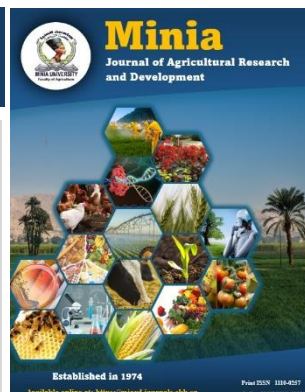




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Impact of Water Irrigation from an Aquaculture System with Different Levels of NPK on Growth and Product of Okra Plant.

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ABSTRACT

The plant and fish growing system has recently come under the spotlight as a form of modern agriculture that serves both scientific and economic objectives as Egypt looks to increase water exploitation. An option for boosting irrigation water productivity in permaculture under the restrictions of limited water supply is the integration of fish and crop production in an aquaponics system. The results of this study showed how the characteristics of sandy soil, vegetable production, and soil infiltration affected the water quality while recycling aquaculture (catfish) water for irrigation. The okra growth quality Measurements showed that the crop produced in pots receiving 50% of the suggested levels of NPK and irrigated with catfish culture water, was of the highest quality. According to the study's findings, using aquaculture water rich in microbes and phytoplankton to irrigate vegetables and as a soil fertilizer to partially substitute synthetic fertilizers can help to maintain a balanced soil ecology with thriving crops. The findings showed that irrigation with aquaculture water improved okra growth and output through enhancing soil health, which in turn increases productivity of yield and water use efficiency.

Keywords: Fertilizer use efficiency, okra plant, aquaculture, water use efficiency.

1. INTRODUCTION

In order to feed Egypt's expected 125 million inhabitants by 2030, food output must rise, exceeding the requirements that arable soil and water quality be improved. Under the strain of a growing population and a food shortage, Egypt is forced to boost water productivity and exploit all low-quality unconventional water resources (Abd El-Azeim et al., 2022). In regions where water is scarce, utilizing

saline or brackish water for agriculture and aquaculture requires the use of state-of-the-art technology and sustainable farming methods. Various solutions, such as aquaponics, are crucially required to enhance the production of this water (Ennab, 2022).

The allocation of water resources in Egypt is heavily skewed towards agriculture, which accounts for around 85% of the Nile's water budget. Irrigated

agriculture is the primary sector responsible for this consumption. Furthermore, a significant amount of this valuable resource, groundwater, is being depleted due to surface irrigation. This approach is widely used in the Nile Valley and Delta regions, although it has a low application effectiveness of less than 50% (Ouda et al., 2020a). The Nile River has served as the essential source of sustenance for the Egyptian population, and the ability to achieve sustainable development is heavily reliant on the availability of water from the Nile. As a result of having a set allocation of 55.5 billion cubic meters of water per year from the Nile and a lack of adequate water resources, Egypt is currently experiencing substantial problems (Hamza et al., 2021). Water is the crucial constituent on Earth for humans and other organisms. Water scarcity refers to the insufficient availability of water resources to meet the demands of a nation. Physical water scarcity, caused by insufficient natural water supplies, and economic water scarcity, resulting from inappropriate management of limited water resources, are both potential factors contributing to a water deficit. Abd El-Azeim et al. (2020) assert that Egypt's water scarcity is primarily a result of restricted water resources, and it is further exacerbated by the inefficient management of these resources (Hamza et al., 2021).

Although arid conditions pose challenges such as water scarcity, infertile soil, desertification, salinity, and low crop productivity, agricultural output remains a key driver of economic revenue and food security. The extensive agricultural regions in Egypt are characterized by dry and semi-arid climates, along with significant salinization problems caused by the use of low-quality irrigation water, insufficient drainage systems, and a deficiency in soil fertility and nutrient availability. Hence, the utilization of saline water for irrigation is compelling farmers in arid areas to devise innovative strategies to preserve water and enhance crop yield and quality while maintaining environmental integrity

(Ismail et al., 2020 and Hamza et al., 2020).

In arid locations, effective irrigation management requires a shift in focus from maximizing production per unit area to maximizing production per unit of water consumed, also known as water productivity (Omran and Negm, 2020). Implementing this will enhance agricultural irrigation techniques and result in advancements in worldwide crop yield. The scarcity of both water quantity and water quality is becoming increasingly evident, even in locations with plentiful rainfall (Ouda et al., 2020b). Regular utilization of saline or brackish water in crop cultivation enhances soil salinity (Ben Hassen et al., 2020). The build-up of soluble salts in the soil and root rhizosphere can greatly reduce the crop quality and productivity of agricultural soils. An ongoing issue in agriculture throughout several countries is the persistent utilization of low-quality irrigation water that has a high saline level (Omran and Negm, 2020; Hamza, et al., 2021).

Despite the widespread use of aquaponics in Egypt, there needs to be more information on integrated farming systems. Additionally, only a small portion of aquaculture water is utilized for crop irrigation due to certain researchers underestimating its positive effects on soil and water production (Abd El-Azeim et al., 2023). Irrigation using aquaculture water has become feasible due to the increasing number of farms utilizing it to water newly fertilized soils. Thus, it was imperative to carry out a practical experiment to determine the most effective types of aquaponics in addressing the food problem as an alternative to traditional agricultural methods in Egypt. The present study utilized the aquaponics technology employed by Egyptian farmers as a means of replicating the current aquaponics system, which is too expensive to install and maintain. The objective was to efficiently cultivate food and fish in a big quantity within field settings, while minimizing costs and maximizing the

utilization of water, which is a limited resource in Egypt.

To explore an effective approach for cultivating and improving plant development through aquaponics, as well as identifying appropriate fish species for the system and a simple method for implementing the aquaponics system on a small scale. Consequently, this study will motivate farmers to explore innovative technology to enhance plant output. The present study aims to examine the impact of using aquaculture water for irrigation-on-irrigation water productivity, soil quality, and okra production. Additionally, it seeks to explore the potential of utilizing aquaculture water in sustainable farming methods on arid sandy soil. In order to accomplish this goal, the present study has the subsequent objectives:

1. Assessing if fish farming water can be used to irrigate vegetables.
2. Assessing the influence of using fish farming water for irrigation, either alone or in conjunction with various NPK chemical fertilizers, on the yield of okra crops.
- 3- Examining the impact of irrigating with aquaculture water on specific markers of sandy soil quality.

