

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

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Abstract

An economic evaluation of the effect of irrigating tomato plants with agricultural drainage water remediated with DHS technology was conducted in a field experiment at Rahawy, Giza governorate. According to the findings, Egypt's reuse of agricultural drainage water meets around 15% of its irrigation needs, while the overall expenses of remediating one cubic metre of agricultural drainage water using DHS technology reached LE 1.03. The volume of irrigation water used to grow tomato plants decreased by 5% in non-remediated soil ecosystems, 14% in soil ecosystems remediated by microbial inoculation and fortified by bentonite clay mineral, and 22% in soil ecosystems receiving a mix of clay minerals, rock phosphate, and sulphur and inoculated by *Thiobacillus* sps and phosphate dissolving bacteria PDB. the productivity of one feddan of tomato crop irrigated with non-remediated agricultural drainage water reached 11.31 tons per feddan, irrigation with agricultural drainage water increased tomato crop by about 31%, all studied indicators of the economic efficiency of tomato production grown in remediated soil ecosystem and irrigated with remediated agricultural drainage water were higher than their counterparts grown in non-remediated soil ecosystem and irrigated with non-remediated agricultural drainage water, total tomato yield increased under irrigation with remediated agricultural drainage to LE 31.668, reaching 47% over its counterpart grown in non-remediated soil ecosystem irrigated with non-remediated agricultural drainage water, the net yield per feddan increased by 716% under irrigation with remediated agricultural drainage water over its counterpart irrigated with non-remediated agricultural drainage water. When irrigated with remediated agricultural drainage water, the cost of one tonne of tomato fruits harvested from non-remediated, remediated with bacteria, or remediated with clay minerals soil ecosystems decreased by 11%, 40%, and 44%, respectively, when compared to its counterparts irrigated with non-remediated agricultural drainage water. The profitability of one pound spent on tomato fruits harvested from non-remediated, remediated with bacteria, or remediated with clay minerals soil ecosystems decreased by 598 percent, 1010 percent, and 163 percent more than its counterpart irrigated with non-remediated agricultural drainage water, respectively, under irrigation with remediated agricultural drainage water. The net return of the water unit increased by 761 percent, 1367 percent, and 282 percent in tomato fruits harvested from non-remediated, remediated with certain microorganisms, or remediated with clay minerals soil ecosystems under irrigation with remediated agricultural drainage water, respectively, over its counterpart irrigated with non-remediated agricultural drainage water. The estimated profitability of each pound spent on agricultural drainage water remediation was LE 2.36 for tomato plants growing in an unremediated soil ecosystem, LE 10.07 for those remediated with specific microbes, and LE 33.43 for those remediated with clay minerals. The economic valuation of irrigating tomato plants with agricultural drainage water remediated with DHS technology was good, which will support farmers' social acceptance and sustainability of DHS use.

Keywords: Agricultural drainage water; DHS; Economic study; Tomato plant; field experiments.

INTRODUCTION

Nowadays, water resources management is a top priority in Egypt with regard to the expected problems that the country would face in the next few coming years as a result of the steady supply of water resources, adverse impacts of climate change and the

escalating demands on water associated with the high rate of population increase. Moreover, there are many expected adverse consequences related to the expected reducing Egypt's share of the Nile waters due to the operation of the Grand Ethiopian Renaissance Dam. Hence, the expected gap between supply and demand for water will reduce the annual per capita share of water. At the time being, it is an urgent issue to remediate all available low-quality water resources in Egypt by the proper technology to suit their reuse, after being economically valuated. The present study aims to economically evaluate the DHS technology used in low-quality remediation from an economic perspective.

MATERIALS AND METHODS

EXPERIMENTAL

The experimental site at Rahawy 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 meter. Tomato seedlings (*Solanum lycopersicum* var Ajyad 7) were obtained from a private nursery at Giza governorate and sown on the 5th September. Tomato plants were irrigated with either non-remediated or remediated agricultural drainage water from Rahawy 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.

METHODS

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.

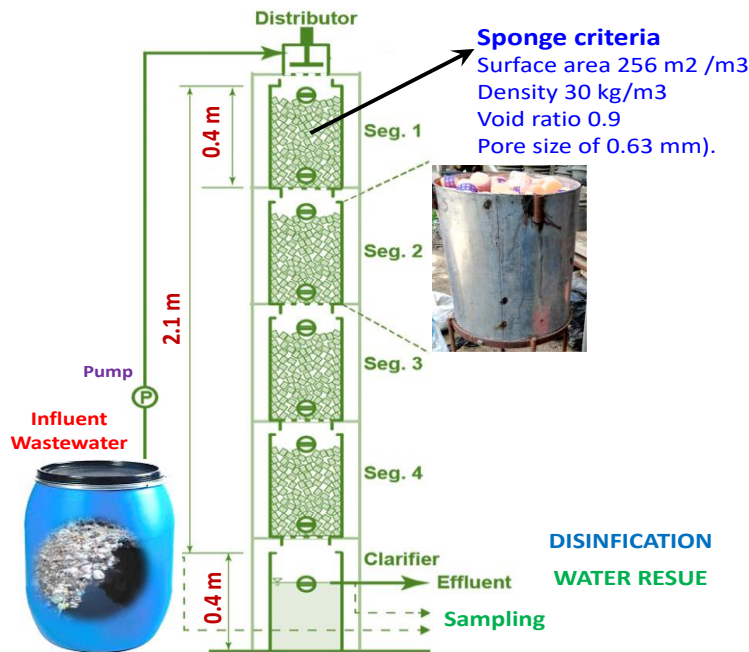


Fig (1) Systematic diagram of down flow hanging sponge system (DHS)

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 (33x22 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 (Eaton et al. 2005). 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).

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 trailed 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 CaCl₂·2H₂O, 132 g (NH₄)₂SO₄, 53 g MgCl₂·6H₂O, 27 g KH₂PO₄. 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 H₂SO₄ before being autoclaved for 30 min at 112 C and cooled to room temperature. Solution B was prepared by adding 20 g FeSO₄·7H₂O to 50 ml H₂SO₄ (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 ZnCl₂, 67 mg CuCl₂·2H₂O, 64 mg CoCl₂·6H₂O, 62 mg MnCl₂·2H₂O, 31 mg H₃BO₃ and 10 gm Na₂FmoO₄ 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 K₂HPO₄, 0.1 g/l, MgSO₄·7H₂O, 0.3 g/l CaCl₂·2H₂O, 0.01 g/l FeSO₄·7H₂O, 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 (NH₄)₂ SO₄, 0.4 g KH₂PO₄, 0.1 g yeast extract, 0.01 MgSO₄.7H₂O, 10 ml trace element solution, 10 ml vanillic acid solution in one liter. The trace element solution contains 0.4g MnSO₄.4H₂O, 0.5mg H₃BO₃, 0.4mg ZnSO₄.7H₂O, 0.2mg FeCl₃, 0.1mg KI, 0.04 mg CuSO₄.5H₂O 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 portions 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

The economic valuation included current water resources status in Egypt, water resources balance and demand, costs of establishing the DHS unit used in agricultural drainage water remediation, costs of the remediation per a cubic meter of agricultural drainage water, the economics of tomato production under irrigation with agricultural drainage water, the productivity of one feddan of tomato irrigated with agricultural drainage water before and after remediation, economic efficiency of tomato crop farmers irrigating their tomato plants with remediated and non-remediated agricultural drainage water, total and net tomato yield per feddan as well the profitability of one pound spent.

