-60ºC boiling point) according to [16] and oil yield (kg/fed) was calculated by Seed yield (kg/fed) * Seed oil (%).

Total N- content in seeds determined and protein% was calculated by multiplying N-content by 6.25 according to [17], proteins yield/fed. Calculated by multiply protein% x seed yield/fed.

2.5 Statistical Analysis

The standard analysis of variance procedure of split plot design with three replications as described by [18] was used. All data were calculated from combined analysis for the two growing seasons 2012 and 2013. The treatments were compared according to L.S.D. test at 5% level of significance.

3. RESULTS AND DISCUSSION

3.1 Calculating the Lost Amount of Drainage Water of Fish Ponds per Season without Any Benefit

To calculate the total amount of drainage water of fish ponds in Nubaria farm experiment, the volume of water discharged per week should be calculated as follow: There are 12 ponds in the fish farm, the dimensions of each basin are 5 m * 5 m * 2 m, however the depth of the actual exchange is 1.5 m and therefore the size of the outgoing water per week = 5 * 5 * 1.5 * 12 basin = 450 m^3 of water weekly. The total volume of waste water of the fish farm under search during the soybean growing season (19 week) = 19 * 450 = 8550 m^3 /season of water as shown in Fig. 3 represents about 241% of soybean necessary irrigation water per season.

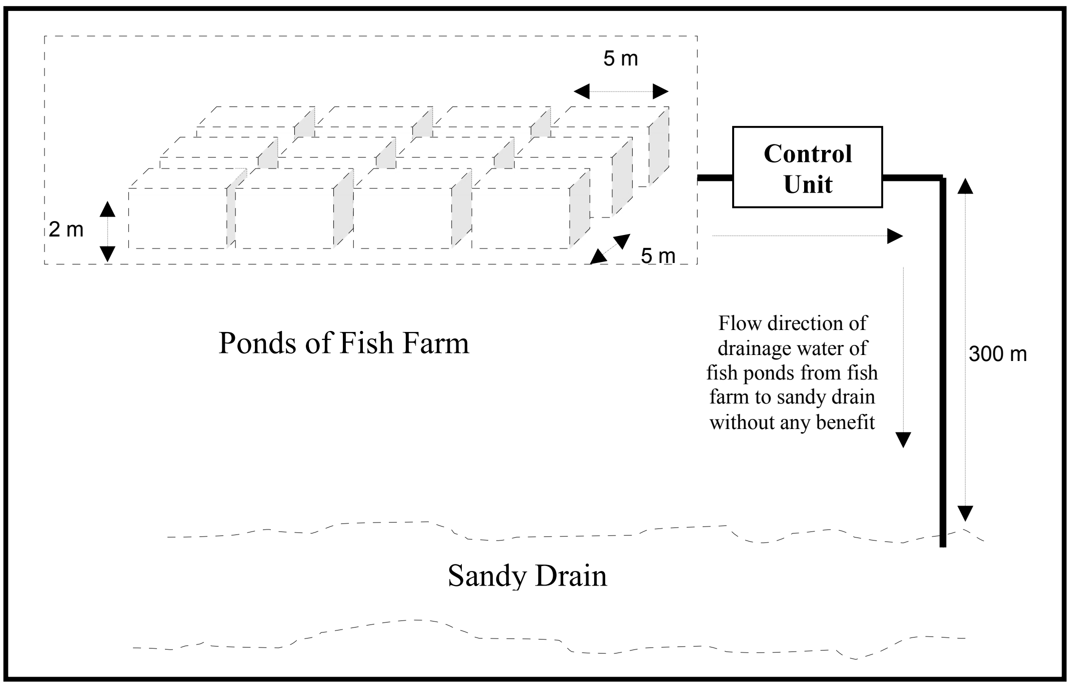
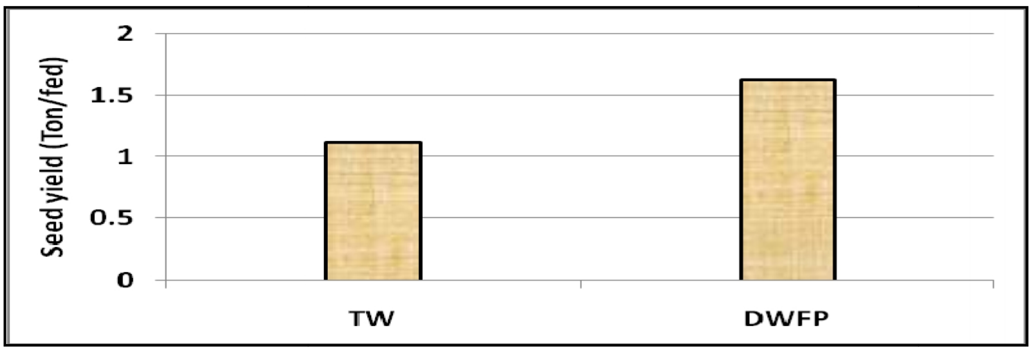


