

ECONOMIC VALUATION OF IRRIGATING GREEN BEANS PLANTS WITH AGRICULTURAL DRAINAGE WATER REMEDIATED WITH DHS TECHNOLOGY

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Abstract

A field experiments were conducted at Belbeis, Sharkia governorate, to evaluate the economic impact of irrigating green bean plants with agricultural drainage water remedied with DHS technology. The obtained results showed that agricultural drainage water is reused in Egypt, where it provides about 15% of the country's irrigation needs. The costs of remediating one cubic metre of agricultural drainage water with the DHS technology totaled LE 1.03, and the amounts of remediated agricultural drainage water used to irrigate green beans grown in a soil ecosystem remediated with either microorganisms or clay minerals was reduced by 50% and 28.6% of their treasury, respectively. The net return per feddan under irrigation with remediated agricultural drainage water reached 261 percent over its counterpart irrigated with non-remediated agricultural drainage water, and the cost of each ton produced decreased under irrigation with remediated agricultural drainage water to LE 35,720. This represents 83 % more for plants grown in non-remediated soil ecosystem and irrigated with non-remediated agricultural drainage water. In comparison to its counterpart irrigated with non-remediated agricultural drainage water and grown in non-remediated soil ecosystem or in soil ecosystems remediated with either microorganisms or clay minerals respectively, the profitability of each pound spent on the production of green beans increased in soil ecosystems irrigated with remediated agricultural drainage water by 201, 99, and 126 %. For a non-remediated soil ecosystem, the return on investment per pound spent on remediating agricultural drainage water was LE 5.17; for a non-remediated soil ecosystem treated with microorganisms, LE 9.8; and for a non-remediated soil ecosystem treated with clay minerals, LE 15.58.

Keywords: Agricultural drainage water; DHS; Economic study; Green beans; field experiments.

INTRODUCTION

Agricultural drainage water remediation and management have become a crucial issue worldwide after being listed as one of the goals of sustainable development [Chernicharo 2001]. Agricultural drainage water remediation should be economically evaluated on sustainability concepts [Xu et al 2017] based on economy, environment, and social well-being. The necessity of remediating agricultural drainage water in Egypt is now precarious to cope with the current shortages of water resources and the dynamics of the environmental regulations. The reuse of remediated agricultural drainage water in Egypt has extended its application to energy recovery, reuse and nutrient recycling. The current work was carried out to economically evaluate the use of DHS technology in the remediation of agricultural drainage water used in irrigating green bean plants.

MATERIALS AND METHODS

EXPERIMENTAL

The experimental site at Belbies was ploughed, leveled, and divided into enough numbers of plots with an area of 12.2 m², each containing rows of 3.5×0.7 meters. Green plant seeds (*Phaseolus vulgaris* var Bronco) were got from the Agricultural Research Center, Egypt and sown on the 5th of September. Green beans plants were irrigated with either non-remediated or remediated agricultural drainage water from Belbeis agricultural drain and were grown in three different soil ecosystems, i.e., un-remediated control soil ecosystem, remediated soil ecosystem inoculated with certain microorganisms or furnished with soil conditioners. The experiment was set in split plot design with three replicates. The main plot included the different remediated soil ecosystems. Water treatments were arranged in sub-plot, raw or reclaimed drainage water. All field plots were irrigated every three days or when needed.

REMEDICATION OF POLLUTED ECOSYSTEMS

AGRICULTURAL DRAINAGE WATER ECOSYSTEM

A pilot-scale DHS reactor (Fig 1) was conducted to worth the quality of the drainage water at Rahway agricultural drains under continuous mode and different HRT. The DHS reactor consisted of four segments connected vertically and was randomly filled with sponge media as the packing material. A distributor was set at the top of the DHS reactor. The DHS reactor volume (vessel volume) and the sponge media volumes were 148.4 L and 113 L, respectively, corresponding to sponge media occupancy of 75%. The sponge media is composed of a polyurethane sponge cylinder (33 x 22 mm) packed inside a cylindrical plastic net ring (33 mm diameter, 25 mm length). The sponge media volume was calculated as a cylindrical shape. Finally, a clarifier was set at the bottom of the DHS reactor with a working volume of 25 L. Raw agricultural drainage water samples were monthly collected from Rahway & Belbeis agricultural drains in polyethylene containers (25-L capacity). Drainage water samples were analyzed on the day of their collection to avoid the any biological decomposition of their solids according to the standard methods for wastewater analysis. The investigated parameters included BOD₅, COD, TSS, dissolved oxygen (DO), pH and turbidity. Got results were compared to the water quality criteria specified in Egyptian guidelines (law 48 for 1982).

