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Impacts of Reuses of Agricultural Drainage Water on Soil Salinity and Suggest Modifications on Leaching Fraction

Mostafa M. A. Soliman, N. N. M. Ramadan and Ali M. A. El-Nagar

Soil Department, Faculty of Agriculture, Cairo University, Egypt

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Abstract

The objective of this work is to study the impacts of using agricultural drainage water in irrigation even direct or after blending with fresh water compared with using fresh water on soil salinity and sodicity. This field study takes place for four continuous seasons in old alluvial soil of the Nile Delta and new reclaimed sandy soils. The reuse study has gone under surface flooding irrigation and drip irrigation with five different drains water, in addition to one type of blended water compared with using fresh water. A column experiment was applied to test the field results of calculated traditional leaching fraction and its suggested modifications in leaching the salts that were added by poor quality water. Leaching fraction means adding extra amounts over the regular irrigation water to leach out amounts of salts from soil equal to that added by using poor quality water. Leaching fraction (LF) = EC_{iw}/EC_{dw} could be calculated to keep the soil salinity as it is without increment in case of cultivating salt tolerant crops such as barley and sugar beet. It may also be calculated to decrease the soil salinity to be below the critical salinity level of 4 dS/m to make the soil suitable for cultivating wide numbers of economic field crops in case of high soil salinity. However, the surface flood irrigation has low irrigation efficiency under alluvial soils in Egypt as 50% increased to 74% under reuses of drainage water, and 90% in drip irrigation. Low Irrigation efficiency provides a surplus of irrigation water ranging between 10 - 50% according to the irrigation type, moves to the drains with capability to leach out significant amounts of soil salinity which should be considered during calculation of the actual LF to save much water.

The obtained data showed that the reuse of agricultural drainage water added much more salts to the soil than blended and fresh ones. Thus the leaching fraction to keep the soil salinity without increments was high under reuse fields. Considering the soil salinity of some alluvial fields that irrigates by drainage water for a long time, recorded high values exceeding 22 dS/m in the surface

layers. These high salinity increased the leaching fraction sharply to decrease the soil salinity to 4 dS/m. considering the irrigation efficiency of 50 and 74% for surface flood irrigation under fresh and reuse systems; the low irrigation efficiency was enough to leach out all added salts by different types of irrigation water and also to decrease soil salinity to 4 dS/m. Thus this study strongly recommends that, in case of alluvial clay and loamy soils that reuse agricultural drainage water or any poor quality water in irrigation, the irrigation efficiency should not exceed 75% to grantee leaching out all amounts of added salts by irrigation water, to prevent the building up of soil salinity. Moreover; the study showed that annual irrigation water should not be less than 6000 m³ /acre under the dry warm weather of arid region such as Egypt. The same trend was observed under drip irrigation with 90% irrigation efficiency with applied tradition LF or modified one to leach out amounts of salts equal to that added by irrigation water and to decrease the soil salinity concerning irrigation efficiency.

Keywords: Reuse, drainage water, blended water, irrigation efficiency, soil salinity, leaching fraction.

Introduction

Agricultural drainage water is a product of irrigation water that exceeds the soil holding capacity. During irrigation, the soil water has only a vertical down mobility carried on its way to some soluble material such as salts, nutrients, pesticides and chemical fertilizers. In this case, the water becomes a solution which lies out in the drain body from the bottom of the drain or through the porous pipes. Thus, the reuse of agricultural drainage water in irrigation will affect soil salinity and Sodicity. These added salts to the soil and should be leached out periodically to prevent the building up of both soil salinity and sodicity. Leaching fraction (LF) means adding an extra amount of irrigation water over the regular ones to leach out amounts of salts from the soil equal to that added by the poor quality water. This takes place during cultivation seasons not during reclaiming saline and sodic soils which need “leaching requirements” not a leaching fraction. Leaching fraction can be calculated by dividing the salinity of irrigation water over the salinity of soil solution which moves towards the drain system (Ayers and Westcot, 1985; Ramadan N.N.M, 2016; and Minhas P.S, *et al.*, 2020), thus it may be replaced by the salinity of drainage water which in fact represents the salinity of soil solution. This method applies when the target is keeping the soil salinity as it is without increments in case of cultivating salt tolerant crops such as barely or sugar beet to save water, time and cost. It may also be calculated to reduce the soil salinity to be around 4 dS/m in case of high soil salinity due to a long history of irrigation for a long time by the drainage water. Under the condition of applying surface flood irrigation with low efficiency of 50% in alluvial soil or under the reuse system which rise the irrigation efficiency to 74% according to the Egyptian Ministry of water resources and irrigation (MWRI, 2021), because the reuses of the drainage water return back the 50% of the irrigation water that went to the drains to the fields again and the soil will keep another 50% from this 50% which means the reuse system rise the surface flood irrigation to almost 74%. The irrigation efficiency even if 50 % in using fresh water or 74% in reuse of drainage water, will provide the amount of water for leaching should be reduced from the LF; thus a modification for leaching fraction should be considered and recalculated.

The objective of this to study is (1) to locate the impacts of reuse of agricultural drainage water in irrigation even directly or after blended with fresh water on both soil salinity and sodicity compared with using fresh water in irrigation.; (2) Studying the effects of reuse policy in both of alluvial and sandy soils of Sharqia Governorate located in the East of Nile Delta.; (3) to estimate the leaching fraction that needed to leach out the added salts of these types of water quality; (4) to suggest some modification on calculation of leaching fraction on clayey and sandy soils in addition to surface and drip irrigation Finally. (5) to suggest the maximum irrigation efficiency can guarantee the needed leaching fraction to leach out the salts that are added to the soil by different types of irrigation water.

