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Towards Wastewater-Aquaculture-Agriculture Integration in Arid and Semi-Arid Regions: Utilization of Aquaculture Effluents in the Irrigation of Khaya and Mahogany Seedlings

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Abstract: Rational use of water in arid and semi-arid regions is fundamental for resource sustainability. The present study aimed at investigating the possibility of using various types of fish culture effluents (intensive catfish (ICCE), intensive tilapia (ITCE) and intensive biofloc tilapia (I-BFT-TCE)) as irrigation and fertilization sources. These effluents were compared with nitrogen, phosphorus and potassium (NPK) mineral fertilization and potable tap water irrigation (control) treatments. To insure controlled irrigation conditions where conclusive deductions could be made, the study was conducted using large sized pots. The investigation was carried out on economically valuable ornamental trees (khaya (*Khaya senegalensis* (Desr.) A. Juss.) and mahogany (*Swietenia mahagoni* L. Jacq.). In order to evaluate the effluent effects; seedling growth traits, photosynthetic pigments, total macro-nutrients, and total carbohydrates contents were examined. All treatments performed noticeably well when compared to the control case. While the NPK treatment was significantly superior to other treatments in improving overall studied seedling metrics, the I-BFT-TCE treatment had surprisingly close effects followed by ITCE then ICCE treatments. The results suggest that usage of various fish culture effluents, especially I-BFT-TCE, in the irrigation of khaya and mahogany seedlings appears to be an excellent way of disposing aquaculture effluents. This provides a good approach for aquaculture-agriculture integration. Furthermore, it is a potentially viable method for improving the seedlings growth by providing them with a biofertilizer as opposed to a mineral fertilizer. A large scale application design is proposed for aquaculture-agriculture integration in arid and semi-arid regions as an environmentally friendly possible development route. This proposal highlights the possibility that biofloc technology can be integrated as an intermediate stage between pre-treated municipal wastewater and agro-forestry plots.

Key words: Integrated · Aquaculture-agriculture · Khaya senegalensis · *Swietenia mahagoni* · Biofloc · Water reuse . Aquaculture waste

INTRODUCTION

Fresh water makes up only 0.01% of the world's water and approximately 0.8% of the Earth's surface [1]. This precious heritage is in crisis if losses, as a result of global warming, continue at current rates and trends in human demands for fresh water remain unaltered [1]. The world will face high risks of fresh water shortage, and the opportunity to conserve the remaining fresh water will vanish before the International Decade for Action 'Water for Life' ends (adopted by the United Nations General Assembly in December 2003 resolution 58/217 proclaiming 2005 to 2015) [1]. At the same time the combined effect of an ever increasing world population and its associated demand and use of municipal water has resulted in the creation of large volumes of wastewater [2, 3]. As a result, the sustainability of critical fresh water resources will depend on effectively balancing between wastewater disposal management and the protection of fresh water resources [2-6]. In this article, we investigate the potential

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use of various types of fish culture effluents (intensive catfish (ICCE), intensive tilapia (ITCE) and intensive biofloc tilapia (I-BFT-TCE)) as irrigation and fertilization sources. We also discuss the possibility of integrating BFT as an intermediate stage between pre-treated municipal wastewater and agro-forestry plots. A large scale application design is proposed for arid and semi-arid regions as an environmentally friendly possible development route.

In recent decades, aquaculture farming has been rapidly developed to serve two major purposes: food security, because of the increasing population growth, and national income generation [7, 8]. Aquaculture ponds require the use of large amounts of water infused with high concentrations of nitrogen and phosphorus in order to be productive [7]. Biologically available forms of nitrogen in ponds are nitrate (NO_3-N), ammonia (NH_3-N), and organic nitrogen (organic-N) which can be made available through conversion to NH_3-N [2]. As for phosphorus, soluble orthophosphate (PO_4-P) is the only form that can be assimilated directly by autotrophs [2]The ecology of aquaculture ponds consists of a number of interrelated physical, chemical and biological processes. Pond systems depend basically on the exploitation of autotrophic (mainly micro-algae) and heterotrophic (mainly detritus associated bacteria) microbial food webs leading to the formation of harvestable and assimilable detritus and inorganic nutrients [9, 10]. The biofloc technology (BFT) is based on the use of constant aeration to allow aerobic decomposition and maintain high levels of bacterial flocs in suspension. Inorganic nitrogen is immobilized into bacteria when the metabolized organic substrate has a high C: N ratio. The C: N ratio can be increased by adding different locally available inexpensive carbon sources and/or a reduction of protein content in feed [9, 11- 15].