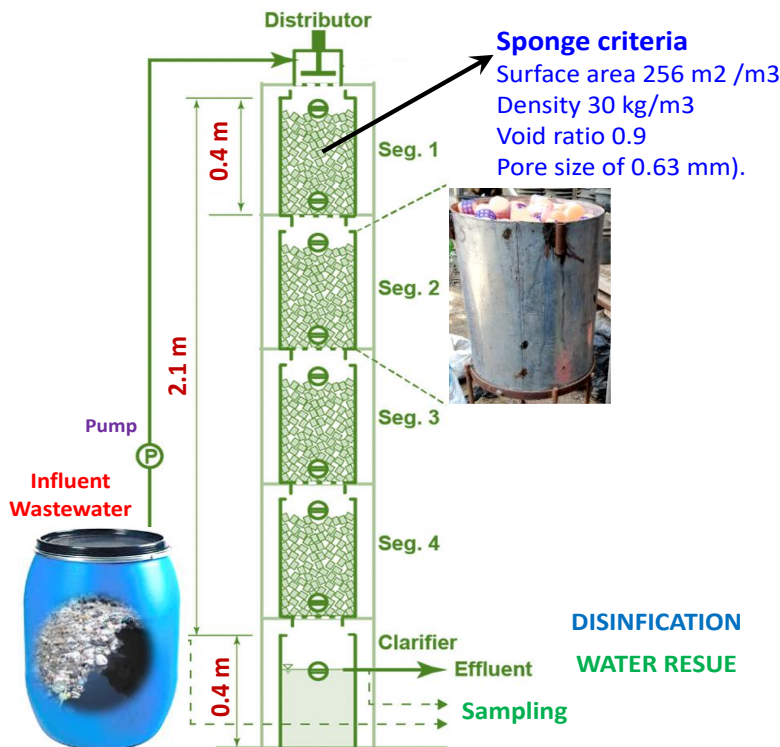


Fig (1) Systematic diagram of down flow hanging sponge system (DHS)

SOIL ECOSYSTEM

Two clay mineral mixtures were used to remediate the soil ecosystem at Rahawy, the first composed of bentonite mixed with elemental sulfur and rock sulfate in a ratio of 1:1:1, and the second is composed of equal proportions of bentonite, kaolinite, Aswan clay, and Ball clay mixed in equal portions (Wahba and Zaghloul, 2007; Zaghloul and Saber, 2019; Saber et al., 2019).

MICROBIAL CULTURE COLLECTION

A microbial culture collection was established for the sake of preserving the isolated remediative microorganisms. The microorganisms were preserved in the form of lyophilized strains. The following microorganisms were isolated and used to remediate the traileed soil the ecosystem, *Acidithiobacillus ferrooxidans*, *Acidithiobacillus thiooxidans*, *Acinetobacter* sp., *Bacillus megatherium* var *phosphaticum*, *Trichoderma* sp., *Pseudomonas putida*, *Pseudomonas fluorescence*.

ISOLATION AND CULTIVATION OF MICROORGANISMS:

Acidithiobacillus ferrooxidans: DSMZ medium 882 (Atlas, 2005) was used to isolate and grow *Acidithiobacillus ferrooxidans*. The medium is composed of 959 ml of solution A and 50 ml of solution B and 1.0 ml trace element solution and with a pH value of 1.8. Solution A is composed of 147 g $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$, 132 g $(\text{NH}_4)_2\text{SO}_4$, 53 g $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$, 27 g KH_2PO_4 . Solution A was prepared by dissolving its components in one liter of distilled water and the pH was adjusted to 1.8 with 10 n H_2SO_4 before being autoclaved for 30 min at 112 C and cooled to room temperature. Solution B was prepared by adding 20 g $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ to 50 ml H_2SO_4 (0.25 n) and the pH was adjusted 1.2 before being autoclaved for 30 min at 112 C and cooled to room temperature. The trace element solution is composed of 68 mg ZnCl_2 , 67 mg $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$, 64 mg $\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$, 62 mg $\text{MnCl}_2 \cdot 2\text{H}_2\text{O}$, 31 mg H_3BO_3 and 10 gm Na_2FmoO_4 in one liter of distilled water and adjusted to pH 1.8 before being autoclaved for 30 min at 112 C and cooled to room temperature. DSMZ medium 882 was prepared by aseptically mixing 950 ml of solution A and 50 ml of solution B and 1.0 ml trace elements solution and thoroughly mixed and adjusted to pH 1.8.

The pure culture of the isolated *Acidithiobacillus thiooxidans* pre-incubated in the medium for 3 days was inoculated at 10% (v/v) concentration in a large container containing 4 L of the medium. The container was continuously aerated by compressed air during 8 to 10 days of incubation. The culture was then centrifuged for 3 min to remove residual sulfur. The supernatant was again centrifuged for 20 min and the cells were harvested. After washing the harvested cells with inorganic salt medium, the cells further suspended within the same medium to obtain the concentrated cell suspension, which is used as an inoculum'. To investigate effects of initial pH on the sulfur oxidation rate of the isolate, the pH values of the medium was adjusted to 2, 3, 4, 5, 6, 7 and 8 by 0.2 to 2 M NaOH and HCl solutions. The concentrated cell suspension previously inoculated into the pH-adjusted medium was incubated at 30°C and 180 rpm. Initial optical density (OD) after inoculation was 0.05 at 660 nm. The culture broth (10 ml) was sampled every 1 or 2 days during incubation to determine pH, OD, and sulfate concentrations. When OD of the cell suspension of the isolated bacterium reached 1 at 660 nm, the actual concentration of the microorganisms corresponded to 0.47 g dry cell weight/L₁.

Acidithiobacillus thiooxidans: A pure culture of the sulfur-oxidizing bacterium *Acidithiobacillus thiooxidans*, active in a wide pH range was isolated from soil moistened and enriched with elemental sulfur and incubated at 30°C for 15 days. Five gram portions of the sulphur enriched soil was placed a 250-ml Erlenmeyer flask containing 100 ml of modified Waksman medium (Ryu et al. 1998 and Cho et al., 1999) and incubated for three weeks at 30°C. Modified Waksman medium is composed of 3.0 g/l K_2HPO_4 , 0.1 g/l, $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, 0.3 g/l $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$, 0.01 g/l $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$, and 10 g/l S as an energy source and with a pH of 4. The mixed culture obtained in this enrichment medium was re-inoculated in fresh modified Waksman medium and was again incubated under the same conditions. From the culture broth, 10 ml aliquot was sampled every 7 days during incubation to determine its pH until reaching 2. The obtained cell suspension of *Acidithiobacillus thiooxidans* was used in inoculating the soil irrigated with sewage effluent..

Pseudomonas sp: Vanillate medium (Atlas, 2005) was used to isolate and grow *Pseudomonas* sp. The components of the medium are 1.0 g $(\text{NH}_4)_2\text{SO}_4$, 0.4 g KH_2PO_4 , 0.1 g yeast extract, 0.01 $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, 10 ml trace element solution, 10 ml vanillic acid solution in one liter. The trace element solution contains 0.4g $\text{MnSO}_4 \cdot 4\text{H}_2\text{O}$, 0.5mg H_3BO_3 , 0.4mg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$, 0.2mg FeCl_3 , 0.1mg KI, 0.04 mg $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ in one liter distilled water. The vanillic solution contains 1.5 g vanillic acid per one liter distilled water. The components of Vanillate medium were dissolved in 980 ml distilled water and heated to boiling, autoclaved for 15 min at 1.5 psi pressure at 121 °C and cooled. The vanillic acid solution and trace element solution were warmed to 50-55 °C, then 10 ml sterile solution portion of both vanillic acid solution and trace element solution were aseptically added to the medium and thoroughly mixed.