Materials and Methods

The water samples were collected to cover winter and summer seasons to follow the cultivation seasons, thus; they were collected in January and July during the years 2021 and 2022 with a total of 4 groups of samples. Water samples include drainage water canals that reuse, blended water canals, and fresh water canals, the locations of the samples were from the beginning, middle and end or irrigation bodies from the middle points of canals away from its two banks.

The same trends were applied with soil samples; which were collected during winter and summer seasons. Soil samples have been taken during January and July of the years 2021 and 2022 and represented the different places of the fields. Fig (1) shows the locations of water and soil samples.

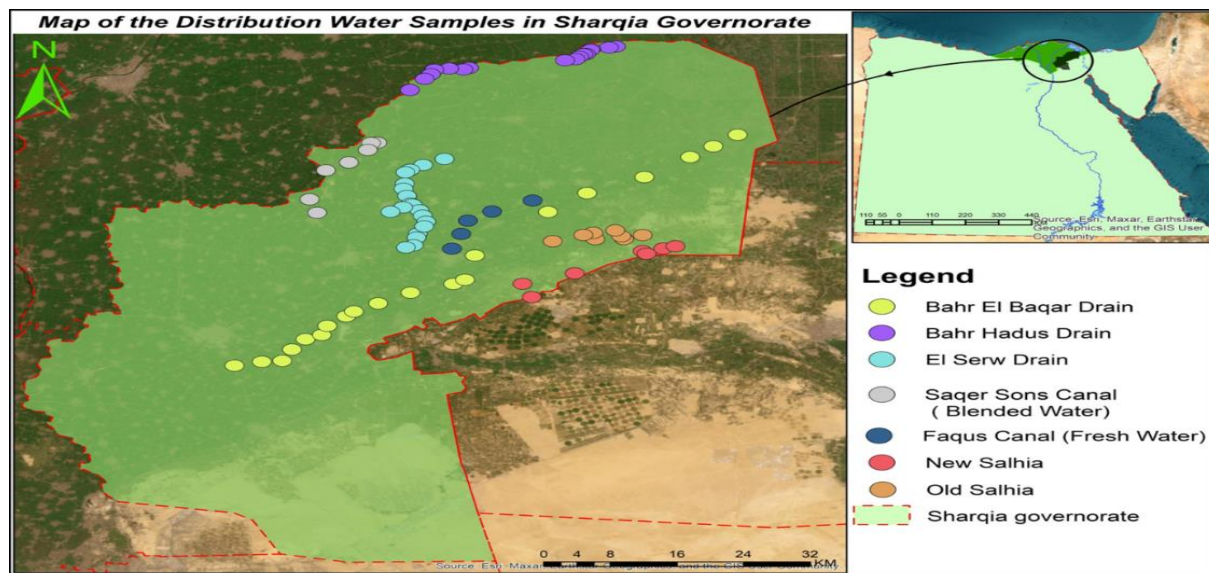


Fig.1. Locations of the selected water samples.

Table.1. Coordinates and descriptions of the selected water and soil samples in Sharqia Governorate

Sites	Coordinates
Bahr Hadus Drain	from (31° 06` 19.8`` N, 32° 00` 11.84`` E) to (31° 01` 33`` N, 31° 44` 41`` E)
Bahr EL-Baqer Drain	from (30° 30` 58`` N, 31° 34` 00`` E) to(30° 56` 41.42`` N, 32° 8` 59.86`` E)
El-Serw Drain	from (30° 54` 12`` N, 31° 47` 23.2`` E) to(30° 44` 42.9`` N, 31° 44` 36.24`` E)
Old Salhia	from (30° 46` 11.46`` N, 32° 02` 24.03`` E)

Almurur Drain Azaziya Canal Arab Shams Canal	to(30° 44` 54.8`` N, 31° 53` 22.29`` E)
New Sahlia Al-Kassara Canal - Abo Shalabi Italian Company Drain	from (30° 39` 35.64`` N, 31° 58` 1.05`` E) to (30° 45` 1.3`` N, 32° 04` 54`` E)
Saqer Son Canal Blending Water	from (30° 55` 53.63`` N, 31° 42` 17.09`` E) to(30° 48` 21.82`` N, 31° 37` 51.57`` E)
Faqus Canal Fresh Water	from (30° 44` 10`` N, 31° 49` 37`` E) to(30° 49` 49`` N, 31° 54` 5`` E)

Chemical analysis of soil and water Samples

Soil samples were prepared for the regular chemical analysis according to the FAO recommended methods (2008). SAR and RSC were calculated for all types of irrigation water and soil samples. Leaching fraction (LF) was calculated in different ways; according to the traditional method to keep the soil salinity as it is without increment (Gois *et al.*, 2019) and according to the suggested modified method by this work to decrease the soil salinity to 4 dS/m. In addition, LF was also calculated concerning irrigation efficiency as another suggestion of the work.

The Leaching Lab Experiment includes a fifty cm of plastic tube that was corrugated in the internal wall with a diameter of (10 cm); 30 cm high. Non-disturbed soil columns were collected from different field sites. The experiment was connected to test the calculated LF and to examine its efficiency in meeting the leaching of the added salts by each type of irrigation water. The experiment was connected for 6 month with adding the equivalent amount of water per acre at the same time of irrigation in the field; it looks like intermittent leaching.