Negative effects of aquaculture waste to the environment are increasingly recognized, though they represent only a small proportion of land-based pollutants [16]. Algae bloom, a widespread problem throughout the world affecting the quality of domestic, industrial, agricultural and recreational water resources, is caused by the accumulation of organic nutrients like nitrogen and phosphorus, which promotes a high biomass in the superficial water [2, 16]. Furthermore, producing and discharging large aquaculture effluent amounts to the environment alongside the traditional principal wastes such as solid wastes (feces and uneaten food) and chemicals (stabilizers, pigments, antimicrobials, and therapeutics) [2, 16, 17] leads to the degradation of water quality, eutrophication, and soil salinization [8, 18, 19]. On the other hand, the use of aquaculture effluents in irrigation would be beneficial for a number of reasons, namely: (1) resolving water shortage, (2) using high-quality water resources for potable uses, (3) avoiding large amounts of effluent disposal problems and/or treatment concerns, (4) considering them as natural soil conditioners, and (5) improving plant growth as long as the amount of nutrients added to soil does not exceed crop absorption capacity.

Despite the many existing pressures on our water resources, there are cost-effective solutions that will transform our relationship with water. Synergisms, in which an output from one sub-system in an integrated farming system, which would otherwise have been wasted, becomes an input to another sub-system, result in greater output efficiency of the desired products from the land/water area under the farmer's control [7]. In desert regions, where designing aquaculture farms take place, water scarcity should be considered. Integrating aquaculture production into traditional agriculture could be one solution that achieves more efficient water use, by maximizing farm production without increasing water consumption. Dual use of the freshwater resource can be achieved by first culturing fish and then applying the resulting fish effluents to agricultural crops as irrigation water. Developing aquaculture-agriculture integration is highly desired as it keeps both the stocking density and pollution loading under environmental capacity simultaneously. Few studies of integrating aquaculture and agriculture have been conducted using different types of fish culture effluents to irrigate and modify the growth of ornamental plants: *Cynodon dactylon* and *Paspalum notatum* irrigated with an ICCE [20], *Atriplex barclayana* [21] and *Chilopsis linearis* [22] irrigated with ITCEs, *Salix viminalis* and *Populus nigra* x *Populus maximowiczii* irrigated with intensive brook trout culture effluent [23]. In this article, we will focus on the use of various types of aquaculture effluents in the irrigation of two trees from the Meliaceae family.

Meliaceae trees have been attracting considerable interest, because of their significant biological activities. Khaya (*Khaya senegalensis* (Desr.) A. Juss.), one of the Meliaceae family members, also known as African mahogany, is a tropical hardwood tree with wide dense crown, thick trunk, and attractive appearance. It is an excellent source of furniture timber that is widely used in building construction, doors and window frames. It is also considered as one of the most popular traditional medicines in Africa; rich in limonoids, it is used as a vermifuge, taeniacide, and antimicrobial agent [4, 24-26]. Mahogany (*Swietenia mahagoni* (L.) Jacq.), on the other hand, also a tropical hardwood tree from the Meliaceae family, is considered one of the most valuable timber trees (rated among the top 12 timber woods in the world). It has a heavy, extremely strong, stable and decay resistant trunk. Its wood is used for making fine jewelry, decorative veneers, shipbuilding and fine boat interiors [5, 27]. Its seeds have been applied as a folk medicine for the treatment of hypertension, diabetes, and malaria, while the decoction of its bark has been used as a febrifuge [28].

Lots of studies have been carried out on irrigating woody tree species established as green belts around the cities with wastewater, as these green belts revive the ecological balance, improve environmental conditions, and help mitigate health hazards associated with industrial technology [5]. In contrast, comprehensive studies on the use of aquaculture effluents for irrigating woody tree species are limited. Based on the previous information, if aquaculture farmers incorporate an agriculture component such as green belts into their farm enterprise in an integrated system, they would increase the efficiency of water usage, especially if these green belts are chosen to be valuable woody trees, whereby the aquaculture effluents are used for irrigation and concurrently as a biofertilizer, which in turn reduce the competition over the freshwater resource. Therefore the specific objective of this study is to present the results of fish culture effluents specifically tilapia culture effluent (I-BFT-TCE) in a novel simplified aquaculture-agriculture integration system. This system combines these effluents with *Khaya senegalensis* (Desr.) A. Juss. and Swietenia mahagoni (L.) Jacq. seedlings in an economic production manner. The two tree species production is measured through quantifying their growth and chemical constituents.

MATERIALS AND METHODS

Plant Cultivation and Experimental Design: The present investigation was conducted at Fish Nutrition Laboratory, Faculty of Agriculture, Cairo University, Giza, Egypt, during two successive seasons (2010 and 2011). Khaya (*Khaya senegalensis* (Desr.) A. Juss.) and mahogany (*Swietenia mahagoni* (L.) Jacq.) seedlings were used. The average height and diameter (7cm from the soil surface) of the seedlings were 30cm and 0.60cm, respectively for khaya and 50cm and 0.85cm, respectively for mahogany in both seasons. To insure a controlled study where conclusive deductions could be made, the seedlings of the two species were transplanted into

Table 1: Averages of the physical and chemical characteristics of the soil used at the beginning of the study during seasons of 2010 and 2011.