2. MATERIALS AND METHODS

The physicochemical properties of the investigated sandy soils, as well as the growth and productivity of okra were evaluated with different formulations of synthetic fertilizers in amounts of 0, 25, 50, 75, and 100% of the recommended

NPK, by plant and irrigation with catfish water in pot experiment. In treatment of zero, 25, 50, 75% synthetic fertilizers, catfish water was used for irrigation, and only in treatment 100 % synthetic fertilizers, groundwater was used for irrigation as a control treatment. Pot and aquaculture experiments were conducted under the facilities of the Faculty of Agriculture, Minia University, Minia Governorate, Egypt for okra cultivation and fish farming. The experimental techniques, materials used, and methodologies modified during the current investigation are as follows:

2.1. Methods and strategies employed in experiments

An experimental method known as a randomized full block design was used. The design consisted of 5 different treatments, each of which was replicated three times. In total, there were 15 pots used in the experiment. The initial component consisted of two types of irrigation water: catfish water and groundwater. The second variable was the proportion of synthetic fertilizer NPK, ranging from 0% to 100% of the amounts recommended by the Ministry of Agriculture, in increments of 25%. Prior to commencing the experimental methods, three water samples from the catfish culture were collected and analyzed to determine the physicochemical features related to the quality of irrigation water. Therefore, the experimental treatments were as shown in Fig. 1.

T_0	Sandy soil irrigated with catfish farm water with 0.0% NPK
T_1	Sandy soil irrigated with catfish farm water and treated with 25% of NPK
T_2	Sandy soil irrigated with catfish farm water and treated with 50% NPK
T_3	Sandy soil irrigated with catfish farm water and treated with 75% NPK
T_4 (Control)	Sandy soil irrigated with tap water and treated with 100% NPK

Figure 1. The experimental treatments of the current study.

After the sandy soil was dried and sifted to a size smaller than 2 mm, each of the 15 pots was filled with 30 kg of the resulting fine earth. In order to establish a stable soil environment, these pots were positioned in the greenhouse at a temperature of 30 ± 5 °C and watered for three days, maintaining the moisture level at 60 % of the soil's maximum water-holding capacity. Okra seeds were sown in pots after 3 days and watered according to the certified amount for 120 days, or until the end of the harvest. By allocating fish farm water to achieve high soil water penetration and maintain soil moisture levels at field capacity, the moisture level of each pot was maintained by daily weighing analyses.

2.2. Evaluation of soil properties

To mitigate soil salinity and degradation, the physical and chemical characteristics of the soil under study were assessed before and after irrigation with aquaculture water. To achieve this, soil samples were collected before and following irrigation with aquaculture water. Subsequently, the samples were dried, pulverized, and sifted through a 2.0 mm stainless-steel sieve. After completely mixing sieved soil samples, a subsample was obtained for soil analysis following procedures outlined by Jackson (1973), Page *et al.* (1982), and Avery and Bascomb (1982). Table 1 shows some soil physicochemical characteristics prior to irrigation.

Table 1. Physiochemical features of sandy soil under investigation.

Soil Property		Value				
Particle Size Distribution, %		Sand			Silt	Clay
		Coarse Sand	Medium sand	Fine Sand		
		36.75	27.84	26.69	2.70	6.02
Texture grade		Sand				
Soluble Cations and Anions						
(cmol _c kg ⁻¹)	Cations	Ca ⁺²	12.61			
		Mg ⁺²	8.43			
		K ⁺¹	2.38			
		Na ⁺¹	2.11			
	Anions	HCO ₃ ⁻¹	13.51			
		CO ₃ ⁻²	0.00			
		Cl ⁻¹	3.43			
		SO ₄ ⁻²	8.48			
CaCO ₃ ⁻ g /kg		38.67	pH (1-2.5 water)		7.89	
Total N g /kg		0.17	EC dS m ⁻¹ at 25 °C		2.55	
Total P g /kg		0.09	TDS (mgL ⁻¹)		1632	
Total K g /kg		0.24	F.C %		18.25	
O.M g/kg		3.56	PWP %		3.87	
** Bulk Density g /cm ³		1.62	A.W%		14.38	

* Organic matter by Loss on ignition method; ** (FAO/IIASA. 2008)

2.3. Aquarium setup and experimental materials

In order to investigate sustainable aquaculture and vegetable production as an integrated agriculture system, this study was conducted within the nursery of the Faculty of Agriculture, Minia University,

Egypt. In the nursery of the Faculty of Agriculture, Minia University, in plastic-lined iron tanks, catfish were raised. In the soil department greenhouse, okra pot experiments were conducted. The okra experiment in the greenhouse was irrigated using water sourced from fishponds.

At the start of the experiment, a cubic tank (2 m³) was put inside the main catfish ponds to receive and incubate 235 catfish fingerlings of North African Catfish (*Clarias gariepinus*) after harvesting them directly from the fish hatchery in the East Nile region. The tank was expanded to its maximum capacity of 2 m³ through sustained incubation, at which point the number of fish was to 93 catfish, weighing between 750 g and 1050 g each. Figure 2

depicting the design of the experiment. Feed of 2 % by weight of fish from poultry manure was used for fish production. Air stones are used to vigorously aerate aquariums while removing a large amount of carbon dioxide. Okra plants require irrigation every three days. After going through a biological filter, water was drawn from the fish tank for okra irrigation.



Figure 2. depicts the experimental design.

Every 72 hours, the water was utilized to irrigate the okra pots in the greenhouse using the flood irrigation technique to assess the water retention capability of the sandy soil. A total of 1280 cm³ of water was introduced to each pot during the irrigation process.