Water resources, balance and demand: Water resources are considered one of the most significant imperative economic resources in Egyptian farming. The main source of water in Egypt is river Nile representing 72.63% of the total available water sources (Table 1). Nearly 80% of this share is used in farming, and the rest covers all other needs for all sectors. Other significant

water resources in Egypt are groundwater in Nile valley and delta (9.38%), reuse of low-quality water (14.9%) rain (1.31%), and seawater desalination (0.1%).

Table (1): Average water balance in Egypt from 11/2012-19/2020

Sources of water	Annual quantity billion m ³	%	Growth rate	Water uses	Annual quantity billion m ³	%	Growth rate
Nile water	55.5	74.22	0	Farming	61.21	81.42	0.31
Groundwater in the Nile valley and delta	6.87	9.05	0.99	Drinking and health use	9.23	12.27	4.1
Agricultural low quality water recycling	9.87	13.22	6.09	Industry	2.4	3.2	11.68
Low quality water recycling	1.28	1.71	0.57	Waste by evaporation from river Nile and canals	2.3	3.06	1.25
Rain	1.14	1.53	0				
Seawater desalination	0.14	0.18	13.42	River Nile navigation	0.2	0.27	0
total water resources	74.67	100	0.8	Total water use	75.18	100	1.31

Source: Compiled and calculated from: Ministry of Water Resources and Irrigation, unpublished data

After the establishment of the high dam, Egypt secured an abundance of water resources sufficient to fulfill its needs for agricultural, industrial and drinking water as well. Data given in Table (1) show the average status of water balance in Egypt between 2011/2012-2019/2020. The total available water resources are estimated at 76.41 billion m³, while the total uses of water are estimated at 77.96 billion m³ that confirm a deficit in the water balance reaching 1.54 billion m³ during the study period.

It is clear from the data given in Table (1) that the agricultural drainage water satisfies around 15% of the irrigation water used in Egyptian farming, yet its use might be associated with some adverse impacts such as lowering harvest quality and injury consumer health. Namita Maharjan (2020) stated that economic sustainability of agricultural drainage water remediation refers to the economic factors affecting social, environmental and cultural aspects of such technology. Therefore, it is urgent to conduct intensive R&D studies on remediating low-quality water to ensure their safe and sustainable reuse.

Remediation costs per cubic meter: Agricultural drainage water collected from Rahawy agricultural drain was remediated with the DHS technology. Results given in Table (2) show that the total costs of remediating one cubic meter of agricultural drainage water by the DHS technology reached LE 1.03 including the manufacturing costs of the device, LE 14 thousand, and considering that the life time of the device is expected to reach 20 years and its actual capacity is estimated at 100 liters/hour costing LE 0.8 pounds, and the costs of electricity consumption is estimated at LE 0.21, and the cost of maintenance reach LE 0.02.

Table (2) Items of remediation costs per cubic meter of agricultural drainage water using DHS unit with an actual capacity of 100 liters / hour

Item	Value (pound)
The cubic meter share of the cost of the device	0.80
Electricity	0.21
Maintenance	0.02
	1.03

Source: collected and calculated from the data of researchers responsible for designing and operating the device

Economics of tomato production irrigated with remediated and non-remediated agricultural drainage water: The costs of the productive of tomato crop irrigated with Rahawy agricultural drainage water before and after remediation were estimated. (Guerrini et al 2017) stated that economic efficiency of agricultural drainage water remediation presents the scenario of investments in terms of input and effluent quality as the output. The costs of one feddan cultivated with tomato crop at Rahawy during the season 2021/2022, and irrigated with agricultural drainage water fortified with either microorganisms or modified clay minerals compared to those irrigated with non-remediated drainage water. The trailed remediative amendments facilitated nutrient absorbing and raised roots efficiency particularly during the early stages of tomato growth. The average value of the variable costs of tomato crop irrigation with remediated agricultural drainage water increased over its non-remediated counterpart in all the studied soil ecosystems up to 19% in the non-remediated soil ecosystem and to 15% in soil ecosystems fortified with microorganisms and clay minerals, and reached 17%, and 13% in the case of total costs respectively. Balkema et al (2002) mentioned that the economic indicators of agricultural drainage water remediation generally represent the costs associated with the construction and the operation of treatment management during its life time. These are driving factors for decision making while selecting a technology in a practical situation. Namita Maharjan (2020) stated that for the economic assessment, the two most common indicators are capital expenditure (Capex) and operational expenditure (Opex) are calculated using the equations provided by Sun et a. (2929). The capital expenditure includes construction and life cycle costs. Operational expenditure included number of mechanical equipment, skilled workers, power consumption, labor, chemicals, and consumables.

The volume of irrigation water used for growing tomato plants decreased by 5% in non-remediated soil ecosystem, by 14% in the soil ecosystem remediated by microbial inoculation and fortified by bentonite clay mineral and by 22% in soil ecosystems receiving all clay minerals, rock phosphate, and sulfur and inoculated by Thiobacillus sps and phosphate dissolving bacteria PDB which was the best trailed treatment (Fig 1) .

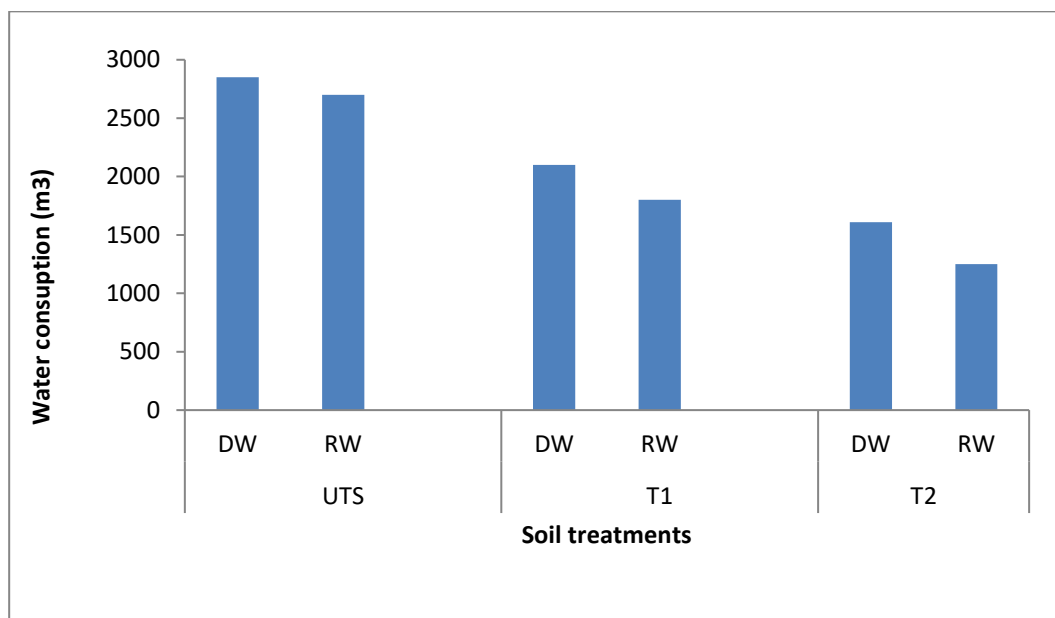


Fig (1): Effect of soil ecosystem remediation and type of water applied on water consumption by tomato plants

The costs of remediating agricultural drainage water used in tomato irrigation are estimated at 2785 pounds/feddan in the non-remediated soil ecosystem, and reached 2205 pound/feddan in the soil ecosystem remediated with microorganisms and reached 1864 pounds / feddan in the best trailed treatment remediated with clay minerals. .