Acinetobacter sp.: A mineral medium with crude oil (Atlas, 2005) was used to isolate and grow *Acinetobacter* sp. The components of the medium, except crude oil, were weighed and added to one liter distilled water and thoroughly mixed. The medium was autoclaved for 15 minutes at 1.5 psi pressure at 121°C. Five ml portions of filter sterilized crude oil was therefore added and thoroughly mixed with medium. The medium was then inoculated with a soil suspension and incubated at 30 °C for 15 days and microscopically examined every week to follow the growth intensity of the bacterium. The medium is composed of 0.45 g K₂HPO₄, 0.1 g (NH₄)₂SO₄, 0.02 g MgSO₄.7H₂O, 0.01 g NaCl, 0.01g CaCl₂, 0.002 g FeCl₂ and 5 ml crude oil per liter and with a pH of 7.2.

Bacillus megatherium var *phosphaticum*: Phosphate dissolving bacteria (PDB) were isolated on Bunt and Rovira medium (1955) as modified by Lauw and webley (1959). The medium is composed of 0.40 gm KCl, 0.50 (NH₄)₂SO₄, 0.50 gm MgSO₄.7H₂O, 0.01 gm FeCl₃.8H₂O, 0.10 gm CaCl₂, 1.0 gm peptone, 1.0 gm yeast extract, 5.0 gm glucose, 20 gm agar, 250 ml soil extract and 750 ml water and with a pH of 6.8. To 10 ml portions of the melted medium 0.5 ml sterile 10% K₂HPO₄ solution was added and followed by 1.9 ml of sterile 10% CaCl₂ solution and thoroughly mixed directly before pouring in plates. PDB was detected by clear zones, isolated and grown on nutrient broth.

Trichoderma sp.: *Trichoderma* sp was isolated by the method described by Kubicek and Harman (2002) and grown on potato dextrose agar (PDA) medium at at 25-30°C.. The medium is composed of 200 gm portions of potatoes suspension, prepared by boiling 200 gram potions of potato tubers for one hour in one liter of water, sieved, completed to volume one liter and supplemented with 20 gram glucose and 18 g agar. The fungus conidia appeared as compact or loose tufts in shades of green or yellow or less frequently white color with a yellow pigment secreted into the agar (Azin et al 2007).. The main branches of the conidiophores produced lateral side branches that might be paired or not, the longest branches distant from the tip and often phialides arising directly from the main axis near the tip.

CULTIVATION AND FORTIFICATION: All microorganisms used in the bioremediation trails were grown in Bioflo & Celligen fermentor/bioreactor, each in its specific medium, to reach 106 CFU. Each microbial suspension was impregnated on a proper mordant at the rate of 20 ml microbial suspension per 100 gm mordant oven-dried soil. Sewage soils were solely inoculated with a single microorganism at the rate of 100 gm impregnated mordant / 400 gm soil.

RESULTS AND DISCUSSION

In a field experiment carried out at Belbeis site, Sharkia governorate, the effect of irrigation with agricultural drainage water remediated with DHS technology was economically evaluated.

PRODUCTIVE COST STRUCTURE OF GREEN BEAN CROP IRRIGATED WITH REMEDIATED OR NON-REMEDIED AGRICULTURAL DRAINAGE WATER AT BELBEIS

Results illustrated given in Table (1) show the costs of the production of one feddan of green beans at Belbeis region during the season 2021/2022 irrigated with either remediated or non-remediated agricultural drainage water, and grown in remediated or non-remediated soil ecosystems.

