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Ambat Indu, Tang Walter, Sillanpää Mika

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Indu Ambat [a]*, Walter Z. Tang[b], Mika Sillanpää [a, b]

[a] Laboratory of Green Chemistry, School of Engineering Science, Lappeenranta University of Technology, Sammonkatu 12, FI-50130 Mikkeli, Finland

[b] Department of Civil and Environmental Engineering, Florida International University, Miami, FL-33174, USA

Abstract

Algal biodiesel is one of the most promising renewable and eco-friendly source of energy for transportation, when algae is produced from wastewater. During the process, both goals of biodiesel production and wastewater treatment could be achieved simultaneously. However, the optimal condition for algae production remained unanswered. Algal biodiesel could be produced from various wastewater treatments. In this study the relationship between biomass production versus lipid productivity in various wastewater sources is statistically analyzed. Chemical oxidation demand, total nitrogen, total phosphorus, and CO_2 sequestration could be achieved during the production of different algal biomass in numerous type of wastewater effluent. The regression of different system models and interpretation of linear coefficients were represented in this statistically approached studies. Apart from that the paper also discuss the uncertainty of linear regressions using Monte Carlo method, influence of physical parameters on biomass production, energy potential and efficiency of nutrient removal using different phototrophic systems.

Key words: Biomass, Chemical oxidation demand, Total nitrogen, Total phosphorus, Wastewater

1. Introduction

The main source of energy for the world is fossil fuels such as petroleum products, methane, and coal. The non-renewable nature of fossil fuels leads to scarcity of energy which have aroused great interest in search for alternative fuels [1]. Rapid increase in population results in expeditious utilization of fossil fuels which lead to two major issues, direct environmental pollution and global warming. To meet the challenges, alternative fuels with renewable, biodegradable and environmental friendly nature are under intensive investigation [2-4]. Biodiesel is one of these renewable fuels because it possess all the features needed as a fossil fuel substitute and it could be produced from numerous feedstocks such as vegetable oil, algal oil and animal fat/oil [5] .

The increase of global CO_2 emission demands effective and efficient techniques for the sequestration of CO_2 [6]. In 1997, the Kyoto protocol suggested that, for the reduction of oil and to meet the GHG reduction targets, affordable supplies of clean, secure transportation fuels using low-carbon technologies have to be found [7]. Ever since, significant attention has been devoted to develop biofuels, for example from microalgal sources. Due to growing demand of petroleum and significantly larger issues regarding global warming and greenhouse effect as a part of ignition of fossil fuels, a substantial importance has been given to the concept of using microalgae as a fuel source. Benefits of microalgae-based biofuels are greater production yields and the ability to capture CO_2. Therefore, algal fuel has great importance due to its environmental friendly nature to decrease global warming [8-10]. Biodiesel can be the best renewable energy option because it is free from sulphur and aromatics along with that it also reduced emission carbondioxide, hydrocarbon and particulate matter. Algal biofuels can lower greenhouse gas emission from 101,000 grams of CO_2 equivalent per million British thermal units to 55, 440 grams [6].

Harder and Witch were the first to propose to use algae for energy and production in 1942. In the 1950s, carbohydrate fraction of algal cells was used for the production of methane gas under anaerobic digestion by Meier (1955) and Oswald and Golueke (1960) [11]. In the early 1970s, the sharp raising of energy price led to a push for energy production from aquatic species mainly algae gained major attention [11]. In recent years, the algal cultivation gained greater attention due to its various applications such as an alternative feedstock for biodiesel production, nutrient control in wastewater remediation process as well as low cost method for biomass harvesting[12].

Microalgae has great potential to assimilate nutrients efficiently and effectively when algal species were grown in wastewater. Rich nutrients in wastewater provide better growth rate of algal species depending upon the algal strains or species [13]. Recently, there is plenty of work related to treatment of various kinds of wastewater such as dairy wastewater, piggery wastewater, olive oil mill wastewater, brewerywastewater, municipal sewage sludge, molasses wastewaters, soybeans processingwastewater, and petrochemical wastewater using algal culture systems [14-20]. Shoener et al., reported that wastewater treatment can be energy positive with transformation of organic matter by anaerobic digestion and removal of nutrients by phototrophic technologies especially using algae [21]. Combination of wastewater treatment with algae cultivation for biodiesel production could lead to a sustainable, cost effective and eco-friendly algal based energy production process. Algae uses the nutrients present in the wastewater for its growth, which offer an effective nutrient treatment technology along with algal biomass for biodiesel production without fresh water [12, 13, 22].

The main objectives of this paper are to: 1) statistically analyze optimal conditions for algae production using wastewater from variety sources such residential or industry; 2) develop predictive equations of algae biomass production using chemical oxygen demand (COD), total nitrogen and total phosphorus, as well as CO_2 fixation rate by different kinds of algal species using regression analysis; and 3) validate the correlation equations using other independently reported research results.

2. Database and statistical methods

The data are obtained from published peer reviewed papers. The collected data were organized to present details of biomass production in various kinds of wastewater. In spite of that, there are other various databases, which are shown in this study, such as the influence of nutrient concentration on algal biomass production, relationship between biomass production and lipid productivity in different kinds of waste water and CO_2 sequestration capabilities of several algal species. Therefore, the database helps to perform regression analysis of biomass produced with respect to lipid productivity, COD, total nitrogen and total phosphorus content in wastewater. SPSS was used to obtain linear regression analysis and MatLab was used to determine uncertainity of the linear regression.

