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Performance of Agricultural Wastes as a Biofilter Media for Low-Cost Wastewater Treatment Technology

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Authors' contributions

This work was carried out in collaboration between all authors. Authors MRG and MAB proposed the research plan, and reviewed the manuscript. Author MHB analyzed the results of the study, processed the calculations and wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The main objective of this work is to evaluate the performance of biofilters with different agricultural wastes media, which widely exist in many regions without being economically used, namely rice straw, date palm fiber and wood chips of orange trees. Using agriculture waste as a biofilter media for municipal wastewater treatment and reducing the accumulation of agricultural waste is an important option to reduce the wastewater treatment cost and for the environmentally safe disposal of agricultural waste in Egypt.
Study Design: Pilot study is conducted to investigate the efficiency of three types of agricultural wastes; rice straw, wood chips, orange trees and date palm fiber as a filter media and bio-film material carrier for municipal wastewater treatment.
Place and Duration of Study: Benha Faculty of engineering, Benha university, Egypt. Between March 21th and October 10th, 2015.
Methodology: The removal efficiency of different municipal wastewater parameters is evaluated

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through column experiments under different operational conditions for hydraulic rates of 4.8, 6, 8 and 12 $m^3/m^2/d$ and medium size of fibers of 2 cm, 4 cm, 6 cm and 8 cm. Samples from four different depths for each media are tested to study the effect of depth change in the removal efficiency.

Results: The removal efficiency of the Biological Oxygen Demand (BOD_5) was (81.5%±4.8, 88.3%±2.8, and 66.7±5.2) for rice straw, date palm fiber and wood chips of orange trees, respectively. The removal efficiency of the studied biofilter media for Chemical Oxygen Demand (COD) removal was (79.7±5 for rice straw, 88.3±3 for date palm fiber and 64.6±7.24 for wood chips of orange trees. Moreover, the removal efficiency of Total Suspended Solid (TSS) was (82.43±4.9, 86.6±3.9, and 68.3±3.5) for rice straw, date palm fiber and wood chips of orange trees, respectively. The removal efficiency of total nitrogen (N) was (50.21%±2.32, 55%±1.31 and 45±2.38) for rice straw, date palm fiber and wood chips of orange trees, respectively. While The percentage of total phosphorus (P) removal efficiency was 41.92±4.14 for rice straw, 50.52±1.32 for date palm fiber and 32.45±2.30 for wood chips of orange trees.

Conclusion: The study revealed that the using of agricultural wastes as biofilter media could be a favorable choice for the biological treatment of municipal wastewater. Date palm fiber was the most efficient media in the removal of wastewater pollutions.

Keywords: Agricultural wastes; rice straw; date palm fiber; orange trees; biofilter media; low-cost treatment technology.

1. INTRODUCTION

In Egypt, there are many millions of tons of agricultural wastes that not utilized and disposed yearly into the environment causing many environmental problems. These wastes may contain valuable materials, however, their economic values are less than the apparent cost of collection, handling, and processing for beneficial use, therefore, they are often discharged as a waste [1]. This raised the interest to search for utilization methods of these wastes as rich sources for low-cost materials in the treatment of wastewater.

On the other hand, rural areas and villages in Egypt are suffering from low coverage of proper sanitation as well as stressful financial problems. As a result, the majority of villages and rural areas in Egypt disposed their raw wastewater into waterways directly [2]. Wastewaters cause many serious environmental problems when is disposed into waterways as eutrophication, water quality problems, and spread of disease around these villages [3].

Conventional wastewater treatment systems are costly and difficult to construct and operated in developing countries, therefore the need for new technologies in wastewater treatment that require low investments and operating costs have been increased [4]. One of these technologies for decentralized wastewater treatment systems is a biofiltration system that uses organic packing media [5]. In a biofilter, wastewater is fed into the top of the biofilter and allowed to infiltrate downwards through the media. This process is similar to that of a trickling filter [6]. The pollutants in wastewater degraded and hydrolyzed by micro-organisms that grow on the surface of packing media [4].

In the past twenty years, biofilters that use organic materials have been studied and applied at both full scale and laboratory scale for drinking water [7], sanitary and agro-industrial wastewater [5].

In Canada and US, Peat was studied to be used as attached media in biofilters. This was the first study of the use of peat as organic media for biofiltration in wastewater treatment [8] and more recently in Ireland by Corely et al. [9]. The technology of using an organic material as agricultural wastes in wastewater has been applied in Canada at full scale during 1990s and first years of 2000s [4].