2.4. Analyses of the water qualities in fishponds

Before the implementation of irrigation, samples of water from a catfish tank used for irrigation were taken and analyzed to determine their appropriateness for irrigation of vegetables and to forecast their impact on the growth and production of okra as well as some chemical characteristics of the examined

sandy soil. Following the guidelines set by the American Public Health Association (APHA, 2012), water samples were collected in a sterile and moisture-free plastic container, filtered, and stored at a temperature of 4.0 °C until further analysis. The laboratory analysis focused on evaluating the quality of irrigation water based on several key variables, including pH, soluble salt content (EC), major soluble anions and cations, sodium absorption ratio (SAR), magnesium hazard (MH%), Ca²⁺/Mg²⁺ ratio, Na⁺/Cl⁻ ratio and (Na%) sodium percentage. Table 2 lists the characteristics and chemical make-up of groundwater and fishpond samples taken prior to watering the okra plant.

Table 2. Chemical analysis and standards of catfish water and groundwater used in irrigation.

Water Property		
Water Chemical Properties	Groundwater (control)	Catfish water
pH	7.62 a*	7.80 b
EC (dS/m)	1.33 a	1.27b
TDS (mg/l)	851.20 a	812.8 b
TSS	0.09 a	0.08 a
Soluble Anions (mmolc/l)	$\text{ICO}_3^- + \text{CO}_3^{2-}$	3.05 a
	CL^-	5.08 a
	SO_4^{2-}	5.18 a
	Ca^{2+}	5.17 a
Soluble Cations (mmolc/l)	K^+	0.08 a
	Mg^{2+}	2.62 a
	Na^+	4.93 a
Chemical criteria for determining the suitability of water for irrigation purposes		
Sodium Adsorption Ratio (SAR)	2.50 a	2.49 a
$\text{Ca}^{2+}/\text{Mg}^{2+}$ Ratio	1.97 a	1.08 a
Magnesium Hazard (M.H %)	33.63 a	48.00 a
Na^+/Cl^- Ratio	0.97 a	1.02 b
Sodium percentage (Na%)	39.14 a	50.63 b

* Numbers that have the same letters throughout entire rows are not significantly varied at a probability threshold of less than 5%.

2.5. Yield and quality indicators for okra plant

The plant quality metrics, including fresh and dry weight, TN concentration (mg kg dry weight), were measured using representative samples of vegetable plants at the time of harvest, which was 120 days following the planting date. Chapman and Pratt (1961) estimated the total nitrogen in the plant digest by utilizing the digested plant material and the Kieldahl apparatus.

2.6. General methods and analytical procedures

Page et al. (1982) and (APHA, 1985) methods were used to analyses the physiochemical parameters of the water and soil. Concentrations of nutrients such as ammonia ($\text{NH}_4\text{-N}$), nitrate ($\text{NO}_3\text{-N}$), and total phosphorous (TP) were estimated using a Shimadzu UV-VIS spectrophotometer (Model UV-1201). Using an inductively coupled plasma mass spectrometer. The following list includes specifics of the analytical techniques used during this experiment:

2.6.1.Sodium Adsorption Ratio (SAR)

The SAR is calculated using Equation 1, which utilizes concentrations expressed in meq/l as specified by Gao et al.,2019

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{+2} + Mg^{+2}}{2}}} \quad ..(1)$$

2.6.2.Magnesium Hazard percentage (Mg ratio)

Equation 2 was used to calculate the levels of magnesium hazard, as described by Escobedo-Monge et al., 2022. The formula requires concentrations to be reported in meq/l.

$$Mg \text{ ratio} = \frac{Mg^{+2}}{Ca^{+2} + Mg^{+2}} \times 100 \quad ..(2)$$

2.6.3.Sodium Percentage ($Na\%$)

In order to determine if water quality is suitable for irrigation, the percentage of sodium (% Na) is also frequently used (Negm and Armanuos 2017), using Equation 3. (Ion concentrations are specified in meq/l).

$$Na \% = \frac{Na^{+1} + K^{+1}}{Ca^{+2} + Mg^{+2} + Na^{+1} + K^{+1}} \times 100 \quad ..(3)$$

2.6.4.Water use efficiency (WUE)

The amount of water consumed during the season is determined by multiplying the value of water by the number of irrigation days (irrigation took place every three days), using Equation 4. Mahmoudi et al.,2020 stated that the following equation was used to determine

WUE as one of the indications used to determine yield increase:

$$WUE (kg.m^{-3}) = \frac{Total\ yield\ (kg.fed^{-1})}{Total\ applied\ irrigation\ water\ (m^3.fed^{-1})} \quad ..(4)$$

2.6.5.Fertilizer use efficiency (FUE)

According to Indira and Chandrakanth (2023) the fertilizer usage efficiency (FUE) for the variables N, P, and K was calculated using Equation 5.

$$FUE (kg.kg^{-1}) = \frac{Total\ yield\ (kg.fed^{-1})}{Fertilizer\ applied\ (kg.fed^{-1})} \quad ..(5)$$

2.7. Statistical analysis

The obtained results were examined using the least significant difference (L.S.D.) test at a significant level of 5% for the completely randomized block design with three replicates, using the MSTAT-C v. 1.42 software. At a significance threshold of 5% ($p < 0.05$), the Duncan test was conducted to assess and quantify the importance of the observed differences.

3. RESULTS AND DISCUSSION

The obtained results were examined using the L.S.D. test at a significant level of 5% for the completely randomized block design with three replicates, using the MSTAT-C v. 1.42 software. At a

significance threshold of 5% ($p < 0.05$), the Duncan test was conducted to assess and quantify the importance of the observed differences.

3.1. Evaluation of catfish aquaculture water quality for irrigation of okra

Prior to utilizing water from catfish fishponds for direct irrigation of vegetables, it is essential to evaluate its appropriateness for this purpose. This assessment is crucial in order to avoid potential problems related to the quality of irrigation water, which could lead to deterioration of plants and soil. The chemical composition and water compatibility parameters of both catfish and groundwater aquaculture water utilized for irrigation are provided in Table 2. Table 3 presents the parameters for assessing water quality for irrigation, as outlined by the FAO (1985) and Ayers and Westcot (1994). The assessment of water quality for irrigation involves a significant focus on the enduring impact that water quality has on crop productivity, soil conditions, and agricultural operations.