Table (1) Measures of economic efficiency of green bean growers in Belbeis region using water of varying salinity for the agricultural season 2020/2021

Treatment	Un-remediated soil			Remediated soil (1)			Remediated soil (2)		
	Drainage water	Reclaimed drainage water	%	Drainage water	Reclaimed drainage water	%	Drainage water	Reclaimed drainage water	%
Seedlings	1250	1250	100	1250	1250	100	1250	1250	100
Chemical fertilizers	2520	2520	100	2520	2520	100	2520	2520	100
Pesticides	2750	2750	100	2750	2750	100	2750	2750	100
Human work	2900	3200	110	3100	3400	110	3200	3500	109
Automatic work	2500	2500	100	2200	1900	86	1950	1600	82

Processing costs	–	2575	–	–	2155	–	–	1860	–
Total variable costs	11920	14795	124	11820	13975	118	11670	13480	116
Rent	2500	2500	100	2500	2500	100	2500	2500	100
Total costs	14420	17295	120	14320	16475	115	14170	15980	113
Irrigation water quantity m ³	2680	2500	93	1950	1750	90	1500	1250	83
Productivity	6.3	9.4	149	9.9	14.2	143	10.6	16.75	158
Total return	19530	35720	183	30690	53960	176	32860	63650	194
Net return	5110	18425	361	16370	37485	229	18690	47670	255
Unit cost	2289	1840	80	1446	1160	80	1337	954	71
Pound profit	0.35	1.07	301	1.14	2.28	199	1.32	2.98	226
Net revenue per unit of water	1.91	7.37	386	8.39	21.42	255	12.46	38.14	306
The profitability of the pound spent on agricultural drainage water remediation	–	5.17	–	–	9.80	–	–	15.58	–

Source: collected and calculated from the data of the research experience in Belbeis area in Giza season 2021/2022

The average value of such costs was higher in plants irrigated with remediated agricultural drainage water compared to those irrigated with non-remediated.

The production cost was 24% higher for plants grown in non-remediated soil ecosystems, and was 18%, 16% higher for plants grown in soil ecosystems remediated with either microorganisms or clay minerals respectively. The increase in costs was estimated at 20%, 15%, and 13% in the case of total costs.

Worthy to state that the amount of remediated irrigation water used in growing green beans was less by 7% compared to that used for non-remediated one and by 10% less for plants grown in a soil ecosystem remediated with microorganisms and by 17% less in soil ecosystem remediated with clay minerals.

Results illustrated in Fig (2) that the decrease in the amounts of remediated agricultural drainage water used in irrigating green beans grown in a soil ecosystem remediated with either microorganisms or clay minerals was less by 50% and 28.6% of their treated counterpart grown in non-remediated soil ecosystem respectively. The costs of remediating agricultural drainage water used in irrigating green beans are estimated at 2575 pounds/feddan when grown in a non-remediated soil ecosystem, and at 2155 pounds/feddan when grown in a soil ecosystem remediated with microorganisms and at 1860 pounds/feddan when grown in a soil ecosystem remediated with clay minerals.

PRODUCTIVITY OF ONE FEDDAN OF GREEN BEANS IRRIGATED WITH REMEDIATED OR NON-REMEDIED AGRICULTURAL DRAINAGE WATER

The productivity of one feddan of green beans irrigated remediated or non-remediated agricultural drainage water is given in Table (1). Such productivity is estimated at 9.4 tons per feddan for plants irrigated with remediated agricultural drainage water with an increase of 49% over its counterpart irrigated with non-remediated agricultural drainage water. The productivity of one feddan of green beans irrigated with remediated agricultural drainage water and grown in a soil ecosystem remediated with microorganisms reached 14.2 tons/feddan which is 43% over its counterpart irrigated with non-remediated agricultural drainage water. The feddan productivity of green beans reached 16.75 tons with an estimated increase of 58% over its counterpart irrigated with non-remediated agricultural drainage water. Got results point to an increase in the feddan productivity of green beans when irrigated with remediated agricultural drainage water compared to its non-remediated counterpart, regardless of the type of soil ecosystem.