Parameter	Average value
Physical characteristics	
Practical size distribution (%)	
VCS	5.3
CS	23.2
MS	43.3
FS	24.8
VFS	2.2
Silt + Clay	1.2
Soil texture	Sandy
Soil moisture constants (%)	
FC	10.3
WP	2.9
AW	7.4
Chemical characteristics	
pH	8.1
EC (dS/m)	1.2
$CaCO_3$ (%)	3. 9
OM (%)	0.05
Available macro-nutrients (ppm)	
N	0.4
P	0.8
K	8.0

VCS: very coarse sand, CS: coarse sand, MS: medium sand, FS: fine sand, VFS: very fine sand, FC: field capacity, WP: wilting point, AW: available water, OM: organic matter.

plastic pots (23 cm height and 30 and 27 cm upper and lower inner diameters, respectively). These pots were filled with about 20 kg of washed sandy soil (one seedling/pot). The physical and chemical characteristics of the soil used at the beginning of the study during the two seasons are shown in Table 1. All seedlings were planted on the first of April in both seasons and were irrigated with potable tap water to adapt for a month, until the first of May, which marks the beginning of the experiment. The layout of the experiment was a randomized complete block design with five treatments. Each treatment was replicated three times, and each replica contained eight seedlings.

Management of Irrigation Sources and Tanks: The irrigation sources used in the study were potable tap water (TW) (control) treatment and three types of fish culture effluents. (1) Intensive catfish culture effluent (ICCE) as African catfish (*Clarias gariepinus*) was randomly distributed among 5 fiberglass tanks, with a weight range of 100-120g/fish fry. The tanks were filled with freshwater to a volume of 1000 liters, stocked at the rate of 35 catfish/tank, and supplied with a complete commercial pelleted feeding diet (40% crude protein) daily. (2) Intensive tilapia culture effluent (ITCE) as Nile tilapia (*Oreochromis niloticus*) was randomly distributed among 10 plastic tanks, with a weight range of 1.82-2.25g/fish fry. The tanks were filled with freshwater to a volume of 70 liters, stocked at the rate of 30 Nile tilapia/tank, and supplied with a complete commercial pelleted feeding diet (30% crude protein) daily. Both the ICC and the ITCEs were aerated using commercial air pumps and their water was exchanged daily. (3) Intensive biofloc tilapia culture effluent (I-BFT-TCE) as Nile tilapia, were randomly distributed among 10 plastic tanks, with a weight range of 2.5-3.0g/fish fry. The tanks were filled with freshwater to a volume of 70 liters, stocked at the rate of 30 Nile tilapia/tank, aerated using three diffusive stone aerators/tank (to maintain dissolved oxygen concentration above 5mg/l and well mixed condition), supplied with Nile tilapia feeding diet (30% crude protein) as N-source and molasses as C-source at ratio of 16:1 C:N daily (the actual amount of molasses varied according to the quantity of tilapia feed added into the tanks), and were covered with transparent plastic sheets to partially allow sunlight. The I-BFT-TCE was exchanged every 45 days. Fish species in all the previous intensive system tanks were stocked and reared according to the standard feeding and water quality management protocols described by Bovendeur *et al.* [29], Suresh and Lin [30], and Azim and Little [12]. In addition to the previous irrigation treatments nitrogen, phosphorus and potassium (NPK) mineral fertilization was also used as a fifth treatment. The mixed NPK fertilizer (1:1:1) was added manually to the pot soil (18g/pot/2 months) as recommended by Abd El-Aziz [31], then the pots were irrigated with tap water. NPK sources of the fertilizer mixture were ammonium nitrate (33.5% N), single superphosphate (15% P_2O_5), and potassium sulfate (48% K_2O), respectively. All pots were irrigated manually with the water type to the field capacity of the soil, making use of fish feces in the fish effluents. The average chemical composition of water types used in irrigation treatments during the 2010 and 2011 seasons are shown in Table 2 (water samples were collected randomly from different sites of the experimental tanks).

Growth Trait Measurements: At the end of the experiment (November, 1st) in both seasons, twelve seedlings from each treatment of both tree species were collected to determine the following growth traits as averages: plant height (cm), stem diameter (cm), compound leaves number/plant, roots number/plant (root samples were washed thoroughly with tap water), and fresh and dry (FW and DW) weights (plant samples were dried at 65ºC to a constant weight for approximately 48h) of leaves, stem, and roots/plant (g).

Analytical Methods for Leaves: Photosynthetic pigment content including total carotenoids, chlorophyll (Chl.) *a*, *b*, and total Chl. *a*+*b* (mg/g) were colorimetrically determined during the two seasons in the fresh compound leaf samples of both tree species using acetone 80% according to the method described by Goodwin [32]. Total macro-nutrients (NPK) content (%) of the two species in both seasons were extracted from dried compound leaf samples that were ground to powder and digested using sulfuric and perchloric acids following the procedure described by Chapman and Pratt [33]. The determination was carried out as follows: N content by the Kjeldahl technique as described by Nelson and Sommers [34], P content by using Inductively Coupled Plasma (ICP) Spectrometer as elucidated by Donohue and Aho [35], and K content by Flame Photometer according

Table 2: Averages of the chemical analyses of the irrigation water types used during seasons of 2010 and 2011.