Productivity of one feddan of tomato irrigated with agricultural drainage water before and after remediation: The productivity of one feddan of tomato crop irrigated with non-remediated agricultural drainage water reached 11.31 tons per feddan. However, irrigation with remediated agricultural drainage water increased crop production by about 31%. The yield of one feddan of tomato grown in a soil ecosystem remediated with bentonite, sulfur, rock phosphate and inoculated with PDB and Thiobacillus sp. and irrigated with treated agricultural drainage water reached 16.9 tons/feddan with an estimated increase of 89% over that irrigated with raw agriculture drainage water (Fig 2)

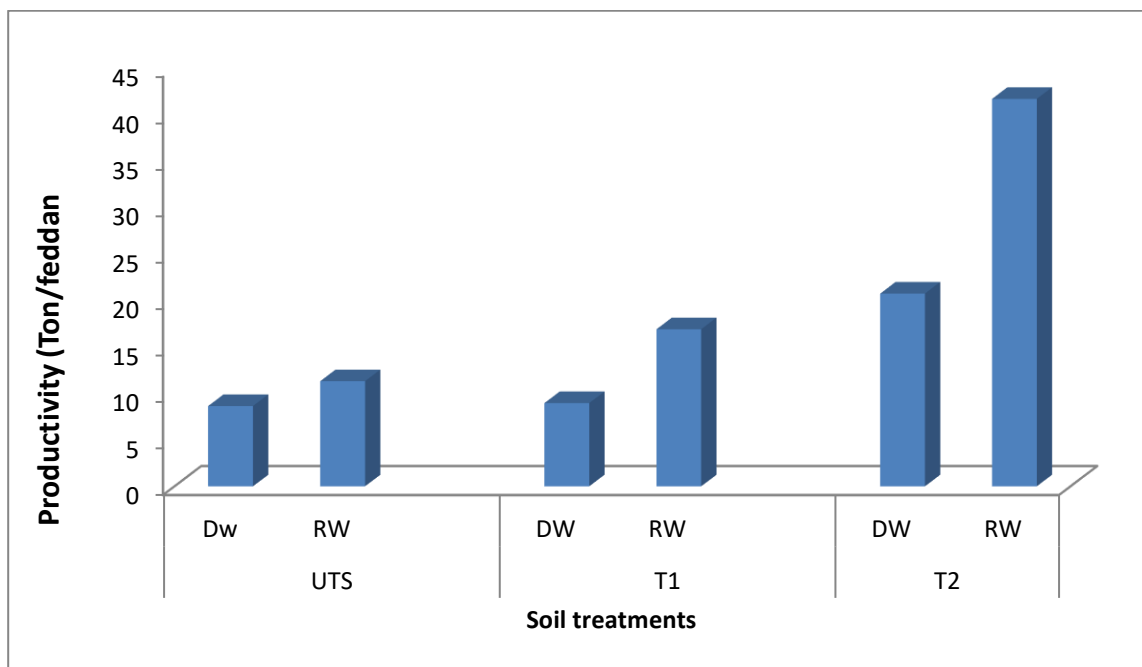


Fig (2): Effect of soil remediation and type of water applied on productivity of tomato plants per one feddan

In the soil ecosystem remediated with a mixture of clay minerals, rock phosphate, elemental sulfur and inoculated with PDB and Thiobacillus sp yielded the maximum crop per feddan reaching 41.69 tons with an estimated increase of 101% over its counterpart irrigated with non-remediated agricultural drainage water. In general, got results showed an increase in the productivity of one feddan of tomato irrigated with remediated agricultural drainage water compared to those irrigated with non-remediated agricultural drainage water, regardless being grown in remediated or non-remediated soil ecosystem, a positive effect was recorded under the influence of irrigation with remediated drainage waters on the soil health status and crop quality.

Economic efficiency of tomato crop farmers using agricultural drainage water before and after remediation: The effect of remediating agricultural drainage water and soil ecosystem on the most important indicators of economic efficiency of tomato farmers during in season of 2021/2022 season. The values of all studied indicators of economic efficiency of tomato production grown in remediated soil ecosystem and irrigated with remediated agricultural drainage water were higher than their counterparts grown in non-remediated soil ecosystem and irrigated with non-remediated agricultural drainage water.

Total tomato yield: The estimates of total tomato yield given point to an increase under irrigation with remediated agricultural drainage reaching LE 31.668, representing an increase of 47% over its counterpart grown in a non-remediated soil ecosystem irrigated with non-remediated agricultural drainage water. The total yield per feddan of tomato is estimated at LE 47,320 under irrigation with remediated agricultural drainage water and grown in remediated soil ecosystem receiving bacterial inoculation, with an increase reaching 111% over its counterpart production in the same soil ecosystem irrigated with non-remediated agricultural drainage water. The total return reached its maximum under irrigation with remediated agricultural drainage water and grown in a soil ecosystem remediated with clay mineral by LE 116,732 per feddan, an increase reaching 125 percent over its counterpart yield produced in the same soil and irrigated with non-remediated agricultural drainage water.

Net tomato yield per feddan: The net yield per feddan was increased by 716% under irrigation with remediated agricultural drainage water over its counterpart irrigated with non-remediated agricultural drainage water. The increase in net tomato yield grown in soil ecosystem remediated with certain types of bacteria and irrigated with remediated agricultural drainage water reached 197% over its counterpart irrigated with non-remediated agricultural drainage water and grown in soil ecosystem fortified with clay minerals. Such increase in the net yield of tomato per feddan might be ascribed to an increase in feddan productivity and an increase in the farm price as a result of the higher quality of the harvest.

Cost of the unit produced: Results given Table (3) indicated that by the cost of one ton of tomato fruits harvested from non-remediated, remediated with bacteria or remediated with clay minerals soil ecosystems decreased under irrigation with

remediated agricultural drainage water by 11%, 40% and 44% compared to its counterparts irrigated with non-remediated agricultural drainage water respectively.

Table (3) Measures of the economic efficiency of tomato growers at Rahawy site during the agricultural season 2020/2021 (cost of net production)

Treatment	Un-remediated soil			Soil remediated with microorganisms			Soil remediated with clay minerals		
	Drainage water	Reclaimed drainage water	%	Raw Drainage water	Remediated drainage water	%	Raw Drainage water	Remediated drainage water	%
Seedlings	4500	4500	100	4500	4500	100	4500	4500	100
Chemical fertilizers	4880	4880	100	4880	4880	100	4880	4880	100
Pesticides	3200	3200	100	3200	3200	100	3200	3200	100
Workers	2800	3500	125	2800	3800	136	3000	4100	137
Machen's	2800	2800	100	2600	2100	81	2100	1700	81
Processing costs	–	2785	–	–	2205	–	–	1864	–
Total variable costs	18180	21665	119	17980	20685	115	17680	20244	115
Rent	2500	2500	100	2500	2500	100	2500	2500	100
Total costs	20680	24165	117	20480	23185	113	20180	22744	113
Unit cost	2394	2137	89	2286	1372	60	973	546	56

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

Profitability of one pound spent: Results given in Table (4) confirm that the profitability of one pound spent on tomato fruits harvested from non-remediated, remediated with bacteria or remediated with clay minerals soil ecosystems decreased under irrigation with remediated agricultural drainage water by 598%, 1010%, and 163% more than its counterpart irrigated with non-remediated agricultural drainage water, respectively (Fig 3).