3. Results and discussion

3.1. Biomass production vs. lipid productivity in different types of wastewater resources

The algal biomass production and lipid productivity data of various algal species in different wastewater effluents are shown in table 1. Table 1 also explains the ability of several microalgal species to grow in wastewater resources with high lipid content. The key factor in biodiesel production and considerable cost reduction and commercialization of algal biofuel production could be achieved with high lipid productivity. The *Chlamydomonas reinhardtii* (biocoil-grown) grown in municipal centrate effluent showed higher biomass production as well as lipid productivity.

Table 1. The biomass and lipid productivities of some of the microalgal species grown in different wastewater resources.

Table 1. The biomass and lipid productivity of some of the microalgal species grown in different wastewater resources.

Type of waste water	Type of algal species	Biomass production (mg L^{-1} d^{-1})	Lipid productivity (mg L^{-1} d^{-1})	References
Artificial Wastewater	*Scenedesmus sp.*	126.54	16.2	[1][2][3]
Carpet mill	*Scenedesmus sp.*	126.54	16.2	[2][3]
Centrate Municipal wastewater	*Chlorella sp.*	231,4	77,5	[3]
Centrate Municipal wastewater	*Hindakia sp.*	275	77,8	[3]
Centrate Municipal wastewater	*Chlorella sp.*	241,7	74,7	[3]

Centrate Municipal wastewater	*Scenedesmus sp.*	247,5	75,5	[3]
Concentrated Municipal wastewater	*Auxenochlorella protothecoides*	268,8	77,7	[3]
Municipal (centrate)	*Chlamydomonas reinhardtii (biocoil-grown)*	2000	505	[1][4]
Municipal (secondary treated)	*Scenedesmus obliquus*	26	8	[1][4]
Municipal (secondary treated)	*Botryococcus braunii*	345,6	62	[1][4]
Municipal (primary treated + CO_2)	*Mix of Chlorella sp., Micractinium sp., Actinastrum sp.*	270,7	24,4	[1][4]
Agricultural (piggery manure with high NO_3–N)	*B. braunii*	34	4,5	[1][4]
Industrial (carpet mill, untreated)	*Dunaliella tertiolecta*	28	4,3	[1][4]
Industrial (carpet mill, untreated)	*Pleurochrysis carterae*	33	4	[1][4]

The Fig1, shows the linear regression between biomass and lipid productivity, which can be expressed as follows:

$$Y = 0.25\,x - 2.9 \qquad R^2 = 0{,}982 \qquad (1)$$

Where: y is biomass production (mg L^{-1} d^{-1}) and x is lipid productivity rate (mg L^{-1} d^{-1})

The regression equation shows linear correlation between lipid productivity in various waste water resources depends on biomass production. Biomass production can explain 93.7% of the variability of our dependent variable, which is lipid productivity. Residual plots denotes the difference between the observed value of the dependent variable, lipid productivity of algal species in different wastewater resources and the predicted value. The residual plots shows random pattern indicating good fit to the linear model.

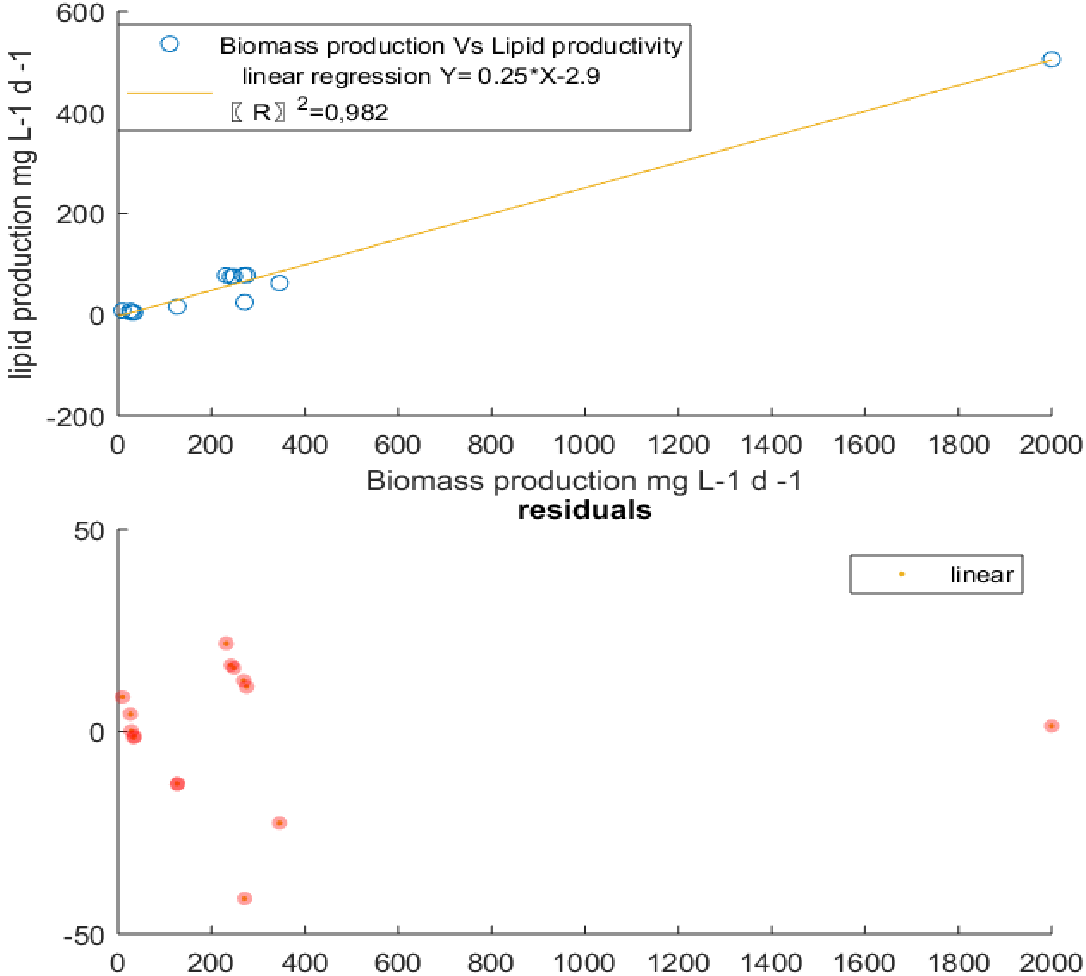

Fig1. Regression between biomass production mg L^{-1} d^{-1} with respect to lipid productivity mg L^{-1} d^{-1} of various algal species in different wastewater resources