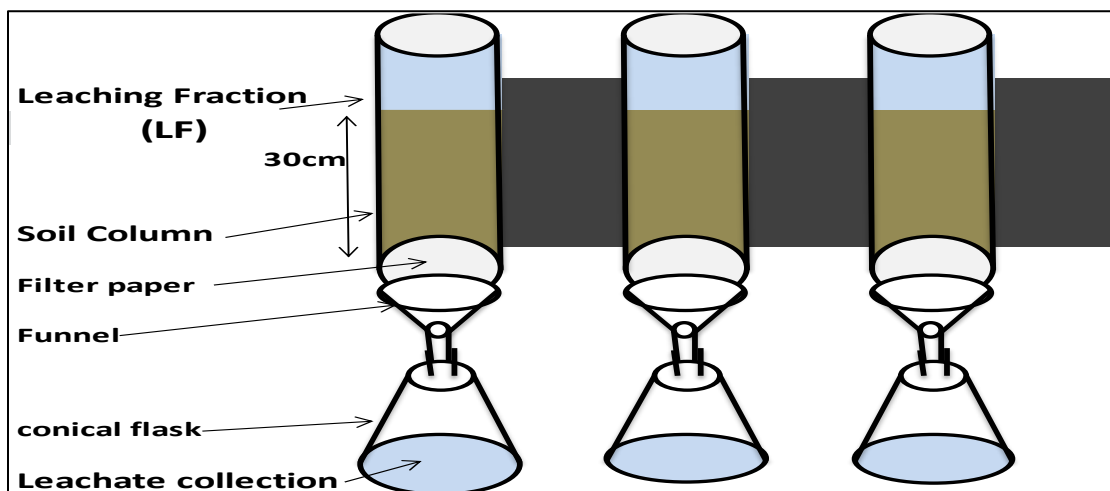


Fig.2. Laboratory column experiment

RESULTS AND DISCUSSION

The main sources of the secondary salinity in Nile Delta alluvial soils are irrigation water, water logging and seawater intrusion even in the soil and shallow groundwater (Kotb *et al.*, 2000; Ramadan .N.N.M, 2016; and SALAD, 2020). There is no initial soil salinity in the Delta land because this alluvial soil was transported by fresh water of the Nile river stream mainly from the sub basin Abyssinian highlands.

In general, all water samples show an increase in its EC value during summer season than in winter season. This may be due to the increase of evapotranspiration gathering with increasing solubility of most salts with increasing the temperature during summer season such as sodium sulphate and sodium carbonate (Khan .M.S and Rogak .S.N., 2004). The EC of drainage water ranged between 1.6 – 2.4 dS/m (1000 – 1500 ppm) which classified as moderate water quality for irrigation with some restriction on use (FAO, 1985; Ejaz *et al.*, 2019; Nayla Hassan, 2019; and Ammar Tiri *et al.*, 2020). The salinity of blended water decreased to be 0.8 – 1.2 dS/m (500- 770 ppm) which is also considered as low marginal water quality; while the salinity of fresh irrigation water recorded 0.35 - 0.55 (225 – 350 ppm) as a good water quality with no restriction on use for all types of soils and all crops (FAO 1985).

Dominant cations and anions in irrigation water showed that the summation of (Ca + Mg) exceeds Na concentration which is a good indication about its future effects on soil sodicity and alkalinity. Carbonate plus bicarbonate is the dominant anion as in freshwater as a slightly soluble salt found in the rivers water (usually calcium and Mg carbonates and bicarbonate as in Nile River water), followed by little concentration of sulphates and chlorides, thus the salinity potential is limited. The pH value of all types of irrigation water is less than 8 which means we should care about the salinity effects of the irrigation water. SAR and RSC of all irrigation water are low and classified as good to medium irrigation water quality (FAO 1988), as shown in table (2, 3).

Table.2. Chemical analysis of drainage, blended and fresh irrigation water

Sites	Season (Two years average)	(EC _w) (dS/m)	pH	Soluble Cations				Soluble Anions			
				(Meq/L)				(Meq/L)			
				Na	K	Ca	Mg	CO ₃	HCO ₃	CL	SO ₄
Bahr Hadus (Drainage Water)	Winter 21,22	1.75	7.25	7	0.3	6.3	4.2	0	6.7	7.3	3.5
	Summer 21,22	2	7.1	7.75	0.4	7	5	0	7.3	9	3.8
Bahr EL-Baqer (Drainage Water)	Winter 21,22	1.65	7.2	6.9	0.4	5.5	4	0	6.5	7.3	3
	Summer 21,22	1.9	7.1	8.5	0.4	6	4.5	0	7.3	8.5	3.2
EL-Serw (Drainage Water)	Winter 21,22	2	7.65	7.9	0.3	6.5	6	0	8.5	9	2.5
	Summer 21,22	2.3	7.55	9	0.4	7.5	7	0	9.5	10.5	3
Old Salhia (Drainage Water)	Winter 21,22	1.45	7.6	6	0.3	4.7	3.5	0	5.5	7.5	1.5
	Summer 21,22	1.85	7.5	7.3	0.4	6.3	4.8	0	6.7	9.5	2.3
New Salhia (Drainage Water)	Winter 21,22	2.15	7.5	10	0.1	6.3	5.2	0	8.3	10	3.2
	Summer 21,22	2.3	7.4	11	0.1	6.8	5.5	0	8.8	10.8	3.4
Saqer Son Canal (Blended Water)	Winter 21,22	0.85	7.8	1.4	0.1	3.8	3.2	0	3.5	4	1
	Summer 21,22	1.1	7.6	1.7	0.1	5.5	3.8	0	4.5	5.5	1
Faqus Canal (Fresh Water)	Winter 21,22	0.38	7.5	1	0.1	1.4	1.3	0	1.8	1.5	0.5
	Summer 21,22	0.53	7.4	1.1	0.1	2.5	1.8	0	2.7	2	0.6
New Salhia (Fresh water)	Winter 21,22	0.38	7.7	0.9	0.1	1.7	1.3	0	1.8	1.4	0.7
	Summer 21,22	0.5	7.6	1.1	0.1	2.2	1.9	0	2.4	1.9	0.9

Table.3. Sodium adsorption ratio (SAR) and residual sodium carbonates (RSC) of the irrigation waters