Table 3. Recommendations for analyzing the quality of irrigation water, Adapted from University of California Committee of Consultants 1974, according to Rhoades, (1977).

Potential Irrigation Problem		Units	Restriction Degree on Use			
Salinity (affects crop water availability)			None	Slight to Moderate	Severe	
	EC _w	dS/m	< 0.7	0.7 – 3.0	> 3.0	
	(or)					
	TDS	mg/l	< 450	450 – 2000	> 2000	
Infiltration (affects infiltration rate of water into the soil. Evaluate using EC _w and SAR together)						
SAR meq/l	= 0 – 3	=	> 0.7	0.7 – 0.2	< 0.2	
	= 3 – 6	=	> 1.2	1.2 – 0.3	< 0.3	
	= 6 – 12	and EC _w	=	> 1.9	1.9 – 0.5	< 0.5
	= 12 – 20	=	> 2.9	2.9 – 1.3	< 1.3	
	= 20 – 40	=	> 5.0	5.0 – 2.9	< 2.9	
Specific Ion Toxicity (affects sensitive crops)						
Sodium (Na)		SAR meq/l	< 3	3 – 9	> 9	
surface irrigation						
sprinkler irrigation			< 3	> 3		
Chloride (Cl)		meq/l	< 4	4 – 10	> 10	
surface irrigation						
sprinkler irrigation						
Boron (B)		mg/l	< 0.7	0.7 – 3.0	> 3.0	
Miscellaneous Effects (affects susceptible crops)						
Nitrogen (NO ₃ - N)		mg/l	< 5	5 – 30	> 30	
Bicarbonate (HCO ₃)		meq/l	< 1.5	1.5 – 8.5	> 8.5	
(overhead sprinkling only)						
pH						
Normal Range 6.5 – 8.4						

3.1.1. Impacts of fish farming water used for irrigating on okra plants and sandy soil properties

Regarding water quality, the examined aquaculture water's (EC_w) was less than 3.0 according to (Table 3), which suggests that using this water to irrigate vegetables shouldn't cause a sodium toxicity problem over the long term. According to FAO (1985) and Ayers and Westcott (1994), the problem of chloride toxicity, catfish aquaculture water had a chloride concentration of 4.3 (mmolc/l), which is considered to have "slight to moderate" use limits. This indicates that using this water to irrigate okra may ultimately raise the danger of chloride poisoning. The Na/Cl ratio of catfish water is greater than one (1.02), indicating that the sodium content of the water is greater than water's chloride concentration. Similar to chloride toxicity, it might be challenging to identify soluble sodium toxicity in soil solutions. The chloride content in irrigation water is crucial for assessing its suitability for irrigation, as chloride ions are detrimental, and most plants exhibit high sensitivity towards them. In addition, plants have the ability to efficiently absorb chloride ions from water, even when the chloride levels are low, due to their strong affinity for chloride ions compared to other ions. (Abdel-Mageed *et al.*, 2018; Hamza, *et al.*, 2021 and Abd El-Azeim, *et al.*, 2023).

Another popular method for figuring out whether the water quality is good enough for irrigation is to look at the specific salt content (Na %) (Szczer, *et al.*, 2010) Increasing the sodium concentration in the water has detrimental consequences because sodium interacts with the soil to limit soil permeability and plant development (Ulaiwi, 2012). The tabulate data in Table 2 showed that the (Na %) level increased from 39.14% to 50.63% after using catfish water, which is within the permitted limits. by assisting cells with Na detoxification, either by blocking Na^+ entry at the membrane level or by restricting Na^+ uptake by plant roots (Cho, *et al.*, 2005).

This is especially true for okra plants which, in comparison to other plant species, are very sensitive to chloride and sodium. Sodium and chloride ions are considered highly detrimental to plant growth and productivity due to the enormous harm they inflict on soil. In order to mitigate the accumulation of sodium and chloride, most farmers periodically employ low-salt water to leach salts below the root zones. Utilizing catfish aquaculture water for irrigation purposes. If not closely monitored and well handled, it may lead to a chloride toxicity problem. According to Ayers and Westcot (1994). Cl concentrations that are below 10 mg/l fall under the category of "Slight to Moderate" use limits. In addition, the amounts of Na did not surpass 9 mg/l. This water falls under the "Slight to Moderate" usage restriction category, indicating that utilizing it for irrigation to produce okra plants may result in a sodium toxicity issue. Except for the pH range, which proved unsuitable for catfish, all other water quality parameters of the aquaponics systems' rearing tanks were within the acceptable range for aquaculture. According to Cerozi and Fitzsimmons' 2016 study, a pH range of 6.5 to 7.2 is optimal for the nitrification process, fish growth, and achieving maximum plant biomass production. Chlorosis, a sign of iron deficiency or chlorophyll inhibition, was a glaring sign that some plants may have had poor nutrition uptake, which may have contributed to their deterioration.

According to the study's findings, the pH of catfish water is 7.80, as shown in Table 1. When compared to Groundwater, which has a pH of 7.62, the pH of catfish water increased by 0.22 units. As per the findings of FAO (1985), Meade (1989), and Lawson (1995). The pH values of both fish farming waters were within the recommended range of 6.5 to 8.4 for irrigation water. This indicates that using this water for plant irrigation is unlikely to cause any changes in soil pH or nutritional imbalances. The range of 6.5 to 8.4 is considered ideal for most organisms and crops, as stated by FAO (1985) and

Egyptian Law 48. Therefore, the pH values of both aquaculture fluids used for irrigation are within this recommended range. Temperature, dissolved oxygen, carbon dioxide and pH, are among the water quality elements that need to be monitored and/or under control. Alkalinity and chloride are additional aspects of water quality to take into account (Abd El-Azeim, et al., 2023).