Peat, Conifer wood chips and Conifer bark were studied to be used as organic media in biofilters in canada by Bulena and Belanger [10] and in Belgium by, Lens et al. [11]. In the same direction, cotton stalks were studied to use as attached media in biofilter by Hashem et al. [12]. Almond shells and Sun flower stalks were also tested as attached media in biofilters by El Nadi et al. [13,14]. El-Sergany [15] used in her study sugar cane stalks waste as attached media in biofilters. Rice husk was studied by El-Sergany [16], to use as attached media for wastewater treatment. Wild thorn, Arum plant, and Date palm bark were used as bio-fillings in the biological filter by Al-Maliky and El-Khyat [17]. The ficus trees pruning's results were used as attached media by El Nadi et al. [18]. All these results reported a good performance for the removal of TSS, COD, and BOD. The using of agricultural wastes in wastewater treatment seems to be a good choice for decentralized treatment in rural and semi-rural areas and regions where there are serious problems due to the lack of wastewater drainage [5].

The purpose of this study is to evaluate the performance of biofilter that adopts three randomly distributed agricultural wastes media; namely (Rice Straw, Woodchips of orange trees and Date Palm Fiber) which widely existed in many regions in Egypt and especially in the study area without being economically used. Four biofilters reactor systems are used to determine their removal efficiency and to evaluate the effects of media size, media depth and hydraulic flow rate on the removal efficiency of pollutants of Total Suspended solids (TSS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD_5), nitrogen and phosphorus according to the Egyptian conditions.

2. MATERIALS AND METHODS

2.1 Characterization of Materials

Rice straw, date palm fiber, and orange tree wood chip samples were collected from Qaha, Kafr Taha and Biltan, Qalyubia governorate, Egypt respectively. The samples are divided into four sizes as shown in Fig. 1 and Table 1.

2.2 Pilot Setup

A pilot plant was developed as shown in Fig. 4 and installed at Benha Faculty of Engineering, Benha University, Egypt. The pilot is composed of four columns of PVC tubes with 25 cm diameter and 2 m height. The biofiltration columns are packed with agriculture wastes in different depths (20,40,60 and 80 cm). At the bottom of each column, 10 cm support media of gravel. The applied agricultural wastes were rice straw, date palm fiber and orange tree wood chips. The raw wastewater was pumped into the upper end of the reactor and the effluent flowed out the bottom of the reactor. The pilot was working continuously during the day. The pilot plant operated for 8 months from March 2015 to October 2015. The pilot consists of submersible pump, screens, feeding tank, four biofilters reactors and Piping and control valves.

2.3 Wastewater Influent Characteristics

The main characteristics of raw sewage influent in this study as shown in Table 2. More than 50 samples are collected and analyzed for each type of agricultural waste during the study period.

2.4 Experimental Procedure

The pilot-scale and experimental program are designed to evaluate the performance of three types of agricultural wastes; rice straw, orange tree wood chips, and date palm fiber. These wastes are applied as a filter media and bio-film material carrier for municipal wastewater treatment. The experimental work of each agricultural waste is applied on three runs.

Table 1. The applied sizes for agricultural wastes; rice straw, date palm fiber and orange tree wood chips

Materials	Size (1)	Size (2)	Size (3)	Size (4)	Sample location
Rice straw	2 cm	4 cm	6 cm	8 cm	Qaha
Date palm fiber	2x2 cm	4x4 cm	6x6 cm	8x8 cm	Kafr Taha
Orange tree wood chips	2 cm	4 cm	6 cm	8 cm	Biltan

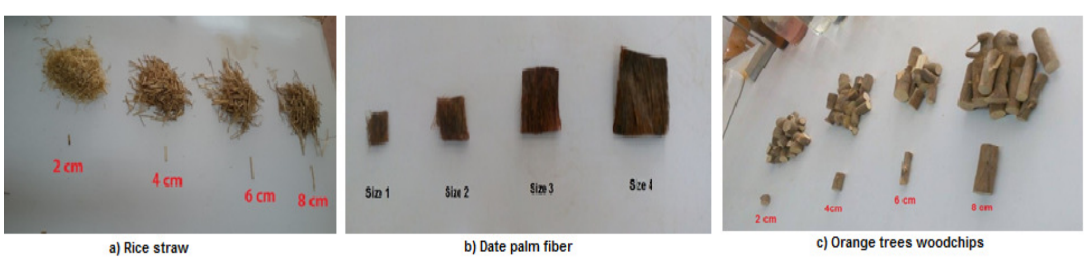

Fig. 1. Sizes of study biofilter media (Rice straw, date palm fiber, and orange tree wood chips)

Each run has taken at least three weeks. On the first run, four sizes (size 1, 2, 3 and 4) of each agricultural wastes were applied to get the most effective size and to check the impact of waste size on the removal efficiency. The second is checked four depths of each waste media (20, 40, 60 and 80 cm) of the most effective size which is obtained from the first run. This run is applied to find the most effective depth of waste media and to check the removal efficiency with different depths. On the third run, four hydraulic rates (4.8, 6, 8 and 12 m3/m2/d) were applied on the most effective size and optimum depth of each agricultural waste. This run is used to find the optimum rate and to check the effect of hydraulic rate on the removal efficiency. Fig. 3 indicates the methodology of the experiment work of this study.