Table (4) Measures of the economic efficiency of tomato growers at Rahawy site during the agricultural season 2020/2021 (Profitability of one pound spent)

Item	Un-remediated soil			Soil remediated with microorganisms			Soil remediated with clay minerals		
	Drainage water	Reclaimed drainage water	%	Raw Drainage water	Remediated drainage water	%	Raw Drainage water	Remediated drainage water	%
Profitability of the pound spent on agricultural drainage water remediation	–	2.36	–	–	10.07	–	–	33.43	–

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

Reached results point to that the combined effect of remediating Rahawy soil ecosystem with bentonite, sulfur, rock phosphate and certain microorganisms associated with irrigation with remediated agricultural drainage water decreased irrigation water consumption and increased both yield productivity and overall net return.

Such results confirm the remediation with T2 was the most efficient when associated with irrigation with reclaimed agricultural drainage water as it decrease the irrigation water consumption to 1250 m³/feddan compared to 1610, 2100 and 2800 m³/feddan under remediation with T1 or in control soil irrigated with non-remediated agricultural drainage water. Moreover, both yield

productivity and net return increased under the action of T2 treatment irrigated with remediated agricultural drainage water to 41.69 tons and 93988 per feddan compared to 20.74, 8.96- and 8.64-tons crop productivity and 31670, 1920 and 920 net returns under the action of T2, T1 and control non-remediated soil ecosystem irrigated with non-remediated agricultural drainage water.

Net return per unit water unit: Gained results show that the net return of the water unit increased in tomato fruits harvested from non-remediated, remediated with certain microorganisms or remediated with clay minerals soil ecosystems under irrigation with remediated agricultural drainage water by the rate of 761%, 1367% and 282% over its counterpart irrigated with non-remediated agricultural drainage water respectively (Table 5 and Fig 3).

Table (5) Measures of the economic efficiency of tomato growers at Rahawy site during the agricultural season 2020/2021(net return per unit water)

Treatment	Un-remediated soil			Soil remediated with microorganisms			Soil remediated with clay minerals		
	Drainage water	Reclaimed drainage water	%	Raw Drainage water	Remediated drainage water	%	Raw Drainage water	Remediated drainage water	%
Net revenue per unit of water	0.32	2.78	861	0.91	13.41	1467	19.67	75.19	382

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

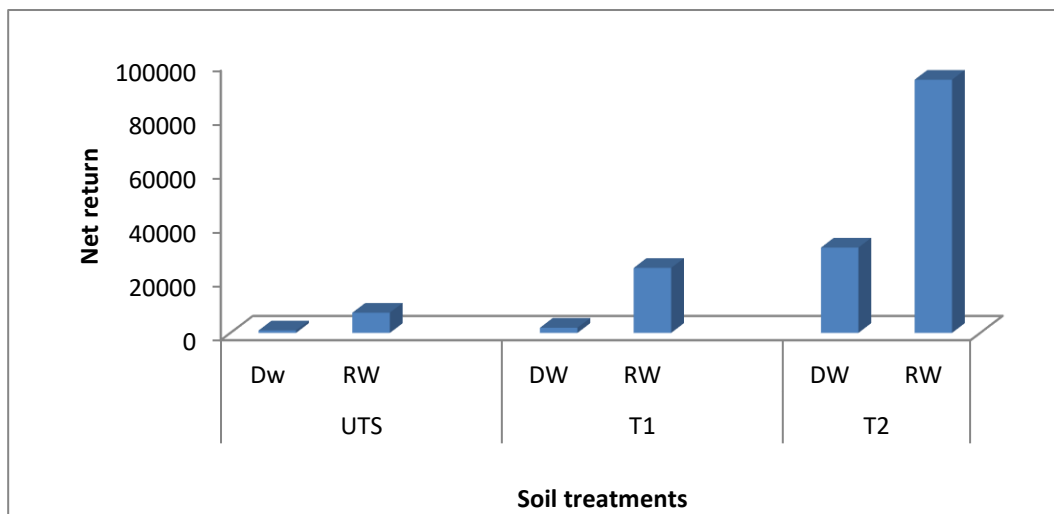


Fig (3): Effect of irrigation with remediated and non-remediated agricultural drainage water on tomato net return per feddan

Profitability of the pound spent on the remediation of agricultural drainage water: The estimated profitability of the each pound spent on remediating agricultural drainage water is given in (Table 6) was estimated at LE 2.36 for tomato plants grown in non-remediated soil ecosystem, and at LE 10.07 for those remediated with certain microorganisms, and at LE 33.43 for those remediated with clay minerals. Such gained results confirm the feasibility of remediating agricultural drainage water before being used in irrigating tomato crop, especially in light of the scarcity of the irrigation water, whether as a result of the construction of the Renaissance Dam or the adverse effects of expected climate changes.

Table (6) Measures of the economic efficiency of tomato growers at Rahawy site during the agricultural season 2020/2021 (productivity of one feddan)

Item	Un-remediated soil			Soil remediated with microorganisms			Soil remediated with clay minerals		
	Drainage water	Reclaimed drainage water	%	Raw Drainage water	Remediated drainage water	%	Raw Drainage water	Remediated drainage water	%
Productivity of one feddan	8.64	11.31	131	8.96	16.9	189	20.74	41.69	201

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

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

The state-of-art of DHS technology is based on sustainability indicators (Namita Maharjan 2020). Yet, the self-sustainability of DHS system has not been explored. From the retrospection of the state-of-art of DHS technology, it has always been considered a sustainable system for developing countries. Even though few efforts have been exercised to test and validate the sustainability of DHS system. Conceptualizing the sustainability assessment framework will encourage and support data collection for better and more quantitative analysis to ensure the applicability and usefulness of DHS technology. Considering the outcomes from sustainability assessment, regardless of data insufficiency, the DHS system fulfilled the criteria of self-sustaining agricultural drainage water remediation to a greater extent.

Many key aspects related to social sustainability such as community management, satisfaction and opinions of users, service quality, materials and personnel management, etc. have to be profoundly analyzed before and after the establishment of agricultural drainage water remediation (Cossio et al 2020). In this light, social indicators are rapidly becoming the preferred tools for policymakers and public communicators for disseminating information on the advantages and disadvantages of agricultural drainage water remediation. However, societal indicators are generally difficult to quantify and often their meaning and relevance is based on the local stakeholders (Padilla-Rivera et al 20116). Caution should be exercised that all the data for social assessment do not represent any generic weighting. The chosen indicators for this assessment are simplicity of the system, aesthetics, and public acceptance of the technology.