3.2.Relationship between biomass production with COD ,TN and TP concentration in piggery wastewater

Zhu et al., (2013) cultivated the microalgae, *Chlorella zofingiensis,* in piggery wastewater effluent under different concentration of nutrients such as COD, TN and TP as depicted in Table 2. Therefore, the effect of nutrients concentration on biomass production could be quantified. The maximum biomass production of *Chlorella zofingiensis*, 296.16 mgL^{-1}d^{-1} was observed with concentrations of COD, TN, TP 1,900mg L^{-1}, 80mg L^{-1}, 85mg L^{-1} respectively [23].

Table 2. Effect of COD, TN, TP concentration in piggery wastewater for biomass production of *Chlorella zofingiensis* [23].

Table 2. Effect of COD, TN, TP concentration in piggery wastewater for biomass production of *Chlorella zofingiensis* [5]**.**

COD (**mg L^{-1}**)	TN (mg L^{-1})	TP (mg L^{-1})	Biomass(mg L^{-1} d $^{-1}$)
3500	148	156	267.81
2500	106	111	273.33
1900	80	85	296.16
1300	55	58	216.63
800	34	36	160.34
400	17	18	106.28

The Fig 2 represents that the linear regression between biomass production and COD concentration in piggery wastewater system can be obtained as follows:

$$Y = 0.0528\,x + 128{,}64 \qquad R^2 = 0{,}667 \qquad (2)$$

Where: y is biomass production (mg L^{-1} d $^{-1}$) and x is COD concentration (mg L^{-1})

The linear regression between biomass production and TN concentration in piggery wastewater system can be obtained as follows:

$$Y = 1.2462\,x + 128.71 \qquad R^2 = 0{,}665 \qquad (3)$$

Where: y is biomass production (mg L^{-1} d^{-1}) and x is TN concentration (mg L^{-1})

The linear regression between biomass production and TP concentration in piggery wastewater system was shown in Figure 5 and can be depicted as follows:

$$Y = 1.1876\,x + 128{,}25 \qquad R^2 = 0{,}668 \qquad (4)$$

Where: y is biomass production (mg L^{-1} d^{-1}) and x is TP concentration (mg L^{-1})

The above regression analysis clearly shows that biomass production in piggery wastewater system depends on COD, TN and TP concentration correspondingly. COD, TN and TP can explain 66.7%, 66.5% and 66.8% of the variability of our dependent variable, biomass production respectively. The residual plots denotes the difference between the observed value of the dependent variable, biomass production of *Chlorella zofingiensis* in piggery wastewater resources and the predicted value. The residual plots shows random pattern’s decent fit to the linear model.

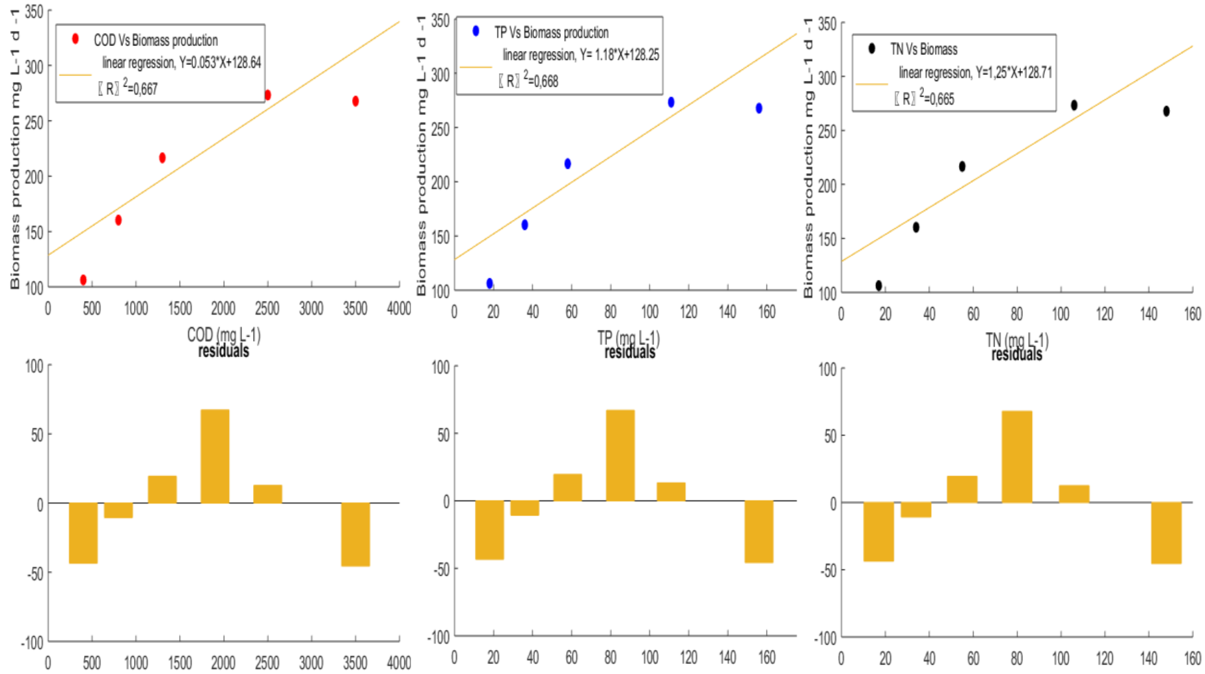

Fig2. Regression between biomass productions of *Chlorella zofingiensis* (mg L^{-1} d $^{-1}$) with respect to COD (mg L^{-1}), TN (mg L^{-1})' TP (mg L^{-1}) in piggery wastewater effluent