3.1.2. Effect of irrigation of aquaculture water on salinity accumulation in sandy soil

Table 2 presents a comparison of the chemical composition and other properties of the aquaculture fluids used for irrigating okra with the ordinary water used in catfish farming. For catfish and plain water, respectively, the electrical conductivity ranged from 1.27 to 1.33 and the TDS ranged from 812.8 (mg/l) to 851.2 (mg/l). Despite the fact that the values of TDS (Total Dissolved Solids) in the water used for agriculture irrigation are considerably greater than those found in Nile water TDS, 186 mg/l (Ouda et al., 2020a), it is still suitable for this purpose. This lies under the degree of restriction of use, Mild to moderate, since more than 450 to 2000 ppm is considered high for many crops. The FAO (1985) recommendations for irrigation water, however, suggest using this water with some caution.

Two ways for categorizing total solids based on size are TDS and total suspended solids (TSS). TDS is a term used to describe all the substances present in a water sample that may flow through a specific pore-size filter paper (1.5 m, Whatman 934 AH). This includes small amounts of organic and inorganic chemicals, as well as mineral salts. The cations calcium, magnesium, sodium, and potassium, along with the anions carbonate and bicarbonate, are frequently the main components. Furthermore, TSS refers to any organic and inorganic substances present in a water sample that have a size larger than 1.5 microns and may be separated from the water by either filtration or sedimentation.

The SAR decreased insignificantly going from 2.50 % in Groundwater to 2.49 % in catfish water. all dissolved anions aside from HCO_3 , SO_4 , K, and Mg ions were dramatically decreased in catfish water samples. The availability of nutrients for the crop is significantly decreased by the salt in the soil and irrigation water, which negatively impacts the crop. The values measured in catfish aquaculture water and groundwater are below the level of use limitation, according to the EC and TDS analyses, Slight to Moderate, as it is less than 2000 (mg/l) limit.

conventional irrigation of soil with fish culture water will cause salts to accumulate, but usually at a lower concentration when using catfish culture water than when using conventional water. The classification of the research soil as "Slight to Moderate" is determined by the electrical conductivity (E.C.) of the saturated extract, which is measured at 1.27 dS/m. With increasing water salinity, it is crucial to ensure that salts are removed from the root zone before they accumulate to a level in the soil that could hinder production. In order for soil to be permeable, proper soil drainage and carefully chosen salt-tolerant crops are required.

3.1.3. Aquaculture irrigation water's effects on soil permeability

The SAR in the water and groundwater used for catfish aquaculture ranged from 0.0 to 3.0 SAR. The E.C. values were more than 0.7 dS/m. These values indicate that the water falls into the "None" degree use restrictions category, as shown in Table 3. This indicates that the use of these aquaculture fluids for irrigation in the sandy soil being studied may not result in infiltration problems (FAO, 1985; Ayres and Westcott, 1994; Abdel-Mageed et al., 2018). When assessing a potential issue with soil infiltration rate using SAR and EC_w together, it is observed that the rate tends to increase as water salinity increases and decrease as either salinity decreases or sodium content increases relative to

calcium and magnesium (FAO, 1985; Abdel-Mageed et al., 2018).

3.1.4. The relation between the calcium/magnesium ratio and the quality of irrigation water

In order to avoid issues with the quality of irrigation water, it is essential to assess the quality of the water source and determine its suitability for plant irrigation. Furthermore, it is necessary to evaluate the levels of Ca^{2+} , Mg^{2+} , and Na^+ in the irrigation water to ascertain its appropriateness for irrigation purposes. Concerning the quality of irrigation water, both the groundwater (with a $\text{Ca}^{2+}/\text{Mg}^{2+}$ ratio of 1.97) and the catfish water (with a $\text{Ca}^{2+}/\text{Mg}^{2+}$ ratio of 1.08) used for irrigation had ratios greater than 1.0. This suggests that using these waters for okra irrigation is unlikely to cause a calcium deficiency or hinder the infiltration of sandy soil. Lowering the $\text{Ca}^{2+}/\text{Mg}^{2+}$ ratios in sandy soils considerably promotes the development of sodic soils.

Calcium appears to play a crucial function in plants, due to its ability to lessen the potential toxicity of other ions like Na^+ and Mg^{2+} in the root zone environment. If the ratio of $\text{Ca}^{2+}/\text{Mg}^{2+}$ is close to 1 or below, this results in poorer Ca^{2+} uptake because of the antagonistic effects of too much Mg or competition for uptake sites, which reduces the uptake and transport of Ca^{2+} . Calcium (Ca^{2+}) and magnesium (Mg^{2+}) are two positively charged ions that are particularly indicative of the hardness of water. Total hardness refers to the combined amounts of Ca^{2+} and Mg^{2+} ions in relation to calcium carbonate (CaCO_3). The level of hardness can vary from being very elevated (>300 ppm) to being low (0-75 ppm).

Concerning the equation utilized for calculating the magnesium hazard index (%). The water samples collected from both groundwater and catfish ponds in the present study exhibit a pH range of 33.63 to 48.00, indicating their suitability for vegetable irrigation purposes. The presence of high concentrations of Mg^{2+} in irrigation water leads to an increase in exchangeable Na^+ in irrigated soils. This, in turn, raises

the magnesium hazard index, which can have negative effects on soil structure and impair the ability of crops to absorb nutrients due to an increase in soil alkalinity. Based on the research conducted by Abdel-Mageed et al. (2018) and Ayers and Westcott (1994), it has been determined that cultivated soils consider water with a magnesium hazard over 50 % to be unsuitable and highly hazardous (Ayers and Westcott 1994).

The analysis of the catfish pondwater revealed that various factors, such as total cations and anions, magnesium hazard, SAR, pH, and the relative percentages of sodium and bicarbonate concentrations in relation to chloride, calcium, and magnesium concentrations, may not be the cause of deterioration or infiltration problems in the sandy soil that was investigated. However, these metrics also indicated that if the use of catfish aquaculture waters for irrigation is not carefully monitored and managed by experienced professionals, it could eventually result in salt-related issues in the sandy soil being examined. Hence, it is crucial to prioritize the use of aquaculture water for crop irrigation in integrated aquaponics farming systems in arid regions, as part of sustainable irrigation management strategies.