Always, one of the major problems faced during the establishment of agricultural drainage water remediation is its location. Very often resistance and protests from the local people significantly impact the implementation of any social infrastructure plan. Therefore, public acceptance is a key component when it comes to establishing a new agricultural drainage water remediation. Further studies need to be undertaken to analyze local conditions in a stepwise manner towards the acceptance of these technologies.

REFERENCES

1. Abd-el-Malek, Y., Monib, M., Zayed, M.N., Saber, M.S. (1972). Action of dry guava leaves on bacteria, contributing to nitrogen transformations in soil. *Zentralblatt für Bakteriologie, Parasitenkunde, Infektionskrankheiten und Hygiene. Zweite naturwissenschaftliche Abt.: Allgemeine, landwirtschaftliche und technische Mikrobiologie*, 1971, 126(7), pp. 672–677
2. Abouziena, H., Hoballah, E., Abd El Zaher, F., ...Saber, M., Zaghoul, A.M.(2014). Use of sesame and sorghum crops to verify the remediation of contaminated sewage soils. *Journal of Applied Botany and Food Quality*, 2014, 87, pp. 196–205
3. Abouziena, H.F., Saber, M., Hoballa, E.M., El-Ashry, A., Zaghoul, A. (2012). Phytoremediation of potential toxic elements in contaminated sewage soils by canola (*Brassica napus*) or indian mustard (*Brassica juncea* Czern.) Plants in association with mycorrhiza. *Journal of Applied Sciences Research*, 2012, 8(4), pp. 2286–2300
4. Atlas, M.R., 2005. *Handbook of Media for Environmental Microbiology*
5. Badr El-Din, S.M., Latif, A., Saber, M.S., Asy, H.I. (1976). Characterization and microbiological evaluation of the red compounds, associated with red rot disease of sugar cane. *Zentralblatt für Bakteriologie, Parasitenkunde, Infektionskrankheiten und Hygiene. Zweite naturwissenschaftliche Abt.: Allgemeine, landwirtschaftliche und technische Mikrobiologie*, 1976, 131(3), pp. 565–568
6. Balkema AJ, Preisig HA, Otterpohl R, Lambert FJD. Indicators for the sustainability assessment of wastewater treatment systems. *Urban Water*. 2002;4(2):153–61.
7. Chernicharo CAL, Nascimento MCP. Feasibility of a pilot-scale UASB/trickling filter system for domestic sewage treatment. *Water Sci Technol*. 2001;44(4):221–8.
8. Cossio C, Norrman J, McConville J, Mercado A, Rauch S. Indicators for sustainability assessment of small-scale wastewater treatment plants in low and lower-middle income countries. *Environ Sustain Indic* 2020;6(March):100028
9. El-Ashry, S., Saber, M., Zaghoul, A.M. (2011). Chemical characterization of sandy soils irrigated with sewage effluent for extended periods from a kinetic perspective
10. El-Din, S.M.S.B., Saber, M.S.M. (1983). Effect of phosphate dissolving bacteria on P-uptake by barley plants grown in a salt affected calcareous soil. *Zeitschrift für Pflanzenernährung und Bodenkunde*, 1983, 146(5), pp. 545–550
11. Guerrini A, Romano G, Indipendenza A. Energy efficiency drivers in wastewater treatment plants: a double bootstrap DEA analysis. *Sustainability*. 2017 Jul;9(7):1126.
12. Guirguis, M.A., Saber, M.S. (1972). Investigations on the effect of organic matter on calcareous soils. *Zentralblatt für Bakteriologie, Parasitenkunde, Infektionskrankheiten und Hygiene. Zweite naturwissenschaftliche Abt.: Allgemeine, landwirtschaftliche und technische Mikrobiologie*, 1972, 127(5), pp. 500–508
13. Haggag, W.M., Abouziena, H.F., Hoballah, E., Saber, M. (2015b). *Tilletiopsis pallescens*: Optimization, fermentation and manufacture for managing mango powdery mildew. *Journal of Chemical and Pharmaceutical Research*, 2015, 7(11), pp. 341–352
14. Haggag, W.M., Korayem, A.M., Abouziena, H.F., Hoballah, E., Saber, M. (2015a). Phenolic and antioxidants enzymes accumulation in sugar beet cultivars in response to inoculation with plant growth promoting rhizobacteria. *Wulfenia*, 2015, 22(12), pp. 235–242
15. Haggag, W.M., Korayem, A.M., Abouziena, H.F., Hoballah, E., Saber, M. (2015a). Phenolic and antioxidants enzymes accumulation in sugar beet cultivars in response to inoculation with plant growth promoting rhizobacteria. *Wulfenia*, 2015, 22(12), pp. 235–242
16. Haggag, W.M., Saber, M., Abouziena, H.F., Hoballah, E.M., Zaghoul, A.M.(2016). Climate change potential impacts on plant diseases and their management. *Der Pharmacia Lettre*, 2016, 8(5), pp. 17–24