3.3. *Relationship between various algal biomass production and CO_2*

Based on table 3, the majority of algal species preferred lower concentration of CO_2 where as some algal species especially *Chlorella* species showed capacity to withstand high concentration of CO_2. Moreover the highest biomass production was observed at lower concentration of CO_2. Carbondioxide tolerance limits were specific for algal species, so several studies aimed at determining the optimum CO_2 concentration for each algal species [24]. Table 3 shows the capabilities of various microalgal species in CO_2 sequestration under various CO_2 (%v/v) concentration [24].

Table 3. Biomass production for different microalgal species under various CO_2 (%v/v) concentration

Table 3. Biomass production for different microalgal species under various CO_2 (%v/v) concentration		
Microalgal species	CO_2 (%v/v)	Biomass production ($mg\ L^{-1}\ d^{-1}$)
Chlorella sp. KR1	70	118
Dunaliella sp	12	71
Scenedesmus obliquus AS-6-1	20	380
Nannochloris sp.	15	350
Chlorella sp.	50	950
Chlorella sp.	20	700
Chlorococcum littorale	20	530
Aphanothece microscopic Nageli	15	1250
Chlorella kessleri	12	220
Chlorella vulgaris	18	87
Scenedesmus obliquus SJTU	20	134
S. obtusiusculus	10	520
Scenedesmus sp.	40	404

The Fig. 3 show that there is no apparent correlation between the unit biomass productions with the volume concentration of CO_2. The correlation coefficients (R^2) for the linear relationships of the biomass production, and the CO_2 concentration are extremely low of 4×10^{-5}. The major reason for no correlation could be different experimental reactors and processes. Therefore, different CO_2 utilization rate and efficients could not be used as a predictor for algal biomass production.

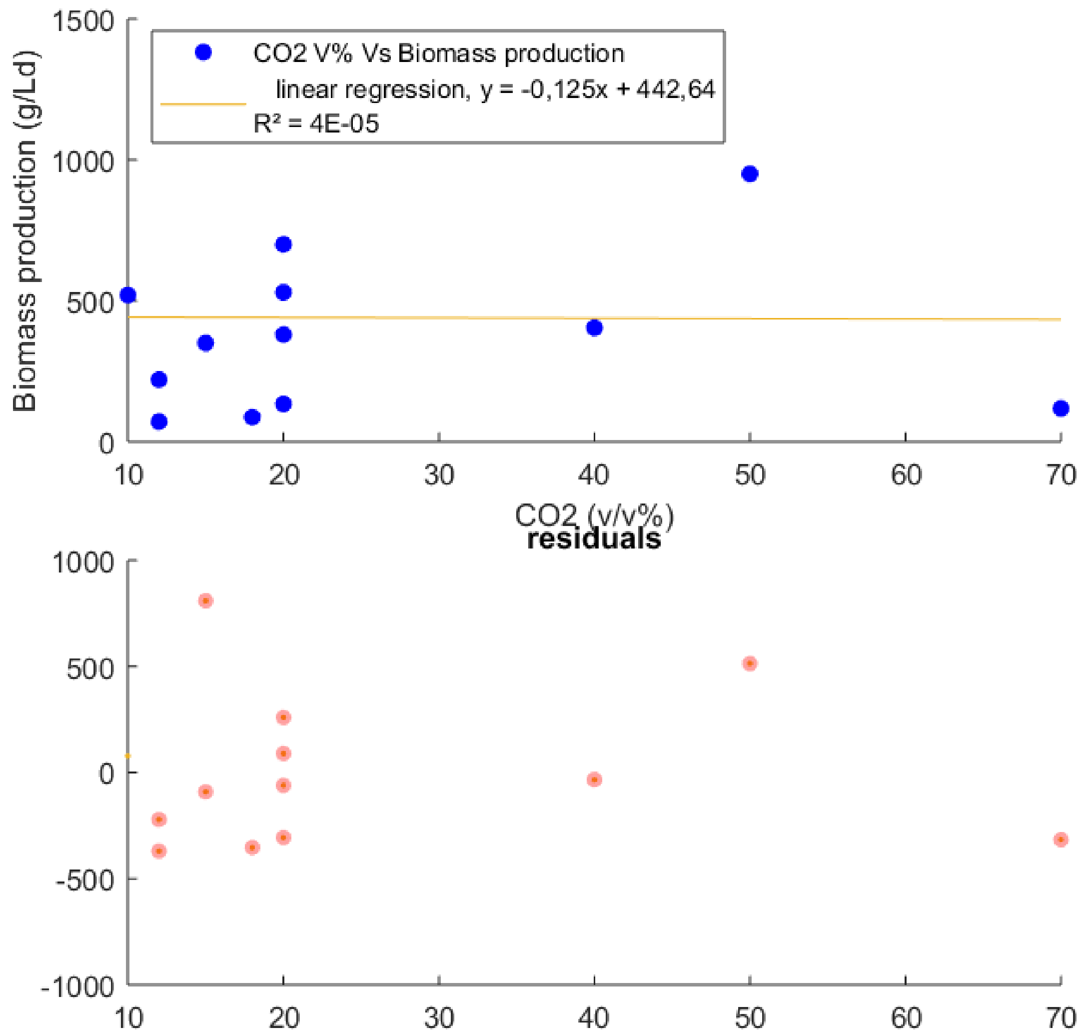

Fig3. Regression between biomass production (mg L^{-1} d^{-1}) with respect to CO_2 concentration (%v/v) of various algal species [24].