Fig. 3. Lost amount of drainage water of fish ponds per season

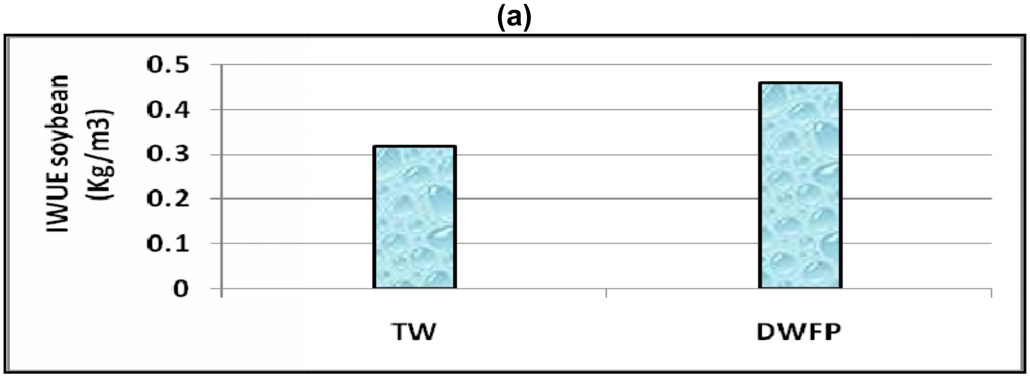
3.2 Effect of Drainage Water of Fish Ponds and Fertigation Rates on Growth, Yield, Irrigation Water Use Efficiency, Oil and Protein Content of Soybean

3.2.1 Effect of drainage water of fish ponds on growth, yield, irrigation water use efficiency, oil and protein content of soybean

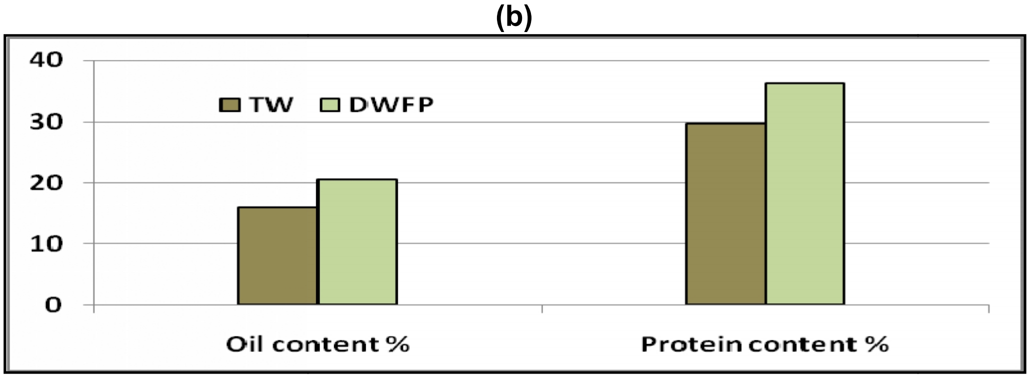
Table 7 and Figs. (5a, 5b, 5c) showed that, there are significant positive effect from drainage water of fish ponds on growth, yield, irrigation water use efficiency, oil and protein content of soybean which was may be due to increasing of nutrient elements such as N, P, K and Zn and biological produced components in DWFP that showed in the last mentioned chemical and biological analysis (Tables 5 and 6) than in TW; that means, healthy growth hence, improving the yield of soybean, increasing of irrigation water use efficiency and improving in soybean quality traits. This result was in agreement with [6], [4] and [1].In conclusion, increasing in growth parameters comes from increasing of dissolved nutrient elements and biological components in DWFP compared with TW and increasing in yield comes from healthy growth and increasing in IWUE comes from increasing in yield under applying the same amount of irrigation water and the improvement of quality traits Due to the same reason.