17. Haggag, W.M., Saber, M.S.M. (2007). Suppression of early blight on tomato and purple blight on onion by foliar sprays of aerated and non-aerated compost teas. *Journal of Food, Agriculture and Environment*, 2007, 5(2), pp. 302–309
18. Hassanain, N., Shaapan, R., Saber, M., Kabary, H., Zaghoul, A. (2021). Adverse impacts of water pollution from agriculture (Crops, livestock, and aquaculture) on human health, environment, and economic activities. *Egyptian Journal of Aquatic Biology and Fisheries*, 2021, 25(2), pp. 1093–1116
19. Hoballah, E., Saber, M., Matter, I., Zaghoul, A. (2014a). Bioremediation of aliphatic hydrocarbons in a sewage soil by certain remediative amendments followed by phytoremediation. *Research Journal of Pharmaceutical, Biological and Chemical Sciences*, 2014, 5(1), pp. 769–788
20. Hoballah, E., Saber, M., Matter, I., Zaghoul, A.(2014b). Bioremediation of polychlorinated biphenyl (PCBs) in a sewage soil by certain remediative amendments followed by phytoremediation. *Research Journal of Pharmaceutical, Biological and Chemical Sciences*, 2014, 5(2), pp. 91–103
21. Huang Y, Ning Y, Zhang T, Fei Y. Public acceptance of waste incineration power plants in China: Comparative case studies. *Habitat International*. 2015 Jun 1;47:11–9.
22. Kabary, H., Hassanain, N., Saber, M., Zagloul, A. (2021a). Enumeration and detection of main pathogenic bacterial genera in rahawy and bilbeis agriculture drains. *Egyptian Journal of Aquatic Biology and Fisheries*, 2021, 25(5), pp. 189–202
23. Kabary, H., Saber, M., El-Ashry, S., Zaghoul, A. (2021b). An integrated chemo- bio- mineral technology for agricultural drainage water remediation. *International Journal of Environmental Analytical Chemistry*, 2021
24. Kabesh, M.O., Saber, M.S.M., Yousry, M. (1975). Effect of phosphate dissolving bacteria and phosphate fertilization on the P-uptake by pea plants cultivated in a calcareous soil. *Zeitschrift für Pflanzenernährung und Bodenkunde*, 1975, 138(6), pp. 605–611
25. Khalafallah, M.A., Saber, M.S.M., Abd-El-Maksoud, H.K.(1982). Influence of Phosphate Dissolving Bacteria on the Efficiency of Superphosphate in a Calcareous Soil Cultivated with *Vicia faba*. *Zeitschrift für Pflanzenernährung und Bodenkunde*, 1982, 145(5), pp. 455–459
26. M. Saber, Wafaa Haggag M., E. Hoballah, Soad El-Ashry, A. M. Zaghoul 2019. Potential impacts of certain remediative amendments in enhancing phytoremediation in various
27. Mansour, H., Saber, M., Kabary, H., Mansour, H., and Zaghoul, H., 2022. Assessing the remediation of contaminated soil ecosystem with some recent chemo biological technologies through bioremediation index. *International Journal of Health Sciences*, 6(S2), 1996–2020. <https://www.researchgate.net/deref/https%3A%2F%2Fdoi.org%2F10.53730%2Fijhs.v6nS2.5421>
28. Mansour, H.A., Abd-Elmabod, S.K., Engel, B.A. 2019. Adaptation of modelling to irrigation system and water management for corn growth and yield. *Plant Archives*, 2019, 19, pp. 644–651
29. Mansour et al., 2019a-e, Hu et al., 2019, Abdalla et al, 2019, Jiandong, et al, 2019, Abd-Elmabod et al, 2019a-b, Tayel et al 2019a-c, Hellal et al, 2019, Mansour and Pibars 2019, Attia et al., 2019, Pibars and Mansour, 2019,
30. Mansour Hani, A., Abd-Elmabod, S.K., Saad, A. 2019d. The impact of sub-surface drip irrigation and different water deficit treatments on the spatial distribution of soil moisture and salinity. *Plant Archives*, 2019, 19, pp. 384–392
31. Mansour Hani, A., Nofal, O.A., Gaballah, M.S., El-Nasharty, A.B. 2019a. Management of two irrigation systems and algae foliar application on wheat plant growth. *AIMS Agriculture and Food*, 2019, 4(3), pp. 824–832
32. Mansour, H., Saber, M., Awad, F., Zaghoul, A. (2019). Dehydrogenase activity and zinc equivalent parameters as indicators for potential toxic elements remediation in polluted soil ecosystem. *Bioremediation Journal*. 23(4), 326–333. <https://doi.org/10.1080/10889868.2019.1670132>.
33. Mansour, H.A. 2015. Performance automatic sprinkler irrigation management for production and quality of different Egyptian wheat varieties. *International Journal of ChemTech Research*, 2015, 8(12), pp. 226–237