						Total macro-nutrients (ppm)		
Irrigation water types	pH	EC (dS/m)	DO (ppm)	TSS (ppm)	TVS (ppm)	N	P	K
TW	7.78	0.47	2.80	Nd	Nd	Nd	Nd	Nd
ICCE	7.69	1.34	5.30	77.20	30.11	4.57	0.91	9.37
ITCE	7.97	1.40	6.50	14.44	7.71	1.54	0.25	4.35
I-BFT-TCE	7.62	1.37	4.50	273.75	150.76	3.68	26.47	35.28

DO: dissolved oxygen.

TSS: total suspended solids.

TVS: total volatile solids.

to Isaac and Kerber [36].Total carbohydrates content (%) were extracted from the powder of the ground dried compound leaf samples of both seasons by sulfuric acid 67% and colorimetrically determined by the phenol-sulfuric acid method as described by Dubois *et al.* [37].

Statistical Analysis: The obtained data for both seasons was statistically analyzed with analysis of variance (ANOVA) as described by Snedecor and Cochran [38]. The MSTAT-C statistical software [39] package was used based on Duncan's Multiple Range Test to determine the statistical significance of differences in means between treatments at probability level of 0.05 as outlined by Walter and Duncan [40].

RESULTS AND DISCUSSION

Growth Traits: Results of growth traits (plant height, stem diameter, compound leaves number/plant, root number/plant, and F and DWs of leaves, stem, and roots) for *K. senegalensis* and *S. mahagoni* seedlings as affected by irrigation with various fish culture effluents during seasons of 2010 and 2011, are shown in Tables 3 and 4, respectively. Application of all treatments significantly increased all the studied growth parameters compared with the control case (TW) in both seasons, except for stem diameter of khaya seedlings irrigated with ICCE. The increase obtained in seedlings growth irrigated with fish effluent treatments was not as high as the seedling growth obtained from NPK mineral fertilization treatment. However, the I-BFT-TCE irrigation treatment elevated seedling growth values to be near NPK mineral fertilization treatment growth values. For instance, the percentage increases in khaya seedling heights were 32.10 and 46.23% in the first season and were 33.90 and 47.43% in the second one for ICCE and ITCE treatments, respectively. As for mahogany seedling heights, the percentages were 100.74 and 110.64% in the first season and were 104.66 and 108.74% in the second one for ICCE and ITCE treatments, respectively. NPK mineral fertilization treatment showed 139.40 and 137.07% in the first and second season, respectively for khaya seedlings and 141.26 and 140.10% in the first and second season, respectively for mahogany seedlings.

Table 3: Effect of irrigating with various fish culture effluents on growth traits of *Khaya senegalensis* (Desr.) A. Juss. seedlings during seasons of 2010 and 2011.

	Growth traits									
Treatments	Plant height (cm)	Stem diameter (cm)	Leaves number/ Plant	Roots number/ Plant	Leaves FW (g/plant)	Stem FW (g/plant)	Roots FW (g/plant)	Leaves DW (g/plant)	Stem DW (g/plant)	Roots DW (g/plant)
Season 2010										
TW (control)	36.60 e	1.15 c	17.00 d	19.50 d	21.85 e	31.09 e	41.55 e	7.76 e	11.75 e	19.30 e
ICCE	39.63 d	1.23 c	19.83 c	24.67 c	30.51 d	35.14 d	51.01 d	12.48 d	14.57 d	23.35 d
ITCE	43.87 c	1.46 b	20.83 c	24.33 c	37.74 c	52.98 c	65.62 c	14.43 c	20.05 c	27.38 c
I-BFT-TCE	67.87 b	1.89 a	30.00 b	41.50 b	101.52 b	114.20 b	103.29 b	51.21 b	50.79 b	55.95 b
NPK	71.82 a	1.93 a	34.33 a	47.50 a	125.62 a	125.45 a	115.79 a	63.08 a	60.06 a	59.74 a
Season 2011										
TW (control)	37.42 e	1.13 c	17.67 d	19.33 d	22.17 e	30.32 e	42.46 e	8.06 d	11.78 e	18.90 e
ICCE	40.17 d	1.21 c	20.67 c	25.00 c	31.52 d	34.88 d	50.95 d	12.98 c	14.54 d	22.35 d
ITCE	44.23 c	1.46 b	21.17 c	25.33 c	36.52 c	51.35 c	66.75 c	13.48 c	20.68 c	27.66 c
I-BFT-TCE	67.73 b	1.85 a	29.67 b	41.33 b	99.92 b	113.46 b	102.18 b	51.60 b	50.09 b	56.24 b
NPK	71.12 a	1.96 a	34.67 a	48.50 a	126.06 a	126.63 a	114.87 a	62.03 a	60.23 a	59.24 a

Means followed by similar letter(s) within the same column are not significantly different at probability level of 0.05 according to Duncan's Multiple Range Test.

Table 4: Effect of irrigating with various fish culture effluents on growth traits of *Swietenia mahagoni* (L.) Jacq. seedlings during seasons of 2010 and 2011.