Sites	SAR mmole/liter	Suitability	RSC mmole/liter	Suitability
Bahr Hadus (Drainage Water)	7.1	Medium quality water	-3	Good quality water
Bahr EL-Baqer (Drainage Water)	6.7	Medium quality water	-2	Good quality water
	5.4	High Normal quality water		
EL-Serw (Drainage Water)	6.1	Medium quality water	-3.5	Good quality water
	5.7	High Normal quality water		
Old Salhia (Drainage Water)	6.2	Low Medium quality water	-2	Good quality water
New Salhia (Drainage Water)	6.1	Low Medium quality water	-3	Good quality water
Saqer Son Canal (Blended Water)	0.74	Good quality water	-1	Good quality water
Faqus Canal (Fresh Water)	0.55	Good quality water	0.2	Good quality water
New Salhia (Fresh Water)	1.6	Good quality water	0.2	Good quality water

Soil texture

Data in Table (4) show mechanical analysis of the studied fields samples which carefully selected from different types of clayey, sandy and loamy soils to study the salt accumulation in different soil types under different types of water quality and different irrigation methods (surface flood and drip irrigation).

Table.4. Mechanical analysis of the studied samples in different fields

Soil under irrigation by	Texture
Bahr Hadus (Drainage Water)	Clay
	Clay Loam
Bahr EL-Baqer (Drainage Water)	Clay
	Clay Loam
EL-Serw (Drainage Water)	Clay
	Clay Loam
Old Salhia (Drainage Water)	Sandy Silt Loam
	Clay Loam
New Salhia (Drainage Water)	Loamy Sand
Saqer Son Canal (Blended Water)	Clay Loam
Faqus Canal (Fresh Water)	Clay
	Clay Loam
New Salhia (Fresh Water)	Sandy

Soil Chemical Analysis

Table (5) shows the soil chemical analysis of different zones of the irrigation canal that were irrigated through the last 30 years with agricultural drainage water, blended water and freshwater.

In general the pH values are around the neutral (7 to 8) except for soils that are irrigated by fresh water. The fresh water of the Nile River is characterized by carbonates and bi-carbonates (MWRI, 2021). This type of low salinity and high carbonates concentration threatens the irrigated soils by sodicity (non-saline sodic soils) problems, (Abou El-Defan *et al.*, 2016).

Regarding the EC value and soil salinity, the data shows that all alluvial soils which are directly irrigated by drainage water have a high salinity in the surface layer (0-60 cm), exceeding 22 dS/m in some sites, with little increase during summer season. In contrast most sites of soil samples that were irrigated by blended or fresh water have an EC value not exceeding 5 dS/m. This explains the accumulation effects of using poor quality water for a long time and its need to apply leaching fraction periodically to prevent the salinity building up.

Most soil sites that are under irrigation by drainage water have a pH value below 8.4, while the soil under irrigation by fresh or blended water, recorded pH up to 8.9. This is due to the effects of using low salinity high carbonates and bicarbonate water in irrigation in some non-saline soils.

Table.5. Chemical analysis of the soils by each type of irrigation water

Zone of	Season (Two years average)	EC _e dS/m	pH	Soluble Cations				Soluble Anions				Texture
				Na	K	Ca	Mg	CO ₃	HCO ₃	CL	SO ₄	
Bahr Hadus Drain	Winter 21,22	11.3	8.3	52	13	38	33	16	29	47	43	Clay
	Summer 21,22	12.8	8.1	60	14.3	44	36.5	18.6	32.4	55.5	48.0	
Bahr EL-Baqer Drain	Winter 21,22	10.2	8.25	45	10	36	31	14	28	42	38	Clay Loam
	Summer 21,22	11.5	8.1	52	10.6	41.5	34.6	16.3	33.3	48.5	40	
EL-Serw Drain	Winter 21,22	8.6	8.3	38.6	4.9	32.5	27.1	8.8	26.3	40.6	27.4	Clay
	Summer 21,22	10.3	8.1	46.3	6.0	38.6	32.8	10.5	30.9	47.3	34.5	
Old Salhia Almurur Drain	Winter 21,22	3.9	8.3	14.5	1.5	12.5	10.5	1.8	15	19	3	Sandy Silt Loam
	Summer 21,22	5	8.1	21	2	15	13	2	18	25	5	
New Salhia Italian Company Drain	Winter 21,22	6.6	8.3	30	2	25	23	2	24	34	19.2	Loamy Sand
	Summer 21,22	8.2	8.1	35	3	30	30	3.5	29	41	24.9	
Saqr Sons Canal	Winter 21,22	2.8	8.3	12	1	10.0	8	1.5	10.5	14.5	2.3	Clay Loam
	Summer 21,22	3.6	8.1	15	1	11.5	8	2.8	12.5	17.5	3.3	
Faqus Canal	Winter 21,22	2.85	8.25	11	1.1	10	7	1	12	13	2.5	Clay Loam
	Summer 21,22	3.9	8.1	15.5	1.35	14	9	1.5	15.5	18	4	
New Salhia Al-Kassara Canal	Winter 21,22	2.4	8.5	9	0.9	8	6	1	10	11	2	Sandy
	Summer 21,22	3	8.4	13	1	9	8	1.5	11	15	2.5	