The carbon dioxide capturing efficiency of microagal species based on significant research studies were represented in Table 4. The maximum CO_2 fixation rate 1.45 $gL^{-1}d^{-1}$ was shown by *Anabaena sp. ATCC 33047* with a biomass production of 0.31 $gL^{-1}d^{-1}$. The main advantage of CO_2 sequestration using microalgae is that the trapped carbon dioxide is combined with carbohydrates and lipids which results in production of value added products such as biomass for biodiesel and other chemicals [6].

Table 4. Unit biomass production of various microalgal species in CO_2 sequestration [6].

Table 4. Unit biomass production of various microalgal species in CO_2 sequestration [6].

Algal species	Biomass production (g L^{-1} d^{-1})	CO_2 fixation rate (g L^{-1} d^{-1})
Chlorella vulgaris	2,03	0,43
Chlorella kessleri	0,87	0,163
Scenedesmus obliquss	0,142	0,253
Chlorococcum littorale	0,12	0,2
Chlorella sorokiniana	0,338	0,619
Anabaena sp. ATCC 33047	0,31	1,45
Spirulina platensis	2,18	0,32
Haematococcus pluvialis	0,076	0,143
Botryococcus braunii SI-30	1,1	1

The linear regression between biomass production and CO_2 fixation rate by different algal species was shown in Figure 4 and can be depicted as follows:

$$Y = -0.019\,x + 0.52 \qquad R^2 = 0,0012 \qquad (5)$$

Where: y is CO_2 fixation rate (g $L^{-1}d^{-1}$) and x is biomass production (g $L^{-1}d^{-1}$)

In this regression analysis, biomass production and CO_2 fixation rate less depends on each other. Biomass production of various algal species can only explain 0.12% of the variability of our dependent variable, CO_2 fixation rate.

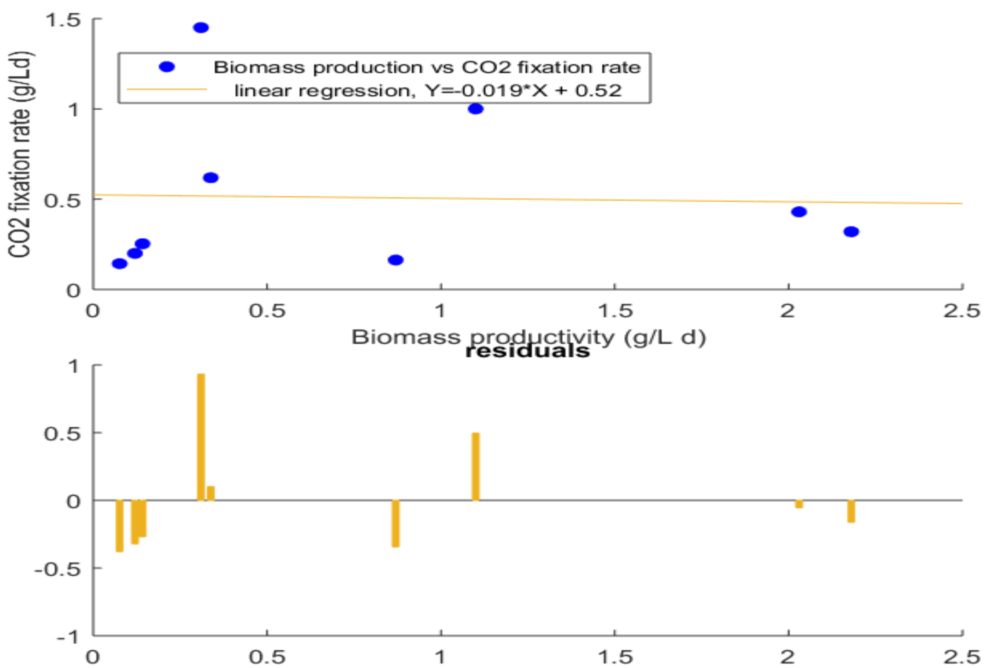

Fig4. Regression between biomass production g $L^{-1}d^{-1}$ with respect to CO_2 fixation rate g $L^{-1}d^{-1}$ of various algal species in wastewater resources [6].

3.4.*Interpretation of regression analysis parameter and linear correlation coefficients*

Correlation equation 1 in table 5 shows summary and parameter estimates of multiple regression analysis of biomass production with respect to COD, TN, TP in piggery wastewater and model 2 represents the CO_2 fixation rate by different algal species. The correlation coefficiency, R^2, measures the quality of the prediction of the biomass production, the dependent variable. When multivariable regression is used, parameters such as COD, TN, TP, and CO_2 explain 98.5% biomass production. On the other hand, CO_2 does not show any linear correlationship with biomass production as in model 2.