	Growth traits									
Treatments	Plant height (cm)	Stem diameter (cm)	Leaves number/ Plant	Roots number/ Plant	Leaves FW (g/plant)	Stem FW (g/plant)	Roots FW (g/plant)	Leaves DW (g/plant)	Stem DW (g/plant)	Roots DW (g/plant)
Season 2010										
TW (control)	88.60 e	1.26 d	33.00 e	44.83 d	27.99 e	69.29 e	45.27 e	12.27 c	36.74 e	21.87 e
ICCE	100.37 d	1.40 c	38.50 d	46.83 c	48.74 d	79.33 d	47.56 d	19.74 b	40.20 d	25.64 d
ITCE	105.32 c	1.46 c	41.50 c	61.50 b	51.82 c	90.32 c	55.86 c	21.79 b	48.45 c	29.33 c
I-BFT-TCE	111.15 b	1.80 b	49.17 b	63.83 a	88.57 b	149.35 b	64.45 b	41.58 a	79.33 b	39.54 b
NPK	120.63 a	1.96 a	53.67 a	65.17 a	92.82 a	169.97 a	69.66 a	43.93 a	90.02 a	42.08 a
Season 2011										
TW (control)	90.03 e	1.29 d	32.33 d	44.33 e	27.83 d	70.25 e	44.55 e	12.03 c	36.90 e	20.96 e
ICCE	102.33 d	1.36 c	39.33 c	47.33 d	47.92 c	80.12 d	49.45 d	20.94 b	40.90 d	25.50 d
ITCE	104.37 c	1.46 b	41.00 c	60.33 c	50.98 b	90.71 c	54.72 c	22.87 b	48.74 c	30.18 c
I-BFT-TCE	112.60 b	1.81 a	49.33 b	64.33 b	89.74 a	150.66 b	64.09 b	42.27 b	80.34 b	39.49 b
NPK	120.05 a	1.87 a	52.33 a	66.83 a	91.13 a	170.40 a	69.49 a	44.50 a	89.56 a	43.13 a

Means followed by similar letter(s) within the same column are not significantly different at probability level of 0.05 according to Duncan's Multiple Range Test.

Meanwhile, the I-BFT-TCE irrigation treatment showed 126.23 and 125.77% in the first and second season, respectively for khaya seedlings and 122.30 and 125.20% in the first and second season, respectively for mahogany seedlings. However, the control seedlings recoded 22.00 and 24.73% increase in the first and second season, respectively for khaya seedling heights and 77.20 and 80.06% in the first and second season, respectively for mahogany seedling heights. The results reveal that seedlings growth was improved by any given treatment compared to the control, suggesting that all treatments contained sufficient nutrients to enhance the growth. It is also important to point out that, while the growth of NPK mineral fertilized seedlings was significantly the largest; it is quite exciting to indicate that seedlings irrigated with I-BFT-TCE showed a comparable growth, among all other fish effluents for the two species during both seasons. This suggests that I-BFT-TCE can be used as an efficient alternative biofertilizer to the mineral NPK form.

Generally, the increase in seedling growth as compared to the control may be due to encouraging cell division and elongation via the macro-nutrients of the fish effluents. These effluents mainly supplied seedlings with N and P (the major nutrients in the pond ecosystem) in addition to K (provided from both fish feed and potassium permanganate which is used in fish ponds to improve water quality). The most likely factor causing differences in seedlings growth irrigated with I-BFT-TCE is its high nitrogen amount. In this case, the combination of more sunlight, more feeds, and low water exchange rates stimulate phytoplankton biomass, which lead to higher nitrogen concentrations in the water column [41]. This nutrient is a constituent of both structural (cell membranes) and nonstructural (amino acids, enzymes, protein, nucleic acids and chlorophyll) components of the plant [42]. In addition, providing the soil with organic matter helped in improving the soil characteristics, which reflected also on seedling growth [22]. This makes I-BFT-TCE particularly attractive given its relative close composition to the mineral counterpart, NPK, but in the form of a biofertilizer. These results are in harmony with the findings of EL-Mahrouk *et al.* [4] who reported that NPK play important roles in different physiological processes of metabolites that enhance cell division and elongation in cambium zone. They also pointed out that, N and P enhance photosynthesis process which causes more accumulation of biochemical products that positively affect the shoot growth of *Khaya senegalensis* seedlings by usage of sewage effluent in irrigation. The direct relationship between nutrient supplementation through effluents and woody tree seedling growth agree with the observations of Ali *et al.* [5] by using sewage effluent in the irrigation of *S. mahagoni*, El-Kady and Suloma [22] by using tilapia culture effluents in the irrigation of *Chilopsis linearis*, El-Helaly and Suloma [43] by using aquaculture effluent in the irrigation of *Brassica oleracea*, and Hanafy *et al.* [44] by using municipal wastewater in the irrigation of *Schinus terebinthifolius*.