The amount of salts added to the soil by each type of irrigation water

In General, all types of irrigation water contain soluble salts except rainfall water. The river's water contains little salts with predominant of slightly soluble salts such as carbonate and bicarbonate of calcium and magnesium as it is in the River Nile water. With increasing salinity, the salt type and the soluble ions are changed from carbonate to sulphate and finally to chloride. That means all types of irrigation water will add amounts of salts to the soils depending on their concentration and their sources (river, ground water, reuse of drainage water and blended water). The Nile water adds about 2 - 3 tons/ acre. year even it is one of the best freshwater quality of the world rivers at a concentration of 350 - 500 ppm. The irrigation rate by surface flood irrigation is 6000 m³/ acre. year (based on the consumption use of wheat as an example of winter crop is 2500 m³/acre, and for maize as a summer crop is 3500 m³/acre) and 4000 m³/acre. year under drip irrigation in dry regions such as Egypt, (MWRI, 2021). Using drainage water or bended water logically will add much more salts to the soils. The quality of drainage water depends on the soil salinity that drain serves, the type of cultivated crop (such as rice which delivers much water to the drains while wheat and winter season crops deliver less and concentrate water and the same with maize, cotton and summer season crops). The temperature, evaporation, sea water intrusion, precipitation, irrigation efficiency and soil texture also affects the salinity of drainage water. Sandy soil retains less water due to its little capillary pores than clayey ones, and also easy to be leached according its predominant of the drain pores, In contrary, clayey soil characteristic by predominant of capillary pore that retain the water against gravity and its difficulty to be leached. This is called the double effect; high water retention of poor quality water and difficult to be leached. While sandy soil has small water retention and is easy to leach. Thus, heavy texture soils should leach out an amount of salts from soil equal to that added by irrigation water annually or every season. This could be achieved through several techniques; lowering irrigation efficiency, applied leaching fraction in surface flood irrigation and pivot system or opening the end of the sub-main lines of drip irrigation pipes system at the end of each season. The amounts of salt which were added by reuse of agricultural drainage water in the studied fields are illustrated in table (6).

Table.6. Amount of added salts to the soil for each type of irrigation water by direct reuse of drainage water

Sites	EC _{iw}	TDS	Irrigation Water (Avg)	Salt added	Texture
	dS/m	mg/L	m ³ / acre. year	Ton/ acre. year	
Bahr Hadus (Drainage Water) (Flood irrigation)	2.03	1299	6000	7.8	Clay
Bahr EL-Baqer (Drainage Water) (Flood irrigation)	1.84	1177	6000	7.1	Clay Loam
EL-Serw Drain (Drainage Water) (Flood irrigation)	2.1	1344	6000	8	Clay
Old Salhia (Drainage Water) (Flood irrigation)	1.9	1216	6000	7.3	Sandy Silt Loam
New Salhia (Drainage Water) (Drip irrigation)	2.5	1600	4000	6.4	Loamy Sand
Saqr Sons Canal (Blended Water)	0.95	608	6000	3.6	Clay Loam

(Flood irrigation)					
Faqus Canal (Fresh Water) (Flood Irrigation)	0.47	300	6000	1.8	Clay Loam
New Salhia (Fresh Water) (Drip irrigation)	0.75	480	4000	1.9	Sandy soil

Salts added by different flood irrigation water and its traditional leaching fraction.

The data in table (6) shows that the amount of salt added to the soil under surface flood irrigation at a rate of 6000 m³ / acre.year, by direct reuse of drainage water reached its maximum as high as 8.2 ton/acre.year in El-Serw drain and the minimum amount was recorded in Bahr El-Baqar drain water of 7.04 ton/acre.year. The amount of added salts by fresh irrigation water was as low as 1.78ton/acre.year in the “faqus canal”, while it was 3.67ton/acre.year in the blended water of the “Saqr Sons” canal.

Under the drip irrigation system applied fresh water at a rate of 4000 m³/acre.year; it is 1.93ton/acre.year under irrigation from “New Salhia” fresh water canal.

Increasing the amount of salt added under drip irrigation more than flood irrigation using fresh water, even the drip only applying 4000 instead of 6000 m³/ acre. year on surface flood, can be attributed due to the high irrigation efficiency of drip system as high as 85 - 90%, while the surface flood irrigation has a low irrigation efficiency of 50%, (FAO, 2014). Thus, the drip irrigation systems never provide, or provide little amounts; of excess water as a leaching fraction and that lead to salt accumulation at the end of wetting front. In contrast, the surface flood irrigation with fresh water provides 50% of irrigation water as leaching fraction which leach out more salts from the soil and lower the building up of soil salinity. This observation was the reason to think about suggesting another modification on leaching fraction concerning the irrigation efficiency.

Leaching fraction to maintain the soil salinity without increment

Globally, leaching fraction (LF) according to (Ramadan .N.N.M, 2016; Minhas .P.S. , *et al.*, 2020; FAO, 2023) is calculated by dividing EC value of irrigation water (EC_{iw}) over the EC value of the soil solution expressed as drainage water (EC_e or EC_{dw}) as the following equation shows:

$$\text{Leaching Fraction (LF) \%} = (\text{EC}_{iw} / \text{EC}_{dw}) \times 100$$

The drainage water represents the EC of the soil solution which should not exceed 4 dS/m, or the EC value of the salinity tolerant for most major crops (such as barley which is salinity tolerant up to EC 8 dS/m) (Maas and Hoffman, 1977; Maas, 1984; NRCS, USDA, 2017).

Calculation of traditional leaching fraction concerning the amount of extra water over the regular irrigation that keeps the soil salinity as it is without increment and just to leach out an amount of salts from the soil equal to that added by irrigation water.

The modified leaching fraction suggested in this work is calculate to decrease the soil salinity to the standard salinity level of EC 4 dS/m, in addition to leach out the salts that were added by irrigation water, Table (7) show the traditional leaching fraction for each type of irrigation water.