Table 2. Physical and chemical characteristics of influent raw sewage

Measuring parameters	Value (Avg ±S.D.)
Total suspended solids (mg/l)	184±22
BOD (mg/l)	211±26
COD (mg/l)	383±69
TN (mg/l)	34±5.17
TP (mg/l)	18.30±1.2
Temperature (ºC)	28.10± 4.30
pH	7.50±0.26

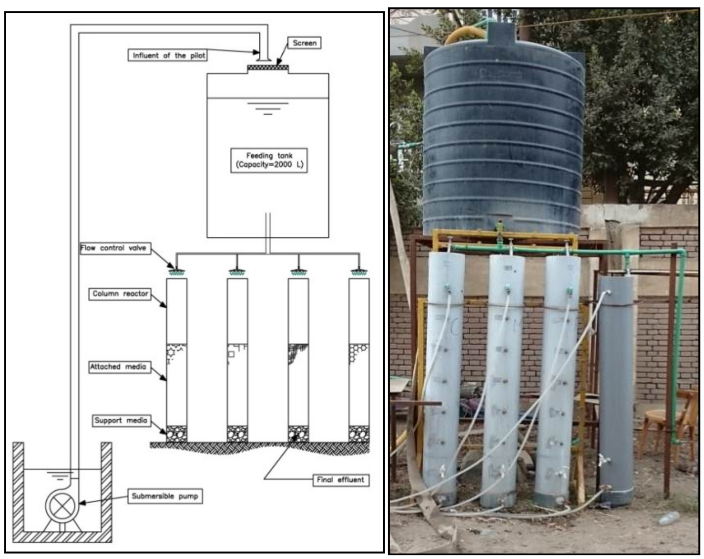

Fig. 2. Pilot unit

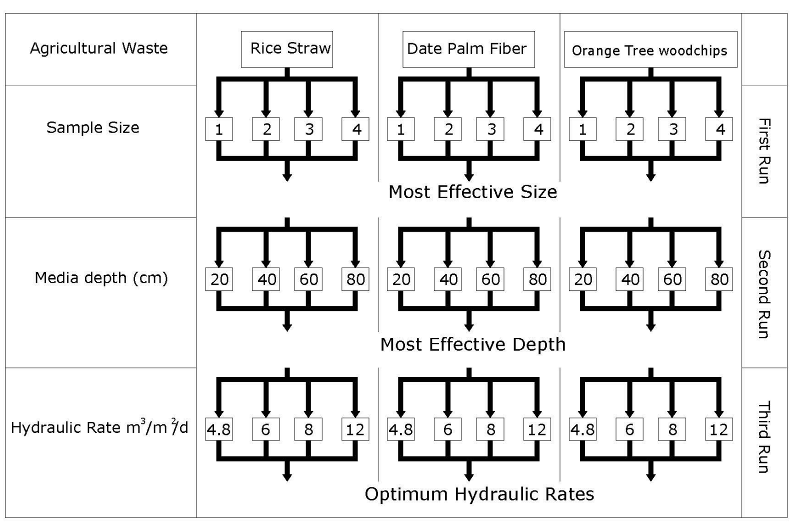

Fig. 3. Methodology of experimental work

Samples were collected 3 times per week from the influent and the effluent of each column reactor and analyzed for BOD5, COD, TN, TP and TSS. All measurements and parameters were analyzed according to American Standards Methods for Water and Wastewater Examination [19].

Removal percentage of each studied parameter (Re%) was calculated as displayed in Figs. (7 to 9).

2.5 System Start up and Operation

The pilot was operated for 3 weeks for each run. The pilot was operating during the first week of each cycle without recording any results to achieve system stabilization. The pilot was feeding with wastewater daily for one week for the accumulation and development of biomass. In the second week after growth of biomass on the media, the results were recorded. During the second and the third week, the removal efficiencies were improved gradually and achieved good results for removal ratios.

3. RESULTS AND DISCUSSION

3.1 Raw Sewage Characteristics

Fig. 4 represents the results of the concentration of biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total suspended solids (TSS) in influent raw wastewater of the study. The BOD5 ranged from 129 and 288 mg/L and the average value was 212 mg/L. The COD varied from 263 mg/L to 540 mg/L and the average value was 383 mg/L. The TSS ranged from 142 to 281 mg/L and the average value was 184 mg/L.

3.2 Effect of Size

Four sizes of each type of the studied biofilter media (Rice straw, date palm fiber, and orange tree wood chips) were applied in four biofilter reactors, consecutively. The four reactors have the same operating conditions for each media. The result of the study of the effect of biofilter media sizes on the removal efficiency of wastewater contaminants is indicated in Fig. 5.