Table 5. Model summary and parameter estimates of regression analysis of biomass production with respect to various predictors

Table 5. Model summary and parameter estimates of regression analysis of biomass production with respect to various predictors

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0,992[a]	0,985	0,962	14,352
2	0,035[a]	0,001	0,141	0,477

a. Predictors: (Constant), TP, TN, COD,CO_2
b. Dependent variable: Biomass production[23,24]

Based on Table 6, model 1 the F-ratio indicates whether the overall regression model is a good fit for the data. The Table 6 also shows that the independent variables such as COD, TN and TP, are statistically significant to predict the dependent variable biomass production, $F(3, 2) = 205.969$, in piggery wastewater. The statistical prediction of dependent variable, that is biomass production of various algal species was determined with help of CO_2 as an independent variable and shown as $F(1, 4) =1833. 243$.

Table 6. Statistical significance of regression analysis

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Model		Sum of Squares	df	Mean Square	F	p-value
1	Regression	27021,152	3	9007,051	43,730	0,022
	Residual	411,939	2	205,969		
	Total	27433,091	5			
a. Dependent Variable: Biomass						
b. Predictors: (Constant), TP, TN, COD						
2	Regression	,007	1	,007	,009	,928
	Residual	5,378	7	,228		
	Total	5,385	8			
a. Dependent Variable: Biomass						
b. Predictors: (Constant), CO_2						

Based on Table 7, the general form of the equation to predict biomass production from COD, TN, TP, is:

$$Predicted\ biomass\ production\ =\ -920{,}535 +\ (0{,}041 \times COD) +\ (9{,}102 \times TN) + (3{,}910 \times TP). \qquad (6)$$

Where: y is biomass production (mg L^{-1} d^{-1}) and predictors are COD, TN, TP concentration (mg L^{-1}) respectively.

Unstandardized coefficients represents how much the biomass production varies with an independent variable COD /TN/TP when all other independent variables are held constant. The statistical significance of each independent variables shown in the "p-value´´ column is presented in Table 7. The equation to predict the biomass production from CO_2 fixation rate is:

Predicted biomass production = 0, 829 - (0,065×CO_2) (7).

Where: y is biomass production (g $L^{-1}d^{-1}$) and x is CO_2 fixation rate (g $L^{-1}d^{-1}$)

Table 7, Illustrations estimated model coefficients

Table 7. Illustrations estimated model coefficients

Model	Unstandardized Coefficients		Standardized Coefficients Beta	t	p-value
	B	Std. Error			
Constant	-920,535	334,849		-2,749	0,111
COD	0,041	0,31	0,633	1,338	0,313
TN	9,102	2,603	0,682	3,496	0,073
TP	3,910	4,350	0,335	0,899	0,464
a. Dependent Variable: Biomass					
Constant	,829	,458		1,809	,113
CO_2	-,065	,694	-,035	-,093	,928

3.5. *Relationship between algal biomass production and nutrient removal*

Biomass production using wastewater sources are currently under intensive invesigation. These studies shows that microalgae have some potential to biomass production, and pollutant removal and can act as source of energy coupled with wastewater treatment. The effect of biomass production and nutrient removal in various wastewater resources are shown in Table 8. Yen et al. (2014) reported about the growth of *Chlorella sp.35* in highly concentrated piggery waste water rich in phosphorus and nitrogen [25]. The *Chlorella sp.35* algal culture resulted in 60 – 95.8%, 22 – 68% and 34 – 73.8% removal of ammonia, total phosphorus and COD of piggery wastewater respectively. Hongyang et al., (2011) observed *Chlorella pyrenoidosa* cultivated in soybean processing wastewater resulted in an average biomass production of 0.64 g $L^{-1}d^{-1}$ and also lead to COD, total nitrogen and total phosphorus removal of 77.8 ± 5.7%, 88.8 ± 1.0%, and 70.3 ± 11.4% respectively in fed-batch process [19]. Wang et al., (2012) investigated the *Chlorella pyrenoidosa* biomass production in diluted piggery wastewater [23]. The *Chlorella pyrenoidosa* algal culture resulted in 55.4 %, 74.6 % and 77.7 % removal of COD, total nitrogen, total phosphorus, respectively from piggery wastewater sample with 1000 mg/L COD concentration. Ding et al. (2015) discussed about the removal of ammonia, phosphorus and chemical oxygen demand in dairy farm waste water with help of microalgae cultivation [26]. The 20% dairy farm waste water sample yields 0.86g/L dry weight in 6 days resulted in 83, 92, and 90 removal percentage of ammonia, phosphorus, COD respectively. Gouveia et al. (2016) reported the performance of three different microalgae such as *Chlorella vulgaris (Cv), Scenedesmus obliquus (Sc) and Consortium C (Cons C)* for wastewater remediation [27]. The maximum removal was attained by Cv, Sc and

ConsC were 84, 95 and 98% for total nitrogen, 95, 92 and 100% for phosphorus and 36, 63 and 64% for COD, respectively.

Table 8. Effect of algal biomass production on removal of COD, TN, and TP from wastewater.

Table 8. Effect of algal biomass production on removal of COD, TN, and TP from wastewater.

Biomass production (g L^{-1})	COD % removal	TN % removal	TP % removal	References
0,19	73,8	68	95,8	[7]
0,64	75,8	88,8	70,3	[8]
0,3	55,4	74,6	77,7	[9]
0,86	90	83	92	[10]
0,1	36	84	95	[11]
0,4	63	95	92	[11]
0,9	64	98	100	[11]

The percentage removal of COD, TN, and TP in various wastewater resources using different algal species was shown in Table 9. Based on the regression analysis, R^2 value (also called the coefficient of determination), which is the proportion of variance in the dependent variables such as percentage removal of COD, TN and TP that can be explained by the independent variable biomass. (Technically, accounted by the regression model represented in table 9). Our independent variable biomass explain 41.5% , 32.7 % and doesn't have any effect respectively with the variability of our dependent variable such as COD removal, TN removal and TP removal respectively.