34. Mansour, H.A., Abd El-Hady, M., Bralts, V.F., Engel, B.A. 2016. Performance automation controller of drip irrigation systems using saline water for wheat yield and water productivity in Egypt. *Journal of Irrigation and Drainage Engineering*, 2016, 142(10), 05016005
35. Mansour, H.A., Abdallah, E.F., Gaballah, M.S., Gyuricza, C. 2015. Impact of bubbler discharge and irrigation water quantity on 1-hydraulic performance evaluation and maize biomass yield. *International Journal of GEOMATE*, 2015, 9(2), pp. 1538–1544
36. Mansour, H.A., Abdelghani, S.S., Al-Jughaiman, A., Saad, S.S. 2020e. Economic evaluation of subsurface drip irrigation pipe fitting machine. *Plant Archives*, 2020, 20, pp. 3565–3572
37. Mansour, H.A., Abdel-Hady, M., Eldardiry, E.I., Bralts, V.F. 2015. Performance of automatic control different localized irrigation systems and lateral lengths for: 1-Emitters clogging and maize (*Zea mays L.*) growth and yield. *International Journal of GEOMATE*, 2015, 9(2), pp. 1545–1552
38. Mansour, H.A., Abd-Elmabod, S.K., Engel, B.A. 2019. Adaptation of modelling to irrigation system and water management for corn growth and yield. *Plant Archives*, 2019, 19, pp. 644–651
39. Mansour, H.A., Aljughaiman, A.S. 2012. Water and fertilizers use efficiency of corn crop under closed circuits of drip irrigation system. *Journal of Applied Sciences Research*, 2012, 8(11), pp. 5485–5493
40. Mansour, H.A., Aljughaiman, A.S. 2020. Assessment of surface and subsurface drip irrigation systems with different slopes by hydrocalc model. *International Journal of GEOMATE*, 2020, 19(73), pp. 91–99
41. Mansour, H.A., El Sayed Mohamed, S., Lightfoot, D.A. 2020a. Molecular studies for drought tolerance in some Egyptian wheat genotypes under different irrigation systems. *Open Agriculture*, 2020, 5(1), pp. 280–290
42. Mansour, H.A., El-Hady, M.A., Eldardiry, E.I., Aziz, A.M. 2019c. Wheat crop yield and water use as influenced by sprinkler irrigation uniformity. *Plant Archives*, 2019, 19, pp. 2296–2303
43. Mansour, H.A., El-Hady, M.A., Eldardiry, E.I., Essa, S.F., Eldwainy, C. 2020c. Sustainable agriculture and food - Challenges and solutions: A review. *Plant Archives*, 2020, 20, pp. 3218–3223
44. Mansour, H.A., El-Hady, M.A., Eldardiry, E.I., Saad, S.S. 2020d. Using aquacrop model to evaluate the effect of pulse drip irrigation techniques and water stress on maize water productivity. *Plant Archives*, 2020, 20, pp. 3232–3242
45. Mansour, H.A., Gaballah, M.S., Nofal, O.A. 2020b. Evaluating the water productivity by Aquacrop model of wheat under irrigation systems and algae. *Open Agriculture*, 2020, 5(1), pp. 262–270
46. Mansour, H.A., Jiandong, H., Hongjuan, R., Kheiry, A.N.O., Abd-Elmabod, S.K. Influence of using automatic irrigation system and organic fertilizer treatments on faba bean water productivity. *International Journal of GEOMATE*, 2019e, 17(62), pp. 250–259
47. Mansour, H.A., Jiandong, H., Pibars, S.K., Feng, B.H., Changmei, L. 2019b. Effect of pipes installation by modified machine for subsurface drip irrigation system on maize crop yield costs. *Agricultural Engineering International: CIGR Journal*, 2019, 21(2), pp. 98–107
48. Mansour, H.A., Pibars, S.K., Abd El-Hady, M., Eldardiry, E.I. 2014. Effect of water management by drip irrigation automation controller system on faba bean production under water deficit. *International Journal of GEOMATE*, 2014, 7(2), pp. 1047–1053
49. Mansour, H.A., Pibars, S.K., Bralts, V.F. 2015. The hydraulic evaluation of MTI and DIS as a localized irrigation systems and treated agricultural wastewater for potato growth and water productivity *International Journal of ChemTech Research*, 2015, 8(12), pp. 142–150
50. Mansour, H.A., Pibars, S.K., Gaballah, M.S., Mohammed, K.A.S. 2016. Effect of different nitrogen fertilizer levels, and wheat cultivars on yield and its components under sprinkler irrigation system management in sandy soil. *International Journal of ChemTech Research*, 2016, 9(9), pp. 1–9
51. Mansour, H.A., Saad, A., Ibrahim, A.A.A., El-Hagarey, M.E. 2016. Management of irrigation system: Quality performance of Egyptian wheat. *Micro Irrigation Management: Technological Advances and Their Applications*, 2016, pp. 279–293
52. Mansour, H.A., Sabreen Kh, P. 2019. Effect of some environmental control parameters and retention time on biogas produced from wastes of buffalo feeding. *Plant Archives*, 2019, 19, pp. 628–635
53. Mansour, H.A.A. 2015. Design considerations for closed circuit design of drip irrigation system. *Closed Circuit Trickle Irrigation Design: Theory and Applications*, Book Chapter. 2015, pp. 61–133
54. Mansour, H.A.A., Aljughaiman, A.S. 2015. Water and fertilizer use efficiencies for drip irrigated corn: Kingdom of Saudi Arabia. *Closed Circuit Trickle Irrigation Design: Theory and Applications*, Book Chapter. 2015, pp. 233–249
55. Mansour, H.A.A., El-Hady, M.A., Gyuricza, C.S. 2015. Water and fertilizer use efficiencies for drip irrigated maize. *Closed Circuit Trickle Irrigation Design: Theory and Applications*, 2015, pp. 207–218
56. Mansour, H.A.A., El-Melhem, Y. 2015. Performance of drip irrigated yellow corn: Kingdom of Saudi Arabia. *Closed Circuit Trickle Irrigation Design: Theory and Applications*, Book Chapter. 2015, pp. 219–232
57. Mansour, H.A.A., Mehanna, H.M., El-Hagarey, M.E., Hassan, A.S. Automation of mini-sprinkler and drip irrigation systems. *Closed Circuit Trickle Irrigation Design: Theory and Applications*, 2015, pp. 179–204
58. Mansour, H.A.A., Tayel, M.Y., Lightfoot, D.A., El-Gindy, A.M. 2015. Energy and water savings in drip irrigation systems. *Closed Circuit Trickle Irrigation Design: Theory and Applications*, 2015, pp. 149–178
59. Monib, M., Abd-el-Malek, Y., Zayed, M.N., Saber, M.S. (1971). The antibacterial effect of dry tomato plants, onion peels, and guava leaves on soil microorganisms. *Zentralblatt für Bakteriologie, Parasitenkunde, Infektionskrankheiten und Hygiene. Zweite naturwissenschaftliche Abt.: Allgemeine, landwirtschaftliche und technische Mikrobiologie*, 1971, 126(6), pp. 630–639
60. Murphy HM, McBean EA, Farahbakhsh K. Appropriate technology—A comprehensive approach for water and sanitation in the developing world. *Technology in Society*. 2009 May 1;31(2):158–67.
61. Namita Maharjan, Choolaka Hewawasam, Masashi Hatamoto, Takashi Yamaguchi, Hideki Harada and Nobuo Araki (2020). Downflow Hanging Sponge System: A Self-Sustaining Option for Wastewater Treatment. In *Promising Techniques for Wastewater Treatment and Water Quality Assessment* Edited by Iqbal Ahmed Moujдин and J. Kevin Summers. DOI: 10.5772/intechopen.94287
62. Padilla-Rivera A, Morgan-Sagastume JM, Noyola A, Güereca LP. Addressing social aspects associated with wastewater treatment facilities. *Environ Impact Assess Rev*. 2016;57:101–13.
63. Ryu, H.W., Y.J. Kim, K.S. Cho, K.S. Kang, and H. Choi. 1998. Effect sludge concentration on removal of heavy metals from digested sludge by *Thiobacillus ferrooxidans*. *Korean J. Biotechnol. Bioeng.* 13:279–283.
64. Saber, M. and Zaghoul, A.M., 2021. Evaluation of biochemical treatments applied in polluted soils irrigated with low quality water for long periods of time through the CO₂ efflux. *Acta agriculturae Slovenica*, 117(4), pp. 1–12.
65. Saber, M., Abouziena, H., Hoballah, E., ...El-Ashry, S., Zaghoul, A.M. (2016c). The use of phytoremediation to combat contamination of soil ecosystems. *Ponte*, 2016, 72(3), pp. 10–27
66. Saber, M., Abouziena, H.F., Haggag, W.M., HobAllah, E., Zaghoul, A. (2016a). Potential toxic elements phytoremediation: Review. *Research Journal of Pharmaceutical, Biological and Chemical Sciences*, 2016, 7(2), pp. 1148–1157
67. Saber, M., Abouziena, H.F., Hoballah, E., Turkey, A., Zaghoul, A. (2015c). Risk assessment and mitigation measures for certain amendments used in the bioremediation of Sewaged soils. *International Journal of ChemTech Research*, 2015, 8(6), pp. 423–440
68. Saber, M., Abouziena, H.F., Hoballah, E.M., Haggag, W.M., Zaghoul, A.E.-D.M. (2016d). Sewage farming: Benefits and adverse effects. *Research Journal of Pharmaceutical, Biological and Chemical Sciences*, 2016, 7(3), pp. 297–313