The first size was the most effective size for all biofilter media. It gave the best removal efficiency for wastewater contaminants (BOD, COD, and TSS) compared with other sizes. The fourth size gave the lowest efficiency for all media. The first size was the best due to its large surface area per unit volume which is more suitable for micro-organisms growth as well as lower the void ratio which is more suitable for biological action to take place. The removal efficiency for the second size was less than the first size because it has a less surface area per unit volume and higher void ratio. The third and fourth sizes have higher values of permeability and lower surface area that decrease the effect of both biological action and physical action to take place. The removal efficiencies for the third and fourth sizes were very close to each others.

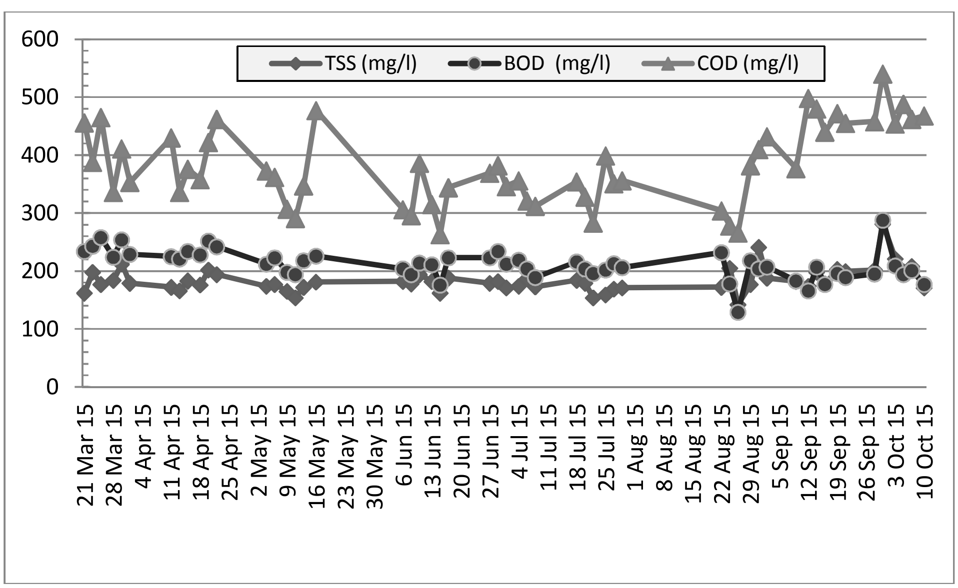

Fig. 4. Temporal series of BOD, COD and TSS concentrations of raw sewage

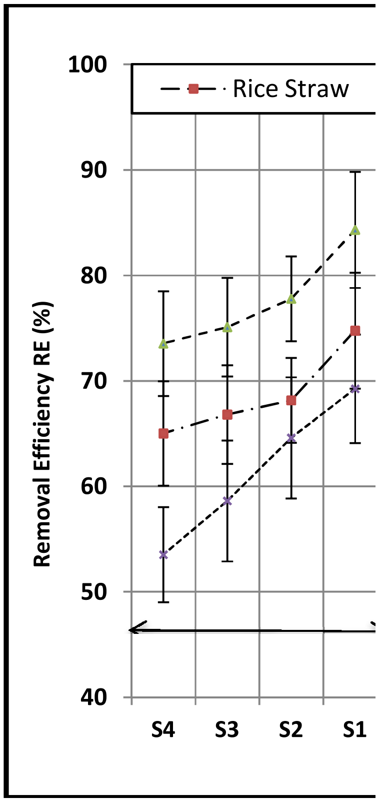

Fig. 5. Removal efficienc

The media of date palm fiber g
removal efficiency for BOD, CC
compared with the other agricu
media for all applied sizes. The
ratios of date palm fiber were
77.80%±4.02, 75.12%±4.67 and
for biofilter media of sizes 1
respectively, while the COD remov
86.10%±5.09 for size 1, 79.73%±3
75.62%±4.14 for size 3 and 73.80%
4. The TSS removal ratios were
75.28%±4.01, 74.40%±5.22 and
for sizes 1, 2, 3 and 4 respectively.

The rice straw media was the
removing BOD, COD, and TSS c
the two other applied agricultural
biofilter media sizes. The BOD r
were 74.78%±5.28 for size 1, 68.
size 2, 66.82%±5.71 for size 3 and
for size 4. The COD removal ratios
were 75.02%±5.22, 70.27%±5.97
and 68.40%±5.74 for sizes 1,
respectively. Moreover, the TSS r
were 76.76%±5.34, 73.20%±4.83,
and 69.30%±4.15 for sizes 1,
respectively.