Table.7. Leaching fraction under using for each type of irrigation water

Sites	EC _{iw}	EC _e	LF	LF %	Irrigation Water (Avg)	LF water	Texture
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	Extract of Soil paste		EC _{iw} / EC _{dw}		m ³ / acre. year	m ³ / acre. year	
	dS/m	dS/m					
Bahr Hadus (Drainage Water) (Flood irrigation)	2.03	11.3	0.18	18	6000	1080	Clay
Bahr EL-Baqer (Drainage Water) (Flood irrigation)	1.84	9.13	0.2	20	6000	1200	Clay Loam
EL-Serw (Drainage Water) (Flood irrigation)	2.1	8.9	0.23	23	6000	1380	Clay
Old Salhia (Drainage Water) (Flood irrigation)	1.9	4.6	0.41	41	6000	2460	Sandy Silt Loam
New Salhia (Drainage Water) (Drip irrigation)	2.5	8.6	0.29	29	4000	1160	Loamy Sand
Saqr Sons Canal (Blended Water) (Flood irrigation)	0.95	3.5	0.27	27	6000	1620	Clay Loam
Faqus Canal (Fresh Water) (Flood irrigation)	0.47	3.9	0.12	12	6000	720	Clay Loam
New Salhia (Fresh Water) (Drip irrigation)	0.75	2.8	0.27	27	4000	1080	Sandy soil

Traditional LF to keep the soil salinity as it is without increment

The data in Tables (8) shows that the, leaching fraction of direct reuse of drainage water is higher than both blended and fresh water.

Table.8. Traditional leaching fraction to maintain the soil salinity without increment under reuse of drainage water.

Sites	EC _{iw}	EC _e Extract of soil paste	LF	LF water	Irrigation Water (Avg)	Irrigation Water + LF	Texture
	dS/m	dS/m	%	m ³ / acre. year	m ³ / acre. year	m ³ / acre. year	
Bahr Hadus (Drainage Water) (Flood irrigation)	2.03	11.3	18	1080	6000	7080	Clay
Bahr EL-Baqer (Drainage Water) (Flood irrigation)	1.84	9.1	20	1200	6000	7200	Clay Loam
EL-Serw (Drainage Water) (Flood irrigation)	2.1	8.9	23	1380	6000	7380	Clay
Old Salhia (Drainage Water) (Flood irrigation)	1.9	4.6	41	2460	6000	8460	Sandy Silt Loam
New Salhia (Drainage Water) (Drip irrigation)	2.5	8.6	29	1160	4000	5160	Loamy Sand

Saqr Sons Canal (Blended Water) (Flood irrigation)	0.95	3.5	27	1620	6000	7620	Clay Loam
Faqus Canal (Fresh Water) (Flood irrigation)	0.47	3.9	12	720	6000	6720	Clay Loam
New Sahlia (Fresh Water) (Drip irrigation)	0.75	2.8	27	1080	4000	5080	Sandy soil

LF reached a maximum of 3400 m³/ acre. year in some sites of Bahr EL-Baqer drain zone, over the regular irrigation water of 6000 m³/ acre. year. The minimum amount in this type of irrigation water was recorded as low as 500 m³/ acre. year because of the high EC value of the soil (which the LF should keep it as it is) even though the relatively high EC of reuse water. This is one of the reasons that give this work a chance to suggest a modified leaching fraction to deal with soil and water salinity to keep the soil healthy, (Ning *et al.*, 2020).

The amount of traditional leaching fraction water in the blended irrigation system was 1680 m³/ acre. year over the regular irrigation water, The same number was 763.33 – 1097 m³/ acre. year in case of using fresh water in irrigation.

Modified leaching fraction to reduce the soil salinity below salinity standard (4 dS/m)

Data in Table (9) show the modified leaching fraction that deals with reducing soil salinity during cultivation concerning salinity of irrigation water. Under the long history of using drainage water in irrigation, the salinity of surface soil increased. The cultivated crops in this soil are mostly salt tolerant with no chance to cultivate sensitive or medium tolerant crops. This is a kind of land degradation due to salinity (Ali .R.R., 2012, Kh.Darwish, *et al.*, 2013). The idea of modified LF is to gradually reduce the soil salinity during cultivation and at the same time leaching out the accumulated salinity that is created by long period using of drainage water.

Accordingly, the modified LF will suppose the EC_{dw} which in fact the soil solution salinity which moves towards the drainage canal and at the same time keeps the soil salinity as non-saline soil.

Table.9. Modified leaching fraction to reduce the soil salinity to (4 dS/m) under reuse of drainage water.

Sites	EC _{iw}	ECe Initial soil salinity	Target Final EC _{dw}	LF EC _{iw} / EC _{dw}	LF %	Irrigation Water (Avg)	LF water	Texture
	dS/m	dS/m	4 dS/m			m ³ / acre. year	m ³ / acre. year	
Bahr Hadus (Drainage Water) (Flood irrigation)	2.03	11.3	4	0.51	51	6000	3060	Clay
Bahr EL-Baqer (Drainage Water) (Flood irrigation)	1.84	9.1	4	0.46	46	6000	2760	Clay Loam
EL-Serw (Drainage Water) (Flood irrigation)	2.1	8.9	4	0.52	52	6000	3120	Clay
Old Sahlia (Drainage Water) (Flood irrigation)	1.9	4.6	4	0.48	48	6000	2880	Sandy Silt Loam

New Salhia (Drainage Water) (Drip irrigation)	2.5	8.6	4	0.62	62	4000	2480	Loamy Sand
Saqr Sons Canal (Blended Water) (Flood irrigation)	0.95	3.5	4	0.24	24	6000	1440	Clay Loam
Faqus Canal (Fresh Water) (Flood irrigation)	0.47	3.9	4	0.12	12	6000	720	Clay Loam
New Salhia (Fresh Water) (Drip irrigation)	0.75	2.8	4	0.19	19	4000	760	Sandy

Modified Leaching Fractions concerning irrigation efficiency to maintain the soil salinity without increment

Another modification on Leaching Fractions concerning irrigation efficiency, it is well-known that the surface flood irrigation has a low efficiency as 50% in the clayey and loamy soils, decreased to 20-30% in the sandy soils according to its small water retention (Shyam *et al.*, 2013; FAO, 2014; Scheierling and Treguer, 2018). That means that about 50% of irrigation water in this method will move to the drains. The reuse means the return back of drain water again to the fields. The fields will retain another 50% of the last 50% that went to the drain system, thus the reuse system raises the surface flood irrigation efficiency to 74% (MWRI, 2021). That means the reuse system under surface flood irrigation provides about 26% as a permanent leaching fraction. Under drip irrigation systems the LF only provides 10 – 15 % as leaching fraction due to the high irrigation efficiency of 85 - 90%. Thus; the calculated leaching fraction should be reduced by this value according to the irrigation efficiency.