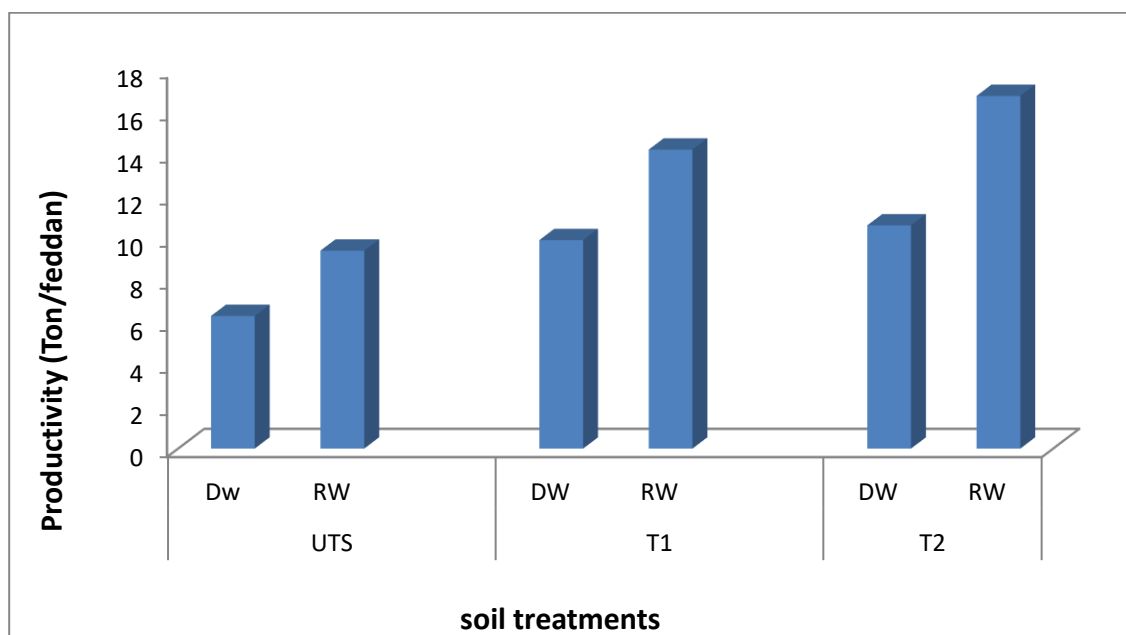


Fig (2): Effect of soil treatments and type of water applied on productivity of green bean plants

ECONOMIC EFFICIENCY OF GREEN BEAN FARMERS USING REMEDIATED OR NON-REMEDIATED AGRICULTURAL DRAINAGE WATER

Results are given in Table (1) show the effect of agricultural drainage water and soil ecosystem remediation on the most imperative indicators of economic efficiency of green bean farmers in the season of 2021/2022 season in terms of total return, net return per feddan, cost of the produced unit, the profitability of each spent pound, net return per water unit, the profitability of each spent pound on remediating agricultural drainage water

TOTAL RETURN: Results given in Table (1) confirm an increase in the total return of green beans when irrigated with remediated agricultural drainage water; reaching LE 35,720. This increase is 83% more for plants grown in non-remediated soil ecosystems and irrigated with non-remediated agricultural drainage water. The increase in the total return of green beans reached LE 53,960 when irrigated with remediated agricultural drainage water and grown in a soil ecosystem remediated with microorganisms. This increase is 76% over its counterpart grown in the same soil ecosystem and irrigated with non-remediated agricultural drainage water. The maximum level of total return was recorded under irrigation with remediated agricultural drainage water for plants grown in a soil ecosystem remediated with clay minerals reaching LE 63,650 per feddan, and representing 94% over its counterpart produced in the same soil ecosystem and irrigated with non-remediated agricultural drainage water.

NET RETURN PER FEDDAN: Results are given in Table (1) confirmed a net yield per feddan under irrigation with remediated agricultural drainage water reaching 261% over its counterpart irrigated with non-remediated agricultural drainage water. The increase under irrigation with remediated agricultural drainage water is estimated at a rate of 129% over its counterpart irrigated with non-remediated agricultural drainage water and grown in a soil ecosystem remediated with microorganisms, while such increase under irrigation with remediated agricultural drainage water was 155% over its counterpart irrigated with non-remediated agricultural drainage water and grown in a soil ecosystem remediated with clay minerals. Such an increase recorded in the net yield per feddan might be ascribed to the increase in feddan productivity and an increase in the farm price as a result of the high quality of the harvest.