(a)



(b)



(c)

Fig. 5. Effect drainage water of fish ponds on (a) yield, (b) irrigation water use efficiency *"IWUE",,* (c) oil and protein content of soybean

TW= traditional irrigation water DWFP= drainage water of fish ponds

3.2.2 Effect of fertigation rates on growth, yield, irrigation water use efficiency, oil and protein content of soybean.

Table (7) and Figs. (6a, 6b, 6c) showed that, there were significant negative effect for decreasing of fertigation rates on growth, yield, irrigation water use efficiency, oil and protein content of soybean, this may be due to decreasing the amount and concentration of mineral fertilizers in the root zone. There are positive relation between yield and increasing of minerals fertilizers up to recommended dose.

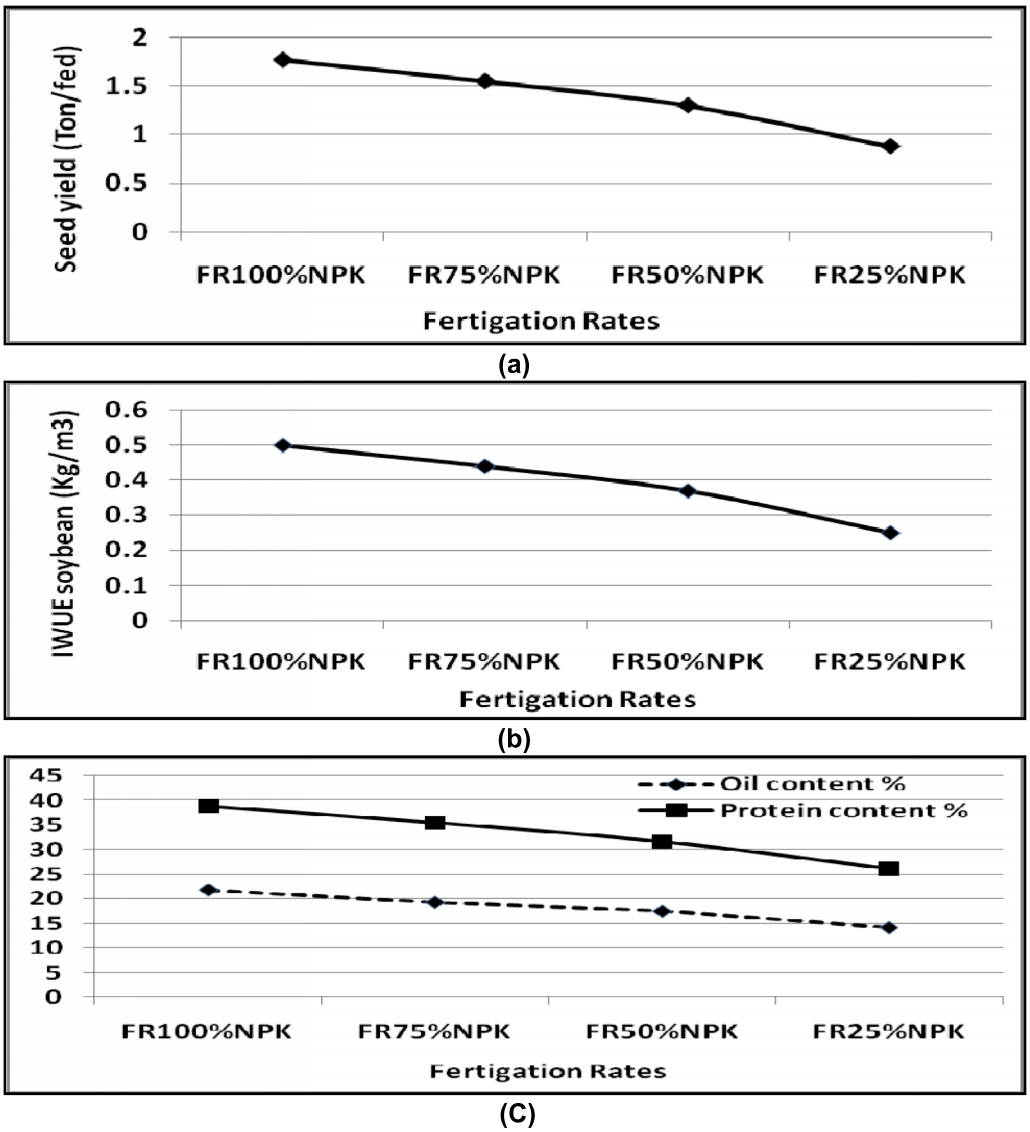
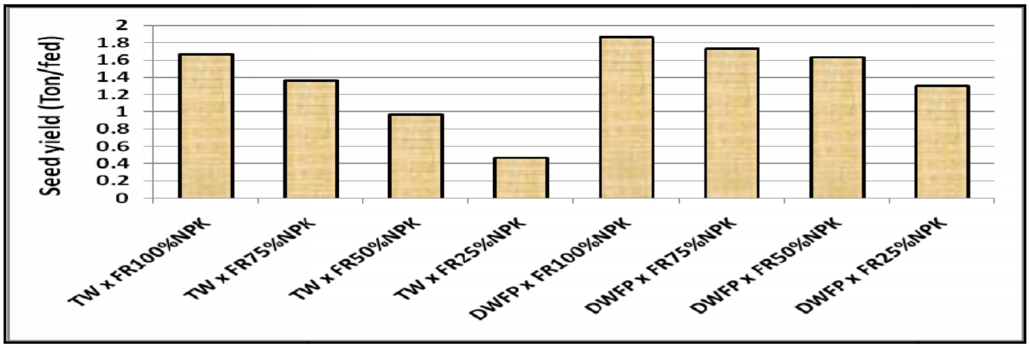