69. Saber, M., Abu-Sedera, S., Matter, I.A., Zaghoul, A. (2016g). Adverse impacts of El-Salam canal irrigation water on chemical characterizations of Sinai soils. *International Journal of PharmTech Research*, 2016, 9(9), pp. 138–149
70. Saber, M., Abu-sedera, S., Matter, I.A., Zaghoul, A.M. (2015b). Seasonal variations in the microbial biomass and pathogenic bacteria in low quality water collected from el-salam canal: Case study. *Research Journal of Pharmaceutical, Biological and Chemical Sciences*, 2015, 6(4), pp. 1709–1717
71. Saber, M., Abu-Sedera, S., Matter, I.A., Zaghoul, A.M. (2016f). Chemical characterization of some low quality water (Sewage effluent) used for irrigation in Egypt: Case study. *International Journal of PharmTech Research*, 2016, 9(9), pp. 150–157
72. Saber, M., Abu-sedera, S., Matter, I.A., Zaghoul, A.M. (2015a). Seasonal variations in the microbial and pathogenic biomass in low quality water collected from two Egyptian agricultural drains. *Research Journal of Pharmaceutical, Biological and Chemical Sciences*, 2015, 6(4), pp. 1700–1708
73. Saber, M., Abu-Sedera, S., Matter, I.A., Zaghoul, A.M. (2015d). Seasonal variations in the microbial biomass and pathogenic bacteria in some Egyptian sewage effluents. *Research Journal of Pharmaceutical, Biological and Chemical Sciences*, 2015, 6(5), pp. 235–242
74. Saber, M., Hoballah, E., Abouziena, H., ...El-Ashry, S., Zaghoul, A. (2016b). Management of sewage farming in arid region: Egyptian experience. *Ponte*, 2016, 72(3), pp. 28–56
75. Saber, M., Hoballah, E., Abouziena, H.F., Haggag, W.M., Zaghoul, A.M. (2016h). Bioremediation of soil irrigated with sewage effluent benefitting new kinetic tactics. *Ponte*, 2016, 72(3), pp. 67–82
76. Saber, M., Hoballah, E., Azza, S.T., Doaa, I.A. (2011). Microbial decontamination of enteric pathogens in sewage soils. *Australian Journal of Basic and Applied Sciences*, 2011, 5(11), pp. 1312–1320
77. Saber, M., Hoballah, E., Matter, I., Zaghoul, A. (2014). Bioremediation of chlorinated hydrocarbons in a sewage soil by certain remediative amendments followed by phytoremediation. *Research Journal of Pharmaceutical, Biological and Chemical Sciences*, 2014, 5(2), pp. 83–90
78. Saber, M., Hoballah, E., Ramadan, R., El-Ashry, S., Zaghoul, A.M. (2016e). Kinetic assessment of potential toxic elements desorption from contaminated soil ecosystems irrigated with low quality water. *International Journal of Soil Science*, 2016, 11(3), pp. 71–78
79. Saber, M., Kabary, H., Ali, D. and Zaghoul, A., 2022. Decontamination of enteric pathogens in soil ecosystems irrigated with low quality water for continuous irrigation practice. *Soil Science Annual*, 73(1), 147964.
80. Saber, M., Kabary, H., Helmi, F., Abd-El-mowla, D., Zaghoul, A. (2021). Indigenous microorganisms in agriculture drains. *Egyptian Journal of Aquatic Biology and Fisheries*, 2021, 25(2), pp. 1081–1091
81. Saber, M., Wafaa Haggag, M., Hoballah, E., El-Ashry, S., Zaghoul, A.M. (2018). Potential impacts of certain remediative amendments in enhancing phytoremediation in various contaminated soil ecosystems. *Agricultural Engineering International: CIGR Journal*, 2018, 20(4), pp. 33–42
82. Saber, M.S., Guirguis, M.A., Hosny, I. (1974). Green and organic manuring in virgin sandy soils. *Zentralblatt für Bakteriologie, Parasitenkunde, Infektionskrankheiten und Hygiene. Zweite naturwissenschaftliche Abt.: Allgemeine, landwirtschaftliche und technische Mikrobiologie*, 1974, 129(6), pp. 565–573
83. Saber, M.S., Guirguis, M.A., Zanati, M.R. (1973). Biological and chemical determination of available phosphorus in soil. *Zentralblatt für Bakteriologie, Parasitenkunde, Infektionskrankheiten und Hygiene. Zweite naturwissenschaftliche Abt.: Allgemeine, landwirtschaftliche und technische Mikrobiologie*, 1973, 128(5), pp. 566–571
84. Saber, M.S.M. (1976a). Antimicrobial substances in certain members of solanaceae. III. Detection of active principles in tomato plant. *Zentralblatt für Bakteriologie Parasitenkunde Infektionskrankheiten und Hygiene Zweite Abteilung*, 1976, 131(1), pp. 53–56
85. Saber, M.S.M. (1976d). Antimicrobial substances in certain members of solanaceae. I. Preliminary investigations. *Zentralblatt für Bakteriologie Parasitenkunde Infektionskrankheiten und Hygiene Zweite Abteilung*, 1976, 131(1), pp. 40–45
86. Saber, M.S.M. (1977). Antimicrobial substances in certain members of Solanaceae. V. Detection of active principles in potato plant. *Zentralblatt für Bakteriologie Parasitenkunde Infektionskrankheiten und Hygiene Zweite Abteilung*, 1976, 131(2), pp. 113–116
87. Saber, M.S.M. (1986). Prolonged effect of land disposal of human wastes on soil conditions
88. Saber, M.S.M., El-Sherif, A.F. (1975a). Studies on Microbial Fertilizers I. Effect of Silicate Dissolving Bacteria on the Potassium Uptake by Sorghum helepensis from Calcareous Soils
89. Saber, M.S.M., El-Sherif, A.F., Osman, A.Z. (1975b). Studies on Microbial Fertilizers. III. Effect of phosphate and silicate dissolving bacteria on the uptake of phosphorus and potassium from calcareous soils by sorghum helepensis. *Zeitschrift für Pflanzenernährung und Bodenkunde*, 1975, 138(6), pp. 613–619
90. Saber, M.S.M., Yousry, M., Kabesh, M.O. (1977). Effect of manganese application on the activity of phosphate-dissolving bacteria in a calcareous soil cultivated with pea plants. *Plant and Soil*, 1977, 47(2), pp. 335–339
91. Saber, M.S.M. (1976c). Antimicrobial substances in certain members of Solanaceae. IV. Detection of active principles in pepper plant. *Zentralblatt für Bakteriologie Parasitenkunde Infektionskrankheiten und Hygiene Zweite Abteilung*, 1976, 131(2), pp. 110–112
92. Sun Y, Garrido-Baserba M, Molinos-Senante M, Donikian NA, Poch M, Rosso D. A composite indicator approach to assess the sustainability of wastewater management alternatives. *Science of The Total Environment*. 2020 Apr 3;138286.
93. Taha, S.M., Zayed, M.N., Saber, M.S., Badr-el-Din, S.M. (1973). Nitrogen transformation in soils. II. In sandy soil under horse-bean and sesame in a two years' rotation. *Zentralblatt für Bakteriologie, Parasitenkunde, Infektionskrankheiten und Hygiene. Zweite naturwissenschaftliche Abt.: Allgemeine, landwirtschaftliche und technische Mikrobiologie*, 1973, 128(1), pp. 126–134
94. Van Lier JB, Vashi A, Van Der Lubbe J, Heffernan B. Anaerobic sewage treatment using UASB reactors: engineering and operational aspects. In *Environmental anaerobic technology: applications and new developments 2010* (pp. 59–89).
95. Wahba, M. M., Zaghoul, A. M. (2007). Adsorption characteristics of some PTEs by some soil minerals. *Journal of Applied Sciences Research*. 3(6), 421-426.
96. Xu J, Li Y, Wang H, Wu J, Wang X, Li F. Exploring the feasibility of energy self-sufficient wastewater treatment plants: a case study in eastern China. *Energy Procedia*. 2017 Dec 1;142:3055–61.
97. Zaghoul, A. (2016). Enhancing phytoremediation technique in contaminated soils using novel biotechnology. *The 18th International Conference on Heavy Metals in the Environment*. Ghent, Belgium
98. Zanati, M.R., Guirguis, M.A., Saber, M.S. (1973). Biological and chemical determination of available potassium in soil. *Zentralblatt für Bakteriologie, Parasitenkunde, Infektionskrankheiten und Hygiene. Zweite naturwissenschaftliche Abt.: Allgemeine, landwirtschaftliche und technische Mikrobiologie*, 1973, 128(5), pp. 572–577
99. Zayed, M.N., Saber, M.S., Abd-el-Malek, Y., Monib, M. (1971). Antibacterial substances in dry residues of certain higher Egyptian plants. *Zentralblatt für Bakteriologie, Parasitenkunde, Infektionskrankheiten und Hygiene. Zweite naturwissenschaftliche Abt.: Allgemeine, landwirtschaftliche und technische Mikrobiologie*, 1971, 126(6), pp. 615–629.
100. Zayed, M.N., Taha, S.M., Saber, M.S., Badr-el-Din, S.M. (1973). Nitrogen transformations in soils. I. In sandy soil under barley and peanut in a two years' rotation. *Zentralblatt für Bakteriologie, Parasitenkunde, Infektionskrankheiten und Hygiene. Zweite naturwissenschaftliche Abt.: Allgemeine, landwirtschaftliche und technische Mikrobiologie*, 1973, 128(1), pp. 116–125 *Zeitschrift für Pflanzenernährung und Bodenkunde*, 1975, 138(2), pp. 173–179