These new modifications were applied to maintain the soil salinity as it is without increments under irrigation with the use of the five types of irrigation, and other ones the modification is to reduce the soil salinity around EC of 4 dS/m.

Table.10. Modified leaching fractions concerning irrigation efficiency to maintain the soil salinity without increment in the different types of irrigation water.

Sites	LF To maintain soil salinity	Irrigation Efficiency	LF	Modified LF Du to Soil salinity and Irri. eff.	Modified LF	Irri water + Modified LF	Texture
	%	%	%	%	m ³ / acre. year	m ³ / acre. year	
Bahr Hadus (Drainage Water) (Flood irrigation)	18	74	26	-	-	6000	Clay
Bahr EL-Baqer (Drainage Water) (Flood irrigation)	20	74	26	-	-	6000	Clay Loam
EL-Serw (Drainage Water) (Flood irrigation)	23	74	26	-	-	6000	Clay
Old Salhia (Drainage Water) (Flood irrigation)	41	74	26	15	900	6900	Sandy Silt Loam
New Salhia (Drainage Water)	29	90	10	19	760	4760	Loamy Sand

(Drip irrigation)							
Saqr Sons Canal (Blended Water)	27	74	26	1	60	6060	Clay Loam
(Flood irrigation)							
Faqus Canal (Fresh Water)	12	50	50	-	-	6000	Clay Loam
(Flood irrigation)							
New Salhia (Fresh Water)	27	9	10	17	680	4680	Sandy
(Drip irrigation)							

In case of Modified LF concerning irrigation efficiency; under using drainage water in surface flood irrigation to maintain the soil salinity as it is. The data showed that the leaching fractions were reduced sharply than its value when it was calculated without concerning irrigation efficiency. Most sites don't need additional irrigation water as a leaching fraction, because the 26% of residual water under irrigation efficiency of 74% as extra to soil water retention is actually enough to leach out amounts of salts from soils equal to that added by poor quality of drainage water. Some sites in this system of reuse show a large decrease of the amount of needed water as a leaching fraction where it was 2241.5 m³/ acre. year in the Hadus drainage water, decreased to 690 m³/ acre. year under this modification. Moreover, the amounts of water as a leaching fraction were m³/ acre. year in bahr El-Baqer drain, reduced to 1290 m³/ acre. year; and from 2357 to 780 m³/ acre. year in El-Serw drain, and from 1500 – 2040 to zero – 480 m³/ acre. year in Saqr sons drain.

Under the use of fresh water in irrigation the surface flood irrigation efficiency will be 50% because there are no reuse systems, this 50% extra water is enough to leach out the added salts from irrigation water and no need to add additional water as leaching fraction. These results will be important in the recommendation of this work where the irrigation efficiency in the alluvial Nile Delta soils should not exceed 75% under use of drainage or bended water in irrigation. The same reductions in LF values were observed under drip irrigation systems as shown in table (11).

Table.11. Traditional and Modified Leaching Fraction concerning Irrigation efficiency under the different types of irrigation water

Bahr Hadus (Drainage Water) (Flood irrigation)	LF to maintain soil salinity	LF water	Irri water + LF . Traditional	LF of soil salinity and Irri. Eff	Modified LF water	Final irrigation water (Irri.Eff +LF)	Texture
	%	m ³ / acre. year	m ³ / acre. year	%	m ³ / acre. year	m ³ / acre. year	
1	16.7	987	6987	-	-	6000	Clay
2	37.5	2250	8250	11.5	690	6690	Clay Loam
Bahr EL- Baqer (Drainage Water) (Flood irrigation)	LF to maintain soil salinity	LF water	Irri water + LF . Traditional	LF of soil salinity and Irri. Eff	Modified LF water	Final irrigation water (Irri.Eff +LF)	Texture
	%	m ³ / acre. year	m ³ / acre. year	%	m ³ / acre. year	m ³ / acre. year	
1	18	1094	7094	-	-	6000	Clay Loam
2	47.5	2850	8850	21.5	1290	7290	Clay Loam