The average BOD removal efficiency of date palm fiber media was 76%, which is higher than the removal efficiency of both rice straw media (72.55%) and orange tree wood chip media (56.10%). The average COD removal ratio of date palm fiber, rice straw, and orange tree wood chip media were 76.76%, 72.99% and 53.66%, respectively. The TSS removal ratios for date palm fiber and rice straw media were close to each other 74.40%, 69.24%, respectively.

3.4 Effect of Hydraulic Rate

The performance of the studied biofilter media with the optimum size and depth was investigated under different hydraulic rates (HLR). Four different hydraulic flow rates 4.8, 6, 8, and 12 $m^3/m^2/d$ were applied. The removal efficiencies of TSS, BOD, and COD at different rates are shown in Fig. 7.

The results indicated that the flow rate of 4.8 $m^3/m^2/d$ gave the highest treatment efficiency. The increase of the hydraulic loading rate causes a decrease in the removal efficiency due to small contact time between sewage and biofilter media.

The date palm fiber media gave the best results of BOD, COD, and TSS removal compared with the other applied biofilter media at different hydraulic loading rates. 88.26%±2.77, 76.02%±2.56, 63.12%±2.81 and 56.70%±3.30 reductions in BOD were observed for hydraulic rates of 4.8, 6, 8, 12 m3/m2/d, respectively. Similarly, 88.29%±2.84, 76.32%±2.50, 63.77%±2.92 and 56.67%±2.88 reductions in COD. The TSS removal efficiencies were 86.57%±3.9 for HLR of 4.8 m3/m2/d, 74.28%±3.92 for HLR of 6 m3/m2/d, 62.48%±4.54 for HLR of 8 m3/m2/d and 54.95%±3.90 for HLR of 12 $m^3/m^2/d$.

The orange tree wood chips gave the lowest removal at different hydraulic loading rates. The BOD removal ratios were 66.67%±5.18, 58.09%±2.77, 50.38%±4.40 and 39.35%±2.10 for HLRs 4.8, 6, 8 and 12 m3/m2/d, respectively. The COD removal ratios were 64.60%±7.24 for HLR of 4.8 m3/m2/d, 56.32%±4.50 for HLR of 6 m3/m2/d, 49.82±4.42 for HLR of 8 m3/m2/d and 38.87±3.41 for HLR of 12 $m^3/m^2/d$.

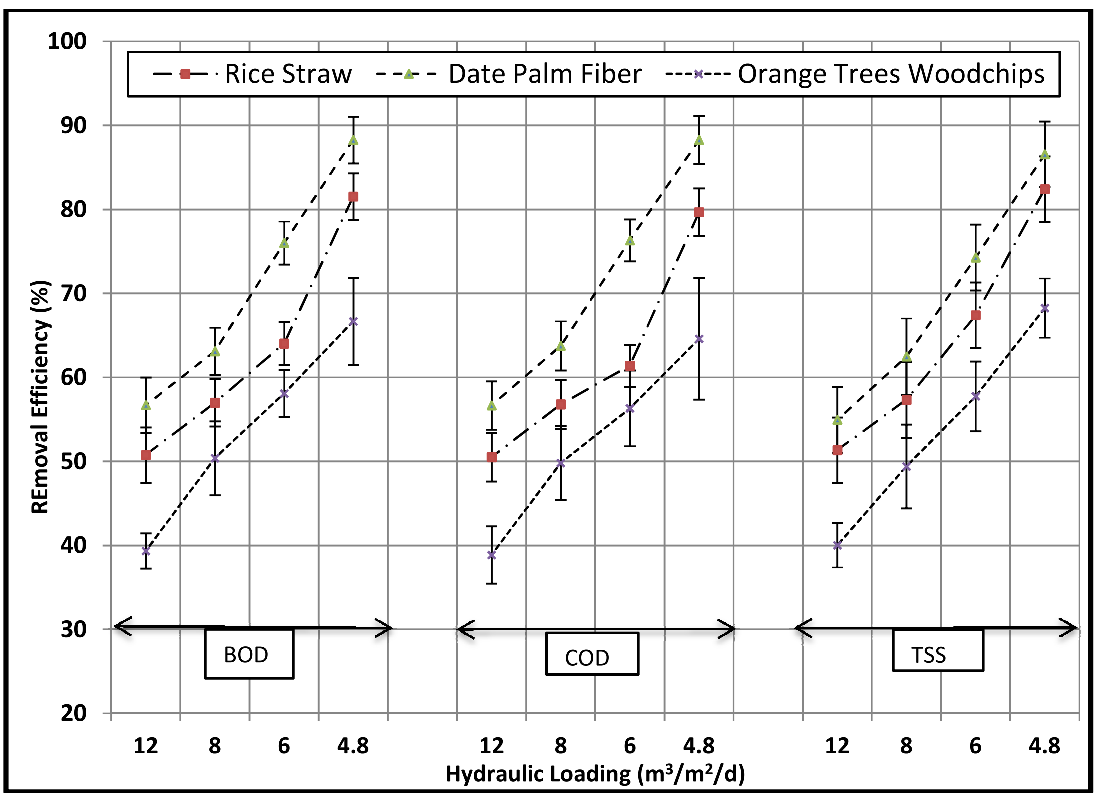

Fig. 7. Removal efficiency of agricultural wastes at different hydraulic loading rates