Fig. 6. Effect fertigation rates on (a) yield, (b) irrigation water use efficiency, (c) oil and protein content of soybean

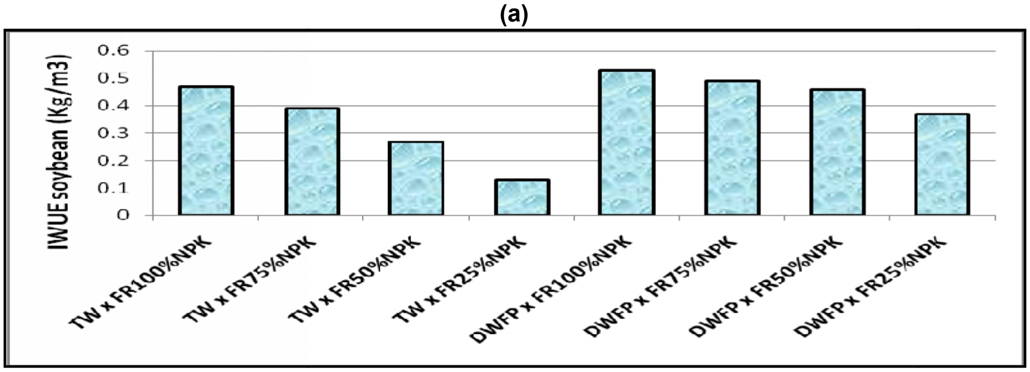
FR=Fertigation Rate IWUE= irrigation water use efficiency

<u>3.2.3 Effect the interaction between drainage water of fish ponds and fertigation rates on growth, yield, irrigation water use efficiency, oil and protein content of soybean</u>

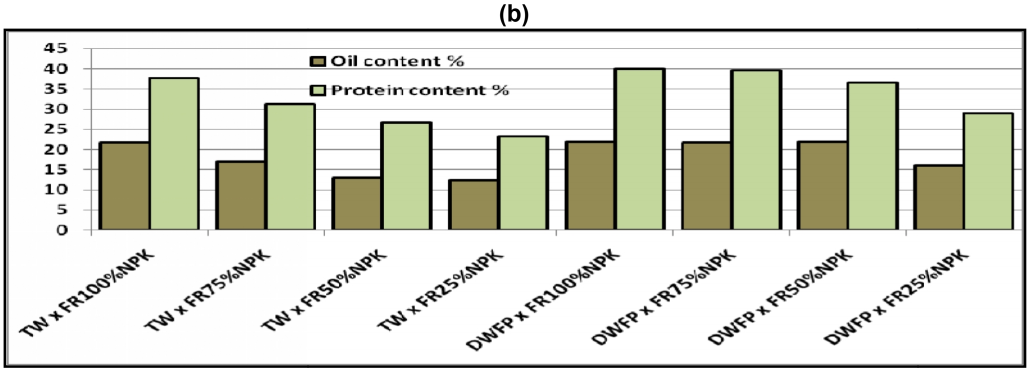
Table (7) and Fig.(7a,7b,7c) showed that, the Effect of the interaction between drainage water of fish ponds “DWFP” and fertigation rates “FR" on growth, yield, irrigation water use efficiency, oil and protein content of soybean. The high growth and yield maximum values were showed in soybean plant. Also, quality traits and IWUE of soybean crop occurred under DWFP x $FR_{100\%NPK}$, however the deference showed as follow: DWFP x $FR_{100\%NPK}$ > DWFP x $FR_{75\%NPK}$ that wasn’t significant. So that, the using of DWFP will save about 100% of conventional irrigation water and save about 25% of chemical fertilizers.