EL-Serw (Drainage Water) (Flood irrigation)	LF to maintain soil salinity	LF water	Irri water + LF . Traditional	LF of soil salinity and Irri. Eff	Modified LF water	Final irrigation water (Irri.Eff +LF)	Texture
	%	m ³ / acre. year	m ³ / acre. year	%	m ³ / acre. year	m ³ / acre. year	
1	21	1252	7252	-	-	6000	Clay
2	39	2340	8340	13	780	6780	Clay Loam
Old Salhia (Drainage Water) (Flood irrigation)	LF to maintain soil salinity	LF water	Irri water + LF . Traditional	LF of soil salinity and Irri. Eff	Modified LF water	Final irrigation water (Irri.Eff +LF)	Texture
	%	m ³ / acre. year	m ³ / acre. year	%	m ³ / acre. year	m ³ / acre. year	
1	37.5	2250	8250	11.5	690	6690	Sandy Silt Loam
New Salhia (Drainage Water) (Drip irrigation)	LF to maintain soil salinity	LF water	Irri water + LF . Traditional	LF of soil salinity and Irri. Eff	Modified LF water	Final irrigation water (Irri.Eff +LF)	Texture
	%	m ³ / acre. year	m ³ / acre. year	%	m ³ / acre. year	m ³ / acre. year	
1	29.5	1180	5180	19.5	780	4780	Loamy Sand
Saqr Sons Canal (Blended Water) (Flood irrigation)	LF to maintain soil salinity	LF water	Irri water + LF . Traditional	LF of soil salinity and Irri. Eff	Modified LF water	Final irrigation water (Irri.Eff +LF)	Texture
	%	m ³ / acre. year	m ³ / acre. year	%	m ³ / acre. year	m ³ / acre. year	
1	25	1500	7500	-	-	6000	Clay Loam
2	34	2040	8040	8	480	6480	Clay Loam
Sites	LF to maintain soil salinity	LF water	Irri water + LF . Traditional	LF of soil salinity and Irri. Eff	Modified LF water	Final irrigation water (Irri.Eff +LF)	Texture
	%	m ³ / acre. year	m ³ / acre. year	%	m ³ / acre. year	m ³ / acre. year	
Faqus Canal (Fresh Water) (Flood irrigation)	13	763	6763	-	-	6000	Clay Loam
New Salhia (Fresh Water) (Drip irrigation)	28	1120	5120	18	720	4720	Sandy Soil

Leaching Experiment Result

The objective of the laboratory experiment is to apply the data of the field work to the soil under control in the laboratory condition to make sure that the calculation of the leaching fraction is correct or it may need to be modified. The experiment concerned one of the applications of leaching fraction to leach out an amount of soil salinity that equal to that was added by the different types of irrigation water and to decrease the soil salinity around 4 dS/m.

Data in Table (12) show the results, the obtained results reflect that; the rate of leaching fraction that theoretically calculated for the field study was fit and it enabled to leach out the salts of irrigation water in addition to reducing the soil salinity around 4 dS/m as planned. As tables (13) show, The data showed that the added of calculated leaching fraction is adequate enough to leach out all added salts with irrigation water and to decrease soil salinity to the safe level of non-saline soil with EC value lower than 4 dS/m.

Table.12. Leaching Fraction under lab experiment for the soil irrigated by the different types of irrigation water

Columns	EC _{iw} dS/m	EC _e Extract of Soil paste dS/m	Target Final EC _{dw} dS/m	LF EC _{iw} /EC _{dw}	LF %	Texture
Bahr Hadus (Drainage Water)	2	11.8	4	0.5	50	Clay
Bahr EL-Baqer (Drainage Water)	1.9	7.5	4	0.47	47	Clay Loam
EL-Serw (Drainage Water)	2.3	9.5	4	0.57	57	Clay
Old Salhia (Drainage Water)	2.2	5.5	4	0.55	55	Sandy Silt Loam
New Salhia (Drainage Water)	3.3	13.2	4	0.82	82	Loamy Sand
Saqr Sons Canal (Blended Water)	1.05	5	4	0.26	26	Clay Loam
Faqus Canal (Fresh Water)	0.49	5.7	4	0.12	12	Clay Loam

Soil salinity after applied modified leaching fraction for 6 months

Table.13. Soil salinity after applied modified leaching fraction under direct use the different types of irrigation water

Column	Initial Soil EC _e (dS/m)	Final soil EC _e (dS/m)	Texture
Bahr Hadus (Drainage Water)	11.8	4.2	Clay
Bahr EL-Baqer (Drainage Water)	7.5	2.6	Clay Loam
EL-Serw (Drainage Water)	9.5	3.1	Clay
Old Salhia (Drainage Water)	6.5	1.8	Sandy Silt Loam
New Salhia (Drainage Water)	19	6	Loamy Sand
Saqr Son Canal (Blended Water)	5	1.8	Clay Loam
Faqus Canal (Fresh Water)	5.7	1.9	Clay Loam

Conclusion and Recommendation

The reuse of agricultural drainage water became one of the Egyptian policies to overcome the water shortage in warm and dry countries. The drain water mostly is medium suitability to poor quality water will add an amount of salts to the soil that may affect the plants growth and cause salinity building up. Thus leaching fraction should be applied to the soil over the rate of regular irrigation water to prevent plant hazard over water salinity and also the increasing of soil salinity. In Egypt which applied mostly the surface flood irrigation in the old alluvial soils with low irrigation

efficiency as 74%; this will be enough to achieve the two past targets. The use of fresh water in irrigation has good water quality; it can raise the irrigation efficiency up to 90% as in surface and subsurface drip irrigation. The other recommendation can be summarized in:-

- 1- Direct reuse of agricultural drainage water in irrigation will add a significant amount of salts to the soils according to the soil salinity of the soils that drains serve.
- 2- The use of fresh or blended agricultural drainage water with fresh water will add less salt to the soil.
- 3- The amount of added salts to the soil by irrigation will differ according to soil texture.
- 4- Using leaching fraction may only be applied to keep the soil salinity without increment when the fields cultivated by some tolerant crops such as barley, sugar beet; and also may be modified to reduce the soil salinity around salinity level of 4 dS/m to grantee soil suitable for most economic crops.
- 5- When using medium or poor quality water in irrigation; applying leaching fraction is obligated to leach out an amount of salts from the soil that is equal to that added by this poor quality water.
- 6- Leaching fraction should be connected with irrigation efficiency to reduce its value from the calculated leaching fraction and to save much water.
- 7- In case of low efficiency of the irrigation system below 75%; this will be enough to leach out the salts that are added to the soil.
- 8- In the clay and loamy soil of the Nile Delta even under reuse or even fresh water under both high evaporation and evapotranspiration of Egypt weather, the irrigation efficiency should not exceed 75% to guarantee avoiding building up of soil salinity and also not to reduce the soil productivity in addition to stopping the osmotic pressure effects on holding water from the plant roots.

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