Chemical Constituents of Leaves: Data presented in Tables 5 and 6 shows leaf chemical constituents (photosynthetic pigments, total macro-nutrients, and total carbohydrates contents) of *K. senegalensis* and *S. mahagoni* seedlings influenced by irrigation with various fish culture effluents during seasons of 2010 and 2011. Photosynthetic pigments content such as total carotenoids, Chl. *a*, *b*, and total Chl. *a*+*b* contents of both khaya and mahogany seedling leaves during the two seasons were elevated when treating seedlings with NPK

Table 5: Effect of irrigating with various fish culture effluents on leaves chemical constituents of *Khaya senegalensis* (Desr.) A. Juss. seedlings during seasons of 2010 and 2011.

Treatments	Photosynthetic pigments content (mg/g)				Total macro-nutrients content (%)			Total carbohydrates content (%)
	Total carotenoids	Chl. *a*	Chl. *b*	Total Chl. (*a*+*b*)	N	P	K	
Season 2010								
TW (control)	0.90 c	2.05 d	0.69 b	2.74 d	1.06 d	0.19 c	0.65 d	9.34 d
ICCE	1.82 b	3.62 c	1.57 a	5.19 c	1.14 cd	0.22 c	0.77 c	9.48 d
ITCE	2.29 ab	4.38 b	1.65 a	6.03 b	1.21 bc	0.27 bc	0.79 c	10.00 c
I-BFT-TCE	2.10 ab	5.02 a	1.78 a	6.80 a	1.27 b	0.32 b	0.88 b	11.26 b
NPK	2.57 a	5.08 a	1.90 a	6.97 a	1.38 a	0.49 a	1.12 a	11.89 a
Season 2011								
TW (control)	1.22 b	2.31 c	0.84 c	3.14 d	1.29 b	0.27 c	0.77 d	10.57 c
ICCE	2.03 ab	3.62 b	1.68 ab	5.30 c	2.04 ab	0.33 c	0.97 c	10.96 bc
ITCE	1.98 ab	4.01 b	1.62 b	5.64 bc	2.25 a	0.38 bc	1.16 b	11.67 b
I-BFT-TCE	2.23 ab	4.64 b	1.70 ab	6.34 b	2.38 a	0.47 ab	1.27 ab	12.97 a
NPK	3.01 a	6.02 a	1.97 a	7.99 a	2.64 a	0.57 a	1.40 a	13.49 a

Means followed by similar letter(s) within the same column are not significantly different at probability level of 0.05 according to Duncan's Multiple Range Test.

Table 6: Effect of irrigating with various fish culture effluents on leaves chemical constituents of *Swietenia mahagoni* (L.) Jacq. seedlings during seasons of 2010 and 2011.

Treatments	Photosynthetic pigments content (mg/g)				Total macro-nutrients content (%)			
	Total carotenoids	Chl. *a*	Chl. *b*	Total Chl. (*a*+*b*)	N	P	K	Total carbohydrates content (%)
Season 2010								
TW (control)	1.40 c	3.12 c	1.77 d	4.89 d	1.11 c	0.20 d	0.80 c	6.36 c
ICCE	1.64 c	3.26 c	1.79 d	5.05 d	1.26 c	0.23 cd	0.87 c	7.21 bc
ITCE	1.99 bc	4.37 c	2.68 c	7.05 c	1.34 c	0.31 bc	0.95 bc	7.63 bc
I-BFT-TCE	2.56 ab	6.80 b	3.79 b	10.58 b	2.43 b	0.39 b	1.07 ab	8.51 b
NPK	2.84 a	10.51 a	4.99 a	15.49 a	3.72 a	0.88 a	1.20 a	10.41 a
Season 2011								
TW (control)	1.50 d	3.08 c	1.83 d	4.91 c	1.46 d	0.23 d	0.79 d	7.21 d
ICCE	1.62 d	3.49 c	1.79 d	5.28 c	1.69 cd	0.27 cd	0.91 cd	8.90 c
ITCE	2.08 c	4.21 c	2.36 c	6.57 c	1.93 c	0.34 c	1.00 bc	10.35 bc
I-BFT-TCE	2.58 b	7.17 b	3.57 b	10.74 b	3.66 b	0.48 b	1.14 b	10.51 b
NPK	3.13 a	10.01 a	5.28 a	15.28 a	4.34 a	0.96 a	1.39 a	12.53 a

Means followed by similar letter(s) within the same column are not significantly different at probability level of 0.05 according to Duncan's Multiple Range Test.

mineral fertilizers followed by I-BFT-TCE, ITCE, ICCE, and then TW treatment. Significant differences were observed between treatments and control except for total carotenoids content of khaya leaves in the second season as there were insignificant differences between the three fish culture effluent treatments and control. For mahogany leaves, all photosynthetic pigments content in both seasons revealed an insignificant difference between ICCE and control, in addition to Chl. *a* content of seedling leaves irrigated with ITCE treatment and control. For instance, leaf total Chl. *a*+*b* contents of khaya seedlings irrigated with fish effluents, in the first season, ranged from 5.19 to 6.80mg/g, whereas leaf total Chl. *a*+*b* contents of seedlings irrigated with TW or fertilized with NPK were 2.74 or 6.97mg/g, respectively. The range in the second season was 5.30 to 6.34mg/g for leaves of effluent treated seedlings compared to 3.14 and 7.99mg/g for leaves of untreated and NPK fertilized seedlings, respectively. The total Chl. *a*+*b* content ranges of mahogany leaves affected by fish effluents were 5.05 to 10.58 and 5.28 to 10.74 in the first and second season respectively. Meanwhile, the contents for the control seedlings in the two seasons respectively were 4.89 and 4.91mg/g. The NPK fertilized seedlings, on the other hand, showed Chl. *a*+*b* contents of 15.49 and 15.28mg/g in the first and second season, respectively.