The average BOD removal efficiency at different HLR was 71.02% for date palm fiber media, 63.34% of rice straw media and 53.62% of orange tree wood chip media. The average COD removal ratio was 71.26%, for date palm fiber media and 62.10% for, rice straw and 52.40% of orange tree wood chip media. The TSS removal ratios were 69.57%, 65.64% and 53.86%, respectively.

3.5 Removal of Nitrogen (N) and Phosphorus (P)

Fig. 8 indicates the average removal efficiencies of nitrogen (N) and phosphorus (P) with the studied biofilter media. The average removal ratios of nitrogen (N) was 50.21%±2.32 for rice straw, 55%±1.31 for date palm fiber and were 45±2.38 for wood chips of orange tree media. The removal ratio of P was 41.92± 4.14 for rice straw, 50.52±1.32 for date palm fiber and in wood chips of orange tree media was 32.45±2.30. The date palm media indicated the highest removal efficiencies for N and P rather than rice straw and orange trees while the orange tree media showed the lowest removal efficiency.

3.6 BOD Removal Efficiency Model

A number of trials were applied to develop a suitable mathematical model for the removal efficiency of each biofilter media under the Egyptian operation conditions.

The actual removal efficiency was calculated based on the following equation:

$$E_{act.} = \frac{BOD_{in} - BOD_{out}}{BOD_{in}}$$

$$\mathrm{E}_{NRC} = \frac{1}{1 + 0.4432\sqrt{\frac{\mathrm{W1}}{\mathrm{V\,F}}}}$$

The error was calculated from the following equation

$$\boldsymbol{E_{error}} = \mathbf{E}_{\boldsymbol{act}} - \mathbf{E}_{\boldsymbol{NRC}}$$

Where E_{act}= actual removal efficiency, E_{error}= the difference between actual and predicted removal efficiency from equation $E_{NRC.}$, E_{NRC}= BOD removal efficiency at 20ºC calculated from the fundamental equation of NRC, W1 = BOD loading to filter (kg/d), V= volume of filter packing (m^3) and F= recirculation factor (F=1 for standard rate).

The removal efficiencies are studied under different operation conditions for a set of samples represent the three media at the optimum media size, depth, and hydraulic flow rates. Each set of samples consists of 9 samples. Fig. 9 indicates the results of the removal efficiencies of each biofilter media calculated by the fundamental equation of NRC considering the temperature effect and the actual removal efficiency (E_{act}.)

The results revealed that the error from NRC formula ranged from -19.45% to +16.16%, +16.50% to +36.07% and +14.89% to +33.32% for rice straw, date palm fiber and wood chips of orange tree media, respectively, which is a relatively wide range of variation. The NRC equation in its traditional form doesn't represent the removal efficiency of the applied biofilter media.