3.1.5. The relationship between the bicarbonate content and the quality of irrigation water

Bicarbonate concentrations were 3.05 meq/l in the Groundwater and 3.76 meq/l in the catfish water. Both are subject to "Slight to Moderate" use restrictions, which means that using this water for irrigation may result in a problem with white scale accumulation on plants or fruit when sprinklers are used, or drippers are clogged. The study's findings revealed that even if the plant is not overtly hazardous, continual use of this water may cause some issues in the soil. Abdel-Mageed et al., (2018) provided some sources, and the research data support those sources (Ayers and Westcott, 1994).

3.1.6. Impacts of catfish water and NPK on Fertilizer and water use efficiencies with okra plant

The primary metrics employed to measure the rise in crop yield per unit of water or fertilizer are water use efficiency (WUE, kg/kg) and fertilizer use efficiency (FUE, kg/kg). The hypothesis suggests

that utilizing catfish water for irrigation will enhance both water and nutrient use efficiency, thereby leading to increased crop yield, when compared to irrigation with groundwater. Table 4 displays the findings of the impact of catfish water treatment on various parameters following irrigation.

Table 4. The impact of catfish water on the FUE, WUE, and yield of okra plants.

Treatment	T ₀₍₀₎	T ₁₍₂₅₎	T ₂₍₅₀₎	T ₃₍₇₅₎	T ₄₍₁₀₀₎
Yield (Kg/fed)	720.55 c	1806.09 b	2784.38 a*	2784.55 a	2787.80 a
Total applied Water (m ³ /fed/season)			3200 m ³		
WUE (kg/m ³)	0.23 c	0.56 b	0.87 a	0.87 a	0.87 a
Total (N) Kg/fed	16.55 c	32.63 b	38.68 a	64.78 d	64.25 e
NUE (kg/kg)	43.54 c	55.35 a	71.99 a	42.98 b	43.39 b
Total (P) Kg/fed	18.00 c	29.25 b	40.50 a	51.75 d	45.00 e
FUE (kg/kg)					
PUE (kg/kg)	40.03 e	61.75 d	68.75 a	53.80 c	61.95 b
Total (K) Kg/fed	20.00 c	29.25 b	40.50 a	51.75 d	45.00 e
KUE (kg/kg)	36.01c	55.55 b	61.86 a	48.41 d	55.76 b

* Numbers that have the same letters throughout entire rows are not significantly varied at a probability threshold of less than 5%.

The examination of FUE involved the calculation of nitrogen use efficiency (NUE), phosphorus use efficiency (PUE), and potassium use efficiency (KUE). The impact of catfish water on WUE was assessed in relation to the growth of okra plants. Water use efficiency significantly improved when catfish water, supplemented with fertilizers at a 50% concentration of NPK, was utilized for irrigation (Table 5). This demonstrates that implementing water treatment for catfish has a beneficial effect on the utilization of irrigation water. Table 5 demonstrates that okra has high water productivity, since it relies on the optimal amount of fertilizer and water to achieve a desired yield. When compared to conventional water irrigation, using catfish water with 50% NPK enhances the absorption of water and fertilizer, leading to improved plant growth, metabolism, and agricultural productivity. Increased product of okra to 2784.38 kg/feddan with used 50% NPK (T₂) and catfish water, compared to the okra crop irrigated with fish farming water was to 720.55 kg/feddan only without

NPK fertilization (T₀). While the production was about 2787.80 kg/feddan (T₄) when using 100% of the NPK fertilizer, mixed with groundwater in the control treatment, and the results showed that there was no significant difference between the treatments T₂ and T₄, while the difference was highly significant with the treatment T₀ and this means that the use of catfish culture water leads to a saving of 50% of the NPK.

The outcomes also demonstrated that the water consumption efficiency of the treatments T₂, T₃, and the control treatment T₄, all of which were 0.87, did not differ significantly from one another. Additionally, research demonstrated a highly significant difference between treatment T₀ (treatment of catfish water alone without applying NPK) and control treatment T₄, demonstrating that using 50% of the artificial fertilizer NPK improves water use efficiency. In the same situation, using 50% of the NPK fertilizers increased the effectiveness of nitrogen, phosphorous, and potassium fertilizers.

3.1.7. The concentration of nutrients in water regarding the quality of water for irrigation

As shown in Table 5, according to the study's findings, catfish farming water has high levels of pollution due to its elevated total nitrate and phosphate concentration.

Table 5. The average levels of nitrate, nitrite, ammonium, and total phosphorus in groundwater and catfish cultivation water.

Water Property		
Water criteria	Groundwater (control)	Catfish water
pH	7.62 a	7.80 b
TP	1.66 a	1.80 b
* $\text{NH}_4^+ - \text{N}$	0.98	3.06
* $\text{NH}_3 - \text{N}$ (UN-ionized at 32 °C)	0.03	0.15
* $\text{NO}_3 - \text{N}$	10.56	13.34

* Acceptable range for aquaculture Meade, 1989 and Lawson, 1995 for $\text{NH}_3 - \text{N} \leq 0.02$ and for $\text{NO}_3 - \text{N} \leq 3$

The presence of nutrients in aquaculture water, which shows an excellent nutritional quality for crop irrigation, may be attributed to the use of chicken dung as a feed source in aquaculture systems or an increase in population density in culture. With concentrations ranging from approximately 10.56 to 13.34 mg/L of ($\text{NO}_3 - \text{N}$), which exceed the high values defined by Meade, 1989, and Lawson, 1995, the average of nitrate ($\text{NO}_3 - \text{N}$) and ammonium ($\text{NH}_4^+ - \text{N}$) reveals considerable variability in groundwater and aquaculture waters. The groundwater's contamination with ($\text{NO}_3 - \text{N}$) from deep seepage may be the cause of the increase in concentration. Despite the fact that the concentration of ($\text{NH}_4^+ - \text{N}$) did not surpass 5, there was no hazard, for fish farming water. Catfish and groundwater according to Meade, 1989 and Lawson, 1995. The same is true for phosphorus, which reaches 1.66 mg P/l in groundwater and roughly 1.8 mg P/l in catfish production water.