Generally, the irrigation with fish effluents increased the total macro-nutrients content of N, P, and K in leaves of both khaya and mahogany seedlings as compared to the control during the two seasons. The increase of the studied nutrients due to treatments compared with TW can be arranged in the following order: NPK > I-BFT-TCE > ITCE > ICCE. For instance, the N contents of khaya leaves affected by the irrigation with fish effluents in the first season ranged from 1.14 to 1.27%, compared to 1.06 and 1.38% for the control and NPK mineral fertilization treatments, respectively. The second season showed a range of 2.04 to 2.38% compared to 1.29% for the control and 2.64% for NPK treatment. In the case of N contents of mahogany leaves in the first season, the range was 1.26 to 2.43% for seedlings irrigated with fish effluents whereas the contents of the control seedlings and seedlings fertilized with NPK were 1.11 and 3.72%, respectively. However, the range in the second season was 1.69 to 3.66% for fish effluent treatments, compared with 1.46 and 4.34% for the control and NPK treatments, respectively.

The seedling total carbohydrates content was shown to be strongly affected by the irrigation with fish effluents, and followed the previous trend compared to TW that gave the lowest values. The highest magnitude increase of total carbohydrates content was observed in seedlings fertilized with NPK (11.89 and 13.49% for khaya leaves in the first and second season, respectively and 10.41 and 12.53% for mahogany leaves in the first and second season, respectively). The I-BFT-TCE showed a close effect to NPK as total carbohydrates content in khaya and mahogany leaves in the first season were 11.26 and 8.51%, respectively, whereas in the second season were 12.97 and 10.51%, respectively. ITCE and ICCE increased the total carbohydrates content of khaya leaves in the first season (10.00 and 9.48%, respectively) and also in the second one (11.67 and 10.96%, respectively). In the case of mahogany leaves, these two effluents recorded 7.63 and 7.21% in the first season and 10.35 and 8.90% in the second one. The lowest total carbohydrates content in leaves of both khaya and mahogany was shown in control seedlings (9.34 and 6.36%, respectively in the first season and 10.57 and 7.21%, respectively in the second one).

The observed increases in N, P, and K concentrations in the seedling leaves by applying fish effluents, especially by I-BFT-TCE, is quite promising from an irrigation point of view. This reinforces the initial suggestion above of its use as an efficient biofertilizer to the mineral NPK form. The increase may be a result of supplying the soil with both nutrients and organic matter. The nutrients around the root zone help in elevating their uptake by roots, whereas the organic matter increase water holding capacity, decrease bulk density, and increase aeration and root penetrability [4, 22, 45]. Each of these factors reflects on the plants' biological activities that in turn, reflect on leaf photosynthetic pigments and total carbohydrates contents [22, 44]. The improvement in soil properties by using wastewater in the irrigation of woody trees confirm the findings of Ali *et al.* [5] who reported that both seedling parts and soil content of NPK increased by irrigating *S. mahagoni* with sewage effluent. El-Kady and Suloma [22] also reported that usage of tilapia culture effluents in the irrigation of *Chilopsis linearis* played an important role in improving soil properties and was a rich source of nutrients which reflected positively on the NPK, photosynthetic pigments and total carbohydrates contents of the seedlings. Hanafy *et al*. [44] pointed out that municipal wastewater contains nutrients and organic matter that increases the uptake and the accumulation of the elements in plant tissue, enhances photosynthetic and metabolic processes which in turn cause more carbohydrate accumulation when used in the irrigation of *Schinus terebinthifolius*.

CONCLUSIONS

The improved growth of both *Khaya senegalensis* and *Swietenia mahagoni* seedlings when irrigated with various fish culture effluents shows dual environmental and economic benefits that: (1) reduce the environmental impact of discharging water rich in nutrient into receiving streams by using it in irrigation instead, (2) reduce the amounts of chemical fertilizers needed for trees, especially for small farmers, to whom fertilizers are often cost prohibitive or unavailable, (3) substitute mineral fertilizers in tree production especially by BFT effluent which is considered a biofertilizer and doubles water use/benefit, (4) an alternative resource of water for agriculture in arid and semi-arid regions, and finally (5) improve tree growth which helps to overcome deforestation.