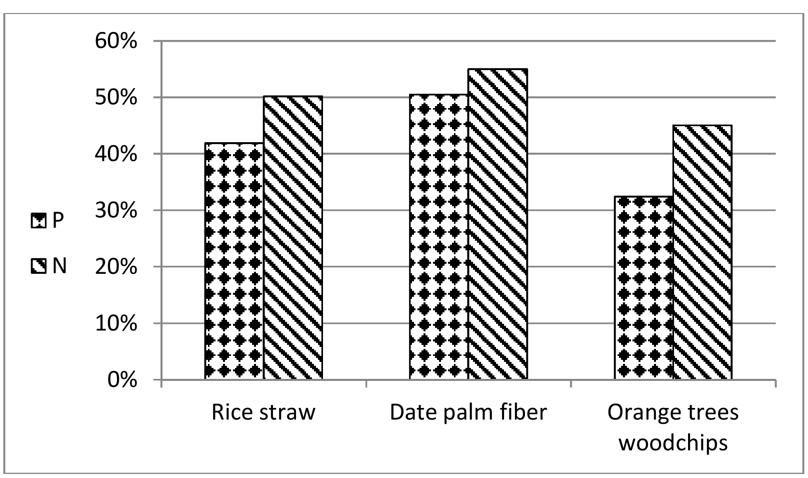

Fig. 8. The average N and P removal ratios for the studied agriculture wastes

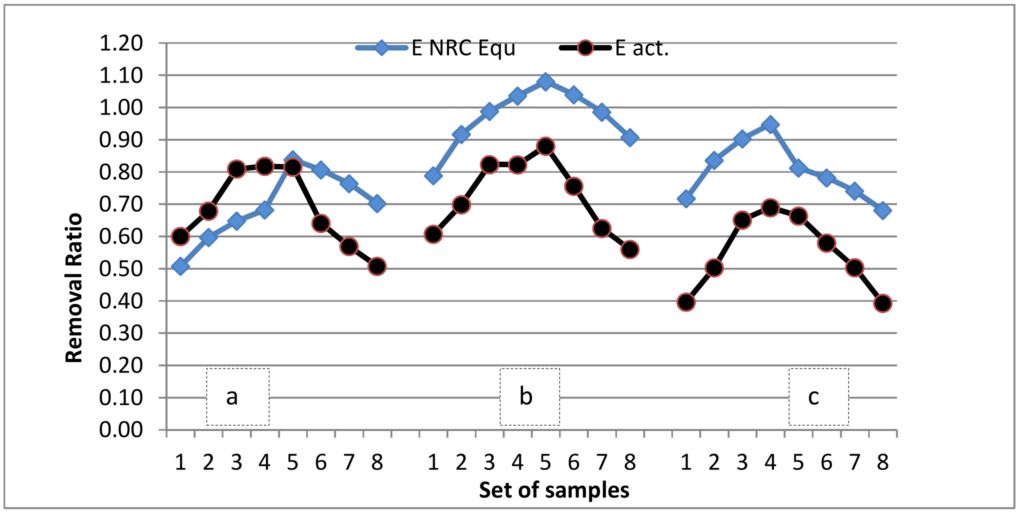

Fig. 9. Comparison of BOD actual removal efficiency and NRC mathematical model

3.7 Updated BOD Removal Model

The constant (K) of NRC formula for estimating the BOD removal efficiency is modified to be more suitable with the applied agricultural waste characteristics. The value of (K) for each type of waste was obtained by substituting by the actual removal efficiency (E_{act}) and other data of each set of samples in the typical NRC formula. The updated NRC formula is developed based on the following.

3.7.1 Without considering the temperature activity effect

Table 3 represents the average K values of the studied media neglecting the temperature effect. The constant K of the updated NRC model for rice straw and date palm fiber media was less than the typical values of 12 and 37% respectively. Where the K value of updated NRC model for orange tree wood chip media was more than the typical value by 35 %.

Table 3. Updated K values of different agricultural wastes without considering Temperature

Type	Rice straw	Date palm fiber	Orange tree wood chips
$K_{updated}$	0.389	0.281	0.600
$K_{typical}$	0.4432		

3.7.2 With considering the temperature activity effect

The temperature activity effect is considered to get a more consistency formula with the actual operation conditions as well as the actual removal efficiency of each biofilter media. The effect of temperature activity was considered by applying the following equations

$$E_T = E_{20}(\Theta)^{T-20}$$

The updated values of temperature activity constant (ϴ) and NRC formula constant (K) for each applied agricultural waste are obtained by the least square fitting of the set of sample data using Mathematica 9 program [20].

Table 4. Updated K and ϴ of different agricultural wastes considering the temperature effect

Type	Rice straw	Date palm fiber	Orange tree wood chips
$K_{updated}$	0.321	0.680	0.940
$\Theta_{updated}$	1.005	1.028	1.031

The estimated BOD removal efficiency of the studied media based on the updated K and (ϴ values are represented in Fig. 10. This figure represents the variation between the actual BOD removal efficiency (E_{act}) of the studied bio filter media and the estimated BOD removal efficiency from the updated NRC formula. The updated NRC removal formula without considering the temperature activity effect is designated by (E_2), while the updated formula considering the temperature effect is nominated by (E_3).

The error of updated BOD removal model (E_2) without considering the temperature activity effect ranges from 8.28% to 15.68% for rice