Aquaculture systems generate substantial amounts of effluent including high levels of particulate and dissolved organic matter, as well as nutrients such as nitrogen and phosphorus. This is due to fish excretion, fecal output, and tissue fragmentation (Cripps and Kumar, 2003). Depending on the species and culture technique, a fish culture system may lose

up to 85% of phosphorus, 80-88% of carbon, and 52-95% of nitrogen to the environment through feed waste, fish excretion, faecal output, and respiration (Wu, 1995; Abd El-Azeim et al., 2023). When aquaculture water, which contains a large amount of organic matter and fertilizers, is released untreated into water bodies, it has a detrimental impact on the ecology. The environmental impacts of aquaculture effluent discharge are influenced by several factors, such as (a) the species being cultivated, (b) the methods used for cultivation, (c) the density of the stock, (d) the type of feed used, (e) the feeding practices, and (g) the hydrography of the location (Wu, 1995 and Cripps and Kumar, 2003).

3.2. Effects of irrigation with catfish water on several soil health parameters

Table 6 presents the effects of irrigating with water from fish farming on specific parameters of soil quality in sandy soil after the growing season of okra. The results indicated that following the growth season, there was a considerable drop in soil electrical conductivity and the overall quantity of dissolved salts. The excessive use of fish farming water for irrigation, which has lower electrical conductivity values, has led to a decrease in soil salinity. Reducing salt levels in the soil with controlled irrigation can significantly

increase crop yields, especially in sandy soil with high internal drainage and infiltration. Conducting thorough soil research is essential for this purpose. The salinity of the soil may pose a major challenge for managing irrigated regions in an integrated aquaponics system. Additionally, the susceptibility of soil deterioration would be heightened by poor water quality. In sandy soil agriculture, the necessity to intensify production may lead to increasing usage of agrochemicals, which can introduce detrimental fertilizers and pesticides. This is particularly accurate for the sandy soil being examined, as internal drainage and infiltration are widespread.

The results from Table 6 indicated a considerable fall in soil pH values when watered with aquaculture water. Nevertheless, it is well acknowledged that any variation in soil pH caused by aquaculture water would occur slowly due to the fact that soil is a highly buffered medium that is resistant to pH changes (Ayers and Westcott, 1994). The slight decrease in soil pH after the okra-growing season was statistically significant ($P < 0.05$). As stated by Kelley and Boyhan (2009), the first stage in any fertilizer or irrigation management program should involve adjusting the soil to the appropriate pH level. Soil pH has a substantial impact on plant development, nutrient availability, and the activities of soil microorganisms (Hamza et al., 2020). Several studies have examined the impact of pond aquaculture water on soils, such as Stickney (2002),

Tucker et al. (2002), and Boyd (2003; Abd El-Azeim et al., 2023).

The primary factor contributing to the creation of saline soil in Egypt is the exclusive reliance on saline water for irrigation, particularly in arid regions. Insufficient irrigation can hinder soil drainage, leading to the accumulation of soil salinity in the root zone during growing seasons and even after harvest. This salinity tends to increase over time (Abdel-Mageed et al., 2018 Hamza et al., 2020). These findings emphasize the need of preserving soil properties and vegetable crop productivity while utilizing long-term aquaculture water for irrigation in arid situations. Following a series of successive applications of aquaculture fluids for irrigation, the accumulation of salt in the soil will gradually stabilize, influenced by the salinity of the water employed. Salts are present in all irrigation water and become more concentrated in the soil profile as the water evaporates (Ayers and Westcott, 1994; Abdel-Mageed et al., 2018), but they do not reach a concentration that restricts crop productivity. Following the growth season of the okra plant, a relationship can be observed between certain dissolved cations and anions in sandy soil and the irrigation water utilized for fish farming. The levels of dissolved cations and anions in the soil slightly decreased after two seasons, in comparison to the levels before and after irrigation with water from fish farming. This moderate drop can be attributed to the leaching of sandy soil (Omofunmi, et al., 2018).

Table 6. Some quality parameters of sandy soil as impacted by irrigation with catfish culture water both before and after okra season.

NPK (%)	Sample collection time	pH (1:2.5)	E.C. (1:2.5) (dS/m)	Soluble Anions (mmol _c /l)			Soluble Cations (mmol _c /l)				SAR
				(HCO ³⁻	CL ⁻	SO ₄ ²⁻	Ca ²⁺	K ⁺	Mg ²⁺	Na ⁺	
				+ CO ₃ ²⁻)							
	before irrigation	7.89c	2.55c	13.51c	3.43d	8.48c	12.61d	2.38b	8.43b	2.11b	0.65
	0 after	7.63a	1.01a	6.43b	1.53c	2.09a	4.10b	1.50c	3.40a	1.07a	0.55
	25 after	7.62a	1.15a	3.10a	5.33b	2.05a	4.69a	2.12a	3.51a	1.19a	0.59
	50 after	7.57a	1.25a	3.85a	6.56b	2.05a	4.65a	2.11a	3.17a	2.56bd	1.29
	75 after	7.51a	1.45a	5.79b	7.59b	2.07a	6.34b	2.11a	3.27a	3.73d	1.70
	100 after	7.45b	2.64b	10.97c	10.35a	5.03b	10.35c	2.09a	7.16c	6.76c	2.28

* Numbers that have the same letters throughout entire rows are not significantly varied at a probability threshold of less than 5%.

The study's findings suggest that utilizing nutrient-rich aquaculture water for crop irrigation and as a substitute for partially synthetic fertilizers in sandy soils can promote a balanced soil ecosystem and lead to the production of robust and plentiful crops (Sharma et al., 2021; Ammar et al., 2022). Utilizing aquaculture water abundant in phytoplankton offers a more secure form of partial fertilizer composed entirely of organic material, in contrast to synthetic fertilizers derived from petrochemicals and mineral extracts, which may contain harmful chemicals or pollutants (Ammar et al., 2022; Abd El-Azeim et al., 2023).

3.3. The impact of using aquaculture water for irrigation on the quality of the okra crop

As shown in Table 7, the plants in the T₀ treatment first had nutritional deficiency, which continued for 2 weeks before improving. This might be as a result of a lack of bacterial colonies to convert ammonia into nitrite, or due to the small size of fingerlings and their inability to produce ammonia in a way that would benefit the plant at the beginning of the experiment. As a result, it is not suggested to irrigate using fishpond water until 30 days have passed since the fish farming system began operation.