(a)



(b)



(c)

Fig. 7. Effect the interaction between drainage water of fish ponds and fertigation rates on (a) yield, (b) irrigation water use efficiency *“IWUE”*, (c) oil and protein content of soybean.
TW= traditional irrigation water DWFP= drainage water of fish ponds FR=Fertigation Rate

Table 7. Effect of drainage water of fish ponds and fertigation rates on growth, yield, irrigation water use efficiency, oil and protein content of soybean (average of two seasons)

Treat	Dry weight/plant (g)		Leaves area/ plant (cm^2)		Chlorophyll content %		Seed yield (Ton/fed)		IWUE soybean (Kg/m^3)		Oil content %		Protein content %	
TW	105.42	b	5191.75	b	33.67	b	1.12	b	0.32	b	16.00	b	29.75	b
DWFP	111.58	a	6139.08	a	40.83	a	1.63	a	0.46	a	20.42	a	36.33	a
LSD at α 0.05 level	4.824		341.500		0.949		0.200		0.056		0.360		2.510	
$FR_{100\%NPK}$	113.83	a	6382.7	a	43.67	a	1.77	a	0.50	a	21.83	a	38.83	a
$FR_{75\%NPK}$	111.33	ab	5990.0	b	39.33	b	1.55	b	0.44	b	19.33	b	35.50	b
$FR_{50\%NPK}$	108.50	b	5527.0	c	36.17	c	1.30	c	0.37	c	17.50	c	31.67	c
$FR_{25\%NPK}$	100.33	c	4762.0	d	29.83	d	0.88	d	0.25	d	14.17	d	26.17	d
LSD at α 0.05 level	3.106		164.2		1.97		0.14		0.04		1.42		2.95	
TW x $FR_{100\%NPK}$	113.67	a	6380.3	a	42.00	b	1.67	ab	0.47	b	21.67	a	37.67	
TW x $FR_{75\%NPK}$	109.00	bc	5596.3	b	35.00	c	1.37	c	0.39	c	17.00	b	31.33	
TW x $FR_{50\%NPK}$	103.67	d	4677.0	c	30.67	d	0.97	d	0.27	d	13.00	c	26.67	
TW x $FR_{25\%NPK}$	95.33	e	4113.3	d	27.00	e	0.47	e	0.13	e	12.33	c	23.33	
DWFP x $FR_{100\%NPK}$	114.00	a	6385.0	a	45.33	a	1.87	a	0.53	a	22.00	a	40.00	
DWFP x $FR_{75\%NPK}$	113.67	a	6383.7	a	43.67	ab	1.73	ab	0.49	ab	21.67	a	39.67	
DWFP x $FR_{50\%NPK}$	113.33	ab	6377.0	a	41.67	b	1.63	b	0.46	b	22.00	a	36.67	
DWFP x $FR_{25\%NPK}$	105.33	cd	5410.7	b	32.67	cd	1.30	c	0.37	c	16.00	b	29.00	
LSD at α 0.05 level	4.39		232.3		2.79		0.20		0.06		2.01		N.S	

TW= traditional irrigation water DWFP= drainage water of fish ponds IWUE=Irrigation Water Use efficiency FR=Fertigation Rate N.S. = Non Significant The means followed by the same alphabetical letters were not significantly different at the probability level of 0.05.

4. CONCLUSION

Limited water resources in Egypt could lead to use the drainage water such as drainage water of fish ponds as a new source for irrigation that will save 100% from traditional irrigation water and save 25% from minerals fertilizers under sprinkler irrigation system.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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The peer review history for this paper can be accessed here:
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