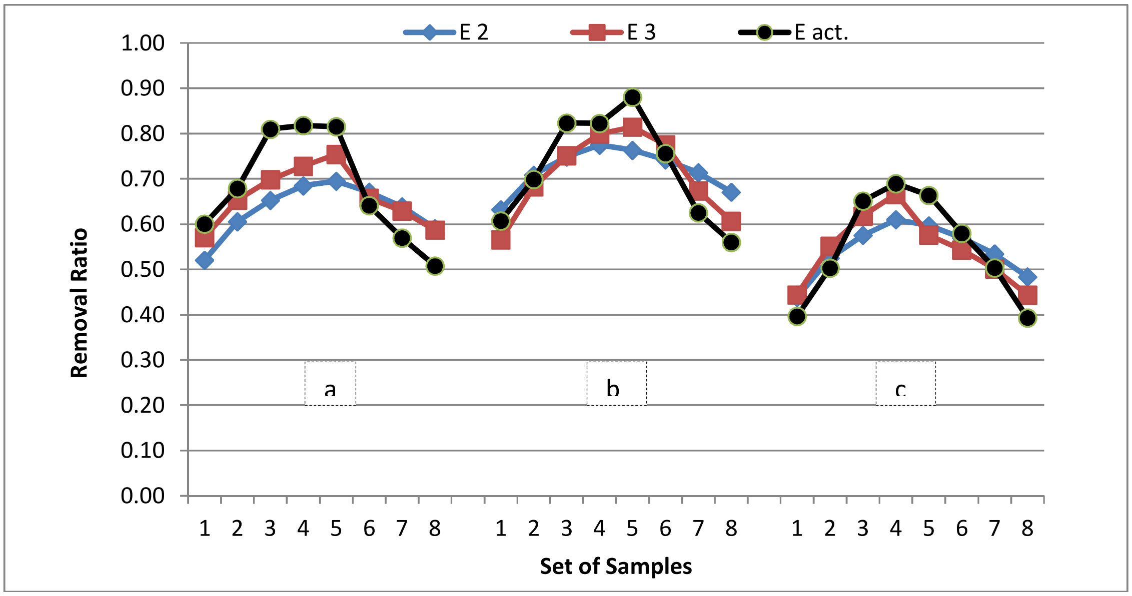

Fig. 10. BOD removal efficiencies of applied media based on actual and updated models estimation

straw media, -11.76% to -11.06% for date palm fiber and -9.06 to 7.95%. For wood chips of orange trees. Considering the temperature effect of the updated NRC model is enhancing the previous model errors. The errors of (E_3) updated model ranges from -11.14% to +7.95%, -7.21% up to +4.83% and -8.76% up to 4.85%. The errors of both E_2 and E_3 updated models are a relatively good range of variation compared with the error of the NRC typical formula for all studied media. Where the error of updated model considering the temperature activity effect (E_3) was a relatively better range of variation than the error of E_2. Its variation is almost equal in positive and negative errors which give the best simulation formula for the BOD removal efficiency of each biofilter media.

4. CONCLUSION

The use of agricultural wastes (rice straw, date palm fiber, orange trees' wood chips and others) in wastewater treatment could be a promising option for the municipal wastewater treatment, especially in rural areas that suffers from lack of sanitation services and have a high amount of these wastes produced annually this option may offer economic and green engineering solution.

Considering the overall performance, the date palm fiber media was found to be the most efficient biofilter media it gave the best wastewater contaminates removal efficiencies. Under different operation conditions, the performance of the orange tree wood chip media was poorer than that are achieved by the other media.

The results indicated the changing of biofilter media size has a considerable effect on treatment efficiency. The highest treatment efficiency was achieved at the smallest size (size 1). The coarser sizes (size 3 and 4) have the least value compared with other size forms. This is due to the finer sizes give the required criteria for the surface area to improve the reaction for biodegradation and for filtration physical reaction.

The biofilter reactors were tested at four different hydraulic loading rates, 4.8, 6, 8 and 12 $m^3/m^2/d$. The result found that the use of biofilter at 4.8 m3/m2/d provides the highest removal efficiencies of BOD5, COD, and TSS from wastewater. The average BOD5 removal efficiency was 71.02% for date palm fiber media, 63.34% for rice straw media and 53.62% of orange tree wood chip media. The average COD removal ratio was 71.26%, for date palm fiber media and 62.10% for, rice straw and 52.40% of orange tree wood chip media. The TSS removal ratios were 69.57%, 65.64% and 53.86%, respectively.

The biofilter reactors were tested at four different depths 20, 40, 60 and 80 cm. It was concluded the increasing of media depth will be increased the treatment efficiency. The higher removal efficiencies were achieved at the biggest applied depth of 80 cm, due to the increase in the total surface area of biofilter media and contact time between constituents and filter bed media. Considering overall efficiency, the medium depth 60 and 80 cm were relatively close to each other which can be concluded that the 60 cm depth could be more effective and economic than depth 80 cm.

The percentage removal efficiency for total phosphorus (P) was (41.92±4.14 for rice straw, 50.52±1.32 for date palm fiber and 32.45±2.30 for wood chips of orange trees). The removal efficiency of total nitrogen (N) was (50.21%±2.32, 55%±1.31 and 45±2.38) for rice straw, date palm fiber and wood chips of orange trees, respectively. This result shows that the date palm fiber has a better nitrogen and phosphorus removal efficiency.

The currently typical NRC formula for BOD removal efficiency is not valid with the studied agricultural wastes. An updated NRC model is developed to be more suitable with the applied agricultural waste characteristics for estimating the BOD removal efficiency in Egyptian climate conditions. The updated mathematical model produced minimum deviation between the computed and actual removal ratios.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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