Table 7. The effects of irrigation with catfish farming water and various NPK fertilizer treatments on the growth and nutritional characteristics of okra plants *.

Treatment	Fresh weight (g/plant)	Dry weight (g/plant)	NPK concentration % and uptake (g/plant)					
			N		P		K	
			%	uptake	%	uptake	%	uptake
T ₀ without NPK	384.86	90.92	3.10	2.82	0.25	0.23	1.22	1.11
T ₁ at 25% NPK	440.16	107.05	3.20	3.43	0.34	0.36	1.26	1.35
T ₂ at 50% NPK	556.21	120.43	3.40	4.09	0.34	0.41	1.32	1.59
T ₃ at 75% NPK	557.06	120.87	3.38	4.08	0.33	0.40	1.31	1.59
T ₄ at 100% NPK with groundwater	559.51	135.32	3.40	4.60	0.35	0.47	1.32	1.79

* All values differ somewhat at the 5% level of probability.

Table 7 displays the impact of irrigating with water from catfish aquaculture and various NPK treatments on the fresh weight (in grams per plant),

dry weight (in grams per plant), plant absorption (in grams per plant), as well as the concentration of nitrogen, phosphorous, and potassium in okra plants

(expressed as a percentage). An examination of the data in Table 7 showed that the application of different amounts of NPK inorganic fertilizers during irrigation with aquaculture water had a significant impact on the growth, yield, and nutritional status of okra, when compared to irrigation with aquaculture water alone or with varying levels of NPK and a control group. Regardless of the application rates or type of water irrigation, the results demonstrated that the inclusion of fertilizer NPK significantly enhanced the growth characteristics of okra plants in comparison to T₀.

The most superior plants were cultivated in pots that received 50 % of the suggested levels and were watered with catfish aquaculture water, as determined by growth parameters (fresh and dry weights) and the overall nitrogen absorption of okra plants across all NPK application rates. The integration of irrigation with aquaculture water and inorganic NPK fertilizers resulted in the advantageous outcome of enhancing soil structure, hence facilitating the efficient blossoming of plant roots. Consequently, this led to an enhancement in the health of sandy soils by the augmentation of soil microbial activity (FAO, 2012; Geletu and Zhao, 2022). The values fell within the optimal range for crop growth, productivity, and yield (FAO, 1979). These findings are consistent with the studies conducted by Jat et al. in 2017, Hassan et al. in 2009.

The various treatments looked at had an impact on the okra plants' uptake, Total nitrogen uptake significantly outperformed lower rates attained by irrigating with fish water alone without fertilizer at the application rate of the recommended amounts of NPK. This shows that irrigation with catfish water makes up for the decreasing nitrogen uptake returns caused by the recommended fertilizers. There is a higher concentration of nitrogen when application rates are greater than 50 % of the NPK levels advised. This finding suggests that okra plants may have absorbed their allotted amount of nitrogen, and any extra nitrogen will likely build up in sandy soils or seep into groundwater. In order to maximize the efficiency of synthetic fertilizer application at a given crop level, it will be necessary to reduce residual soil NO₃-N (Abd El-Azeim et al., 2022).

4. CONCLUSIONS

The primary objective of on-farm water management interventions in Egypt is to enhance water productivity by implementing an integrated aquaponics system that optimizes the use of water. This system aims to improve the output and quality of crops and fish, while also lowering stress caused by the current water crisis. It is crucial to discover new and cost-effective aquaponics techniques. This work contributes positively to addressing this difficulty by examining the implementation of an integrated crop and fish farming system developed by an Egyptian farmer. Aquaculture is still uncommon in rural Egypt today, despite the fact that Egyptian farmers employed it extensively in the past and conducted it in their own distinctive way. This is partly a result of the high startup, ongoing, and maintenance expenses of contemporary aquaculture systems. This system is a useful substitute for contemporary plant and fish farming methods, which require twice as much water and capital and produce higher crop yields. The research findings indicate that integrated aquaponics, which combines fish and vegetable production, is an environmentally sustainable farming system due to its positive impact on water and crop productivity, soil features, farmer's income, and ambient environment. However, further research is required to fully understand the intricacies of diverse integrated aquaponics systems used for sustainable agriculture of various crops.

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اثر الري بمياه من نظام الاستزراع السمكي مع مستويات مختلفة من NPK على نمو وإنتاج نبات البامية.

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نظام زراعة النباتات والأسماك قد أصبح مؤخرًا في دائرة الضوء كشكل من أشكال الزراعة الحديثة التي تخدم الأهداف العلمية والاقتصادية معًا حيث تسعى مصر لزيادة استغلال المياه. خيار لتعزيز إنتاجية مياه الري في الزراعة المستدامة تحت قيود إمدادات المياه المحدودة هو دمج إنتاج الأسماك والمحاصيل في نظام الزراعة المائية. أظهرت نتائج هذه الدراسة كيف أثرت خصائص التربة الرملية وإنتاج الخضروات وتسلسل التربة على جودة المياه أثناء إعادة تدوير مياه تربية الأحياء المائية (سمك السلور) للري. أظهرت مقاييس جودة نمو البامية أن المحصول الذي تُنتج في الأوعية التي تلقت ٥٠% من المستويات المقترحة من NPK وتم ريها بمياه تربية سمك السلور، كان من أعلى جودة. وفقًا لنتائج الدراسة، فإن استخدام مياه الاستزراع المائي الغنية بالميكروبات والطحالب الدقيقة لري الخضروات واستخدامها كسماد للتربة كبديل جزئي للأسمدة الاصطناعية يمكن أن يساعد في الحفاظ على توازن بيئي صحي للتربة مع محاصيل مزدهرة. أظهرت النتائج أن الري بمياه الاستزراع المائي حسن نمو وإنتاج البامية من خلال تعزيز صحة التربة، مما يزيد بدوره من إنتاجية المحصول وكفاءة استخدام المياه.