However, the information on aquatic effluent discharge to the environment is still in its preliminary stages. Therefore, (1) comprehensive studies on the safety of soil-plant systems and nutrient uptake by woody trees in arid and semi-arid zones under aquaculture effluents irrigation should be further examined, (2) the management of aquaculture effluents quality if aquaculture disease occurs should be further considered, (3) selecting the most suitable woody trees species for the site location and climate to facilitate nutrient absorption from an aquaculture effluent is recommended, (4) optimizing the fish diet, density, or both in order to enhance NPK concentrations to that of the mineral fertilizer is recommended to realize a concurrently optimally beneficial system, (5) the application of this idea to different forms of agricultural systems such as vegetables and fruit trees could be interesting avenues for other studies, additionally (6) performing a field scale trial of the study findings would be more meaningful.

The results presented here show a promising solution to cultivate ornamental woody trees under the umbrella of sustainability. As a possible path towards finding simple ways to make existing resources valuable, Fig. 1 shows a schematic of a possible large scale environmentally friendly application design proposed for wastewater-aquaculture-agriculture integration in arid and semi-arid regions. The first stage of this illustration starts from the residential areas adjacent to the desert that produces huge amounts of municipal wastewater. This wastewater is then pre-treated by passing through rows of wetland plants to mitigate, contain, and/or degrade pollutants, metals, pesticides, organic and inorganic molecules and other contaminants in a process known as phytoremediation. The wetland plants biomass is periodically harvested and used for the production of an environmentally friendly lignocellulosic biofuel. This biofuel which represents a renewable bioenergy source, is subsequently used in the BFT systems (with or without fish) for aerating and stirring the BFT water to maintain high levels of bacterial flocs in suspension, as heterotrophic bacteria in this system require aerobic conditions to decompose organic matter. These heterotrophic bacteria turn into a direct fish feed (organic matter) after being periodically collected from the BFT effluent via the dewatering process. To run the BFT system, it is necessary to load it with a carbon source. This can in turn be obtained from agro-wastes (leaves or shoots) of agro-forestry plots adjacent to culture units.

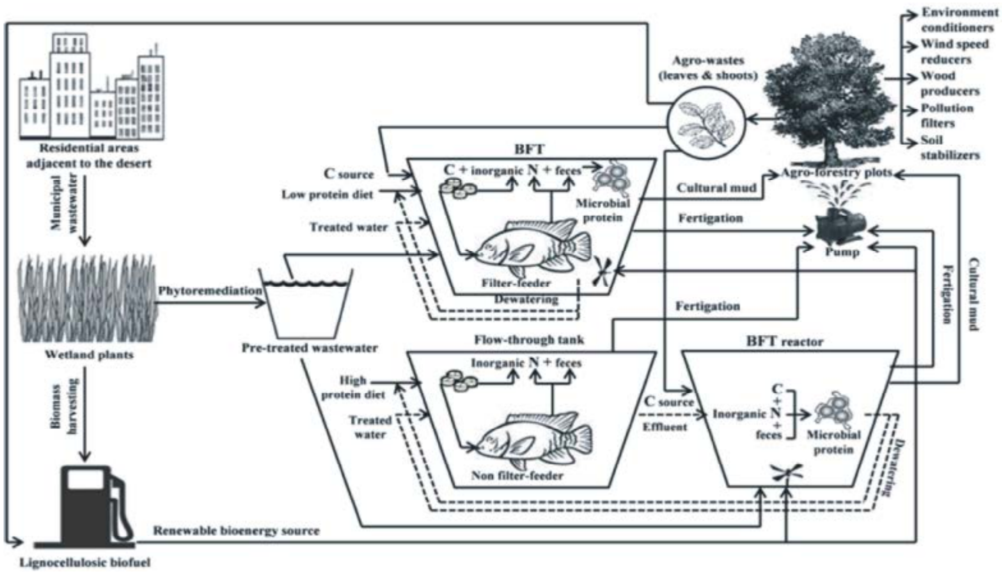

Fig. 1: A large scale application design proposed for wastewater-aquaculture-agriculture integration in arid and semi-arid regions.

These agro-wastes can also be used for the production of the lignocellulosic biofuel. The carbon source changes the C: N ratio in the tanks and allows the growth of heterotrophic bacteria, which will play an important role in converting nitrogen compounds resulting from the initial treatment of municipal wastewater or from feeding fish on commercial diets. This carbon source can also be incorporated into the diets used. By this system, fish production in large quantities as well as fish feed availability can be obtained without further water encumbrance and at a low cost. The woody trees, hedgerows, etc of the forestry plots, by extension, will play important roles in conditioning the environment, reducing the wind speed, producing wood, filtering the pollutants and stabilizing the soil. Finally, the presented effluent, free from suspended organic matter, is considered treated water that can be either reused in other culture units (flow-through tanks), or filtered and pumped through the irrigation network using the previously mentioned biofuel source to other enterprises (agro-forestry plots) for fertigation. Furthermore, the extracted cultural mud may also be collected and stored for further plantations as soil amendments. It is worth pointing out that such a design can be applied almost anywhere globally, but more importantly in the arid and semi arid regions, and would be a powerful tool in breaking hunger, environmental pollution, global warming, and natural degradation.

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