COST OF PRODUCED UNIT: It was found that the cost of each ton produced of green beans decreased when the plants were grown in soil ecosystems irrigated with remediated agricultural drainage water compared to its counterpart irrigated with non-remediated agricultural drainage water and grown in non-remediated or remediated soil ecosystems with either microorganisms or clay minerals, respectively.

PROFITABILITY OF EACH SPENT POUND: It was found that the profitability of the pound spent on the production of green beans grown in soil ecosystems irrigated with remediated agricultural drainage water reached 201%, 99%, 126% than its counterpart irrigated with non-remediated agricultural drainage water and grown in non-remediated soil ecosystem or soil ecosystems remediated with either microorganisms or clay minerals respectively.

NET RETURN PER WATER UNIT: Got results showed that the net return of the water unit was increased in soil ecosystems irrigated with remediated agricultural drainage water by 287%, 155%, 206% over its counterpart irrigated with non-remediated agricultural drainage water and grown in non-remediated soil ecosystem or soil ecosystems remediated with either microorganisms or clay minerals respectively.

PROFITABILITY OF EACH SPENT POUND ON REMEDIATING AGRICULTURAL DRAINAGE WATER: The profitability of each pound spent on remediating agricultural drainage water is given in Table (1). Such profitability reached LE 5.17 in the case of non-remediated soil ecosystem and at LE 9.8 in the case of soil ecosystem remediated with microorganisms, and LE 15.58 in soil ecosystem remediated with clay minerals. Previously, various research studies reports the role of microbiological amendments in enhancing the beneficial soil living consortium with elimination of organic and inorganic contaminants that eventually reflects on general soil health and crop productivity ((Kabary et al, (2021a,b), Saber and Zaghoul (2021), Zaghoul, 2016; Zayed et al, (1971), Monib et al, (1971), Abd-el-Malek et al, (1972), Guirguis et al, (1972), Taha et al, (1973), Zayed et al, (1973), Saber et al, (1973), Zanati et al, (1973), Saber et al, (1974), Saber et al, (1975a,b), Kabesh et al, (1975), Saber (1976a,b,c,d), Badr El-Din et al, (1976), Saber (1977), Saber et al, (1977), Khalafallah et al, (1982), El-Din et al, (1983), Saber (1986), Haggag and Saber (2007), Saber et al, (2011), El-Ashry et al, (2011), Abouziena et al, (2012), Hoballah et al, (2014a,b), Saber et al, (2014), Abouziena et al, (2014), Saber et al, (2015a,b,c,d), Haggag et al, (2015a,b), Haggag et al, (2016), Saber et al, (2016a,b,c,d,e,f,g,h), Saber et al, (2018), Mansour et al, (2019), Hassanain et al, (2021), Saber et al, (2021), Mansour et al., 2022, Saber et al., 2022)). Our present study exhibit that, the combined application of water remediation using DHS as well as soil remediation using microbial amendments has profound effects on soil yield productivity with the less agricultural demands needed that usually used during the traditional agriculture process. Consequently, the gained results confirm the feasibility of the remediation of agricultural drainage water before using it to irrigate green bean crops.

CONCLUSIONS

In conclusion, the results of the economic valuation of the production of green beans irrigated with remediated or non-remediated agricultural drainage and grown in either non-remediated or remediated soil ecosystems with either microorganisms or clay minerals explored the urgent need for the remediation of agricultural drainage water before using it in irrigation. Moreover, soil ecosystem remediation with either microorganisms or clay minerals improved the studied indicators of economic efficiency on the one hand, and reduced rates of irrigation water use in the production of green beans on the other. This, however, necessitates improving and intensifying R&D activities in this field of research as well as teaching farmers about the significance of applying DHS technologies in remediating agricultural drainage water as well as remediating the soil ecosystem before cultivation.

The term sustainability has various interpretations; however, the World Commission on Environment and Development (WCED, 1987) quoted that it is the development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs. To assess the sustainability of a given ecosystem, various dimensions based on the short- or long-term goals should be considered. In developing countries, the sustainability studies focus on economic affordability, the convenience of end users and stakeholders, health risks, technology sustainability, environmental impacts by-products, natural resource optimization and sanitation (Muga et al 2008 and Molinos-Senante et al 2014).

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