Table 9. Regression analysis of biomass production versus percentage removal of COD, TN and TP

Table 9. Regression analysis of biomass production versus percentage removal of COD, TN and TP

Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
COD	,644[a]	,415	,298	14,331
TN	,571[a]	,327	,192	9,596
TP	,015[a]	,000	-,200	11,819

a. Predictors: (Constant), Biomass

3.5.Phosphorus and nitrogen removal using various phototrophic systems and energy potential of phototrophic technologies

Based upon experimental data by Shoener et al., (2014), the major phototrophic technologies used for algal biomass production include high rate algal ponds (HRAT), photobioreactor (PBR), stirred tank reactor (STR) and algal turf scrubber (ATS). Table 10 presents that the best nitrogen and phosphorus removal were obtained by PBR technology. It also indicates that PBR consumed highest energy when mixing which was done by gas sparging. The rate of gas sparging depends on algal species and their tendency to aggregate. ATS is passive system and it does not require any energy where as HRAP require very less amount of energy for paddlewheels per hectare [21].

Table 10, Average percent of phosphorus and nitrogen removal, and ranges of energy consumption (kJ m^{-3}) using different phototrophic technologies [21].

Table 10. Average percent of phosphorus and nitrogen removal, and ranges of energy consumption (kJ m^{-3}) using different phototrophic technologies [12]

Technology	Average percent removal of nitrogen	Average percent removal of phosphorus	Mixing	Pumping	Harvesting
HRAP	67.1	52.1	3.2- 9.6	-	34-170
PBR	78.5	93.2	6300-13000	55-58	-
Stirred tank	62.3	78.2	770-3100	28-31	-
ATS	70.5	78.6	-	-	-

3.6. Physical parameters effect growth of algal species

The growth of conditions of algal species depends on light energy and temperature of wastewater system (Table 11). The algal growth can be inhibited as a result of too intense light known as photoinhibition. The photoinhibitation value depends on algal species and growing conditions. The temperature also influence grazing activity, growth rate and species composition of algal communities [12].

Table 11. Influence of various physical parameters on growth of algal species in different cultural medium

Table 11. Influence of various physical parameters on growth of algal species in different cultural medium

Culture medium	Algal species	Light ($\mu mol\ m^{-2} s^{-1}$)	Photoperiod	Temperature (°C)	Productivity ($g\ m^{-2}\ d^{-1}$)
Raw and anaerobically digested dairy manure	Algal consortia	40-140	16:8	22	5
Anaerobically digested diary manure	Algal consortia	270-390	23:1	19-24	5-23
Dairy manure	Chlorella sp.	110-120	24	20	0.58-2.57
Swine manure	Algal consortia	240-633	23:1	23-26	7.1-9.6
Centrate and raw municipal wastewater	Mixed culture	72-104	16:8	18-27	0.5-3.1
Municipal watsewater	*S.obliquus and C. vulgaris*	100	24	23-27	7
Municipal and synthetic wastewater	Mixed culture	230	24	22	2.1-7.7
Modified BG11	Mixed culture	15,30,60,120	16:8	20,30	0.02-2.9

3.7. *Uncertainties in linear fit using Monte Carlo simulation*

The uncertainity in biomass production (Y) after performing linear fit with uncertainties in x and y, using a Monte Carlo method is shown in Fig 5. Based on Monte Carlo method, the estimated error on Y is: 47.78 and Linear fit function: Y = (0.053 +/- 0.019) * X + (128.64+/- 37.74), where X is COD concentration. For X= TN concentration, based on Monte Carlo method, estimated error on Y is: 47.95 and Linear fit function: Y = (1.25 +/- 0.442) * X + (128.71 +/- 37.89). Futhermore, the estimated error on Y is: 47.75 and Linear fit function: Y = (1.19 +/- 0.419) * X + (128.25 +/- 37.82), where X is TP concentration based on Monte Carlo method.

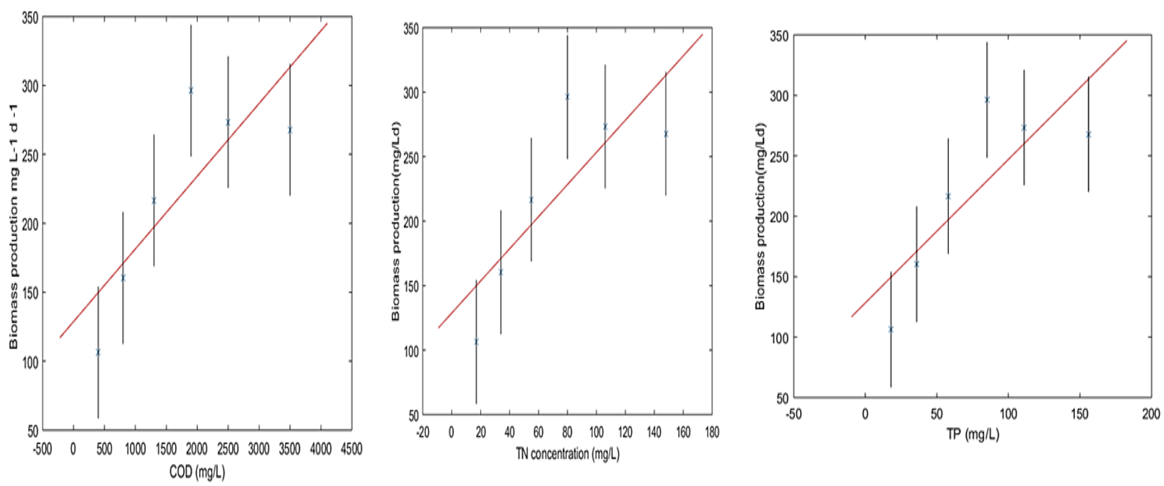

Fig5. Uncertainity in biomass productions of *Chlorella zofingiensis* mg L^{-1} d $^{-1}$ with respect to COD (mg L^{-1}) TN (mg L^{-1}) and TP (mg L^{-1}) in piggery wastewater effluent

Fig 6 displays linear regression analysis of percentage removal of COD by various algal biomass in different wastewater effluent data represented in Table 8 and illustrates the estimated error of Y (percentage removal of COD) as follows: 14.33, Linear fit function: Y = (34.47 +/- 18.295) * X +

(48.734+/- 10.385), where X is algal biomass concentration in different kinds of wastewater effluents.

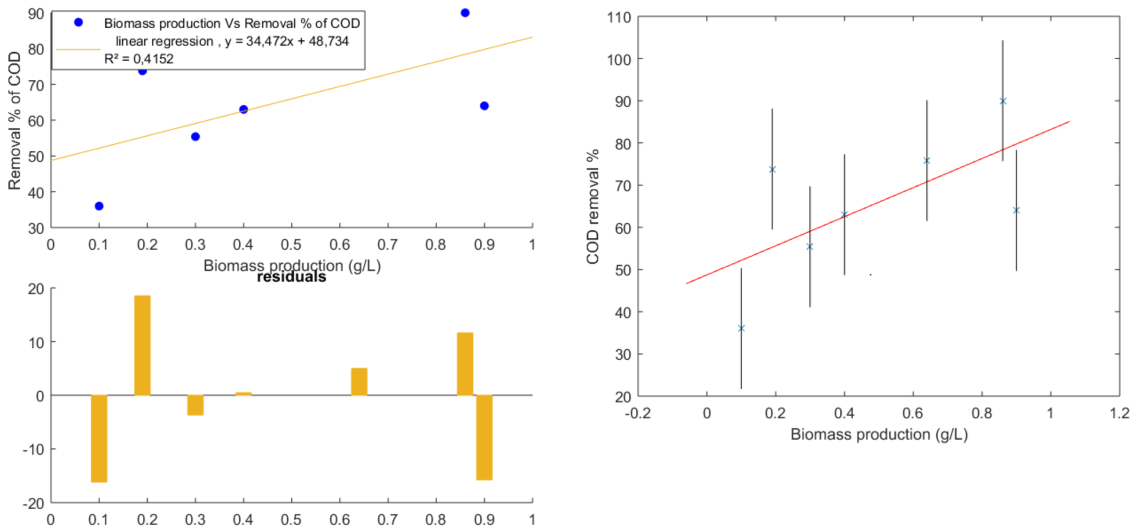

Fig 6. Linear regression analysis of percentage removal of COD by various algal biomass and its uncertainity

The linear regression analysis of percentage removal of TN by various algal biomass in different wastewater effluent data reported in Table 8 is represented in Fig 7. It also illustrates estimated error on Y (percentage removal of TN) is: 9.5962, Linear fit function: Y = (19.078 +/- 12.251) * X + (75.247 +/- 6.954), where X indicates different algal biomass

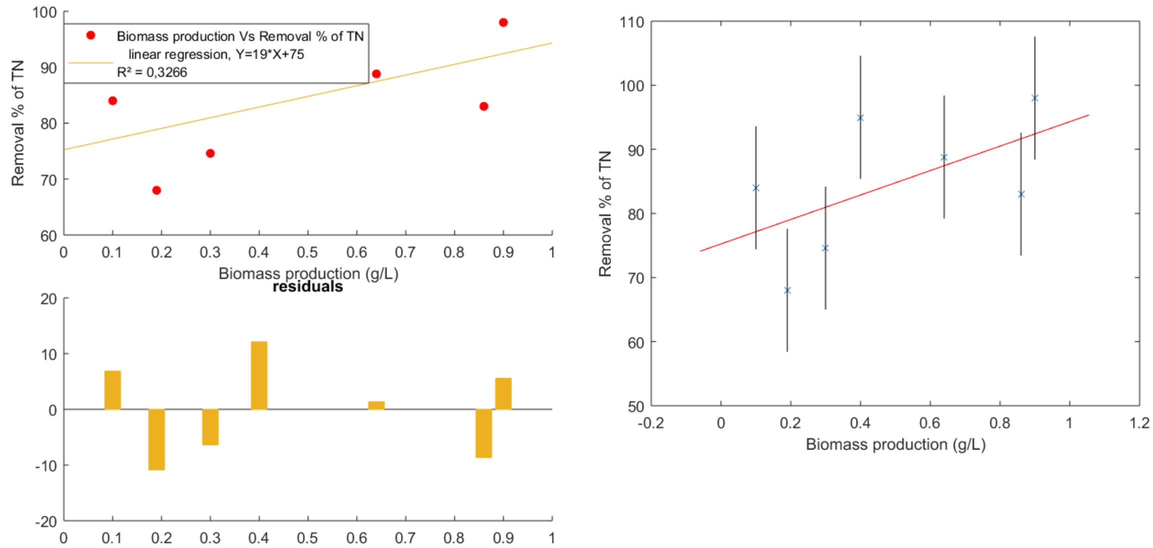

Fig 7. Linear regression analysis of percentage removal of TN by various algal biomass and its uncertainity

The Fig 8 shows linear regression analysis of percentage removal of TP by various algal biomass in different wastewater effluent data represented in Table 8. Estimated error on Y (percentage removal in TP concentration) is: 11.8191 and linear fit function: Y = (0.507 +/- 15.089) * X + (88.726 +/- 8.565) with respect to X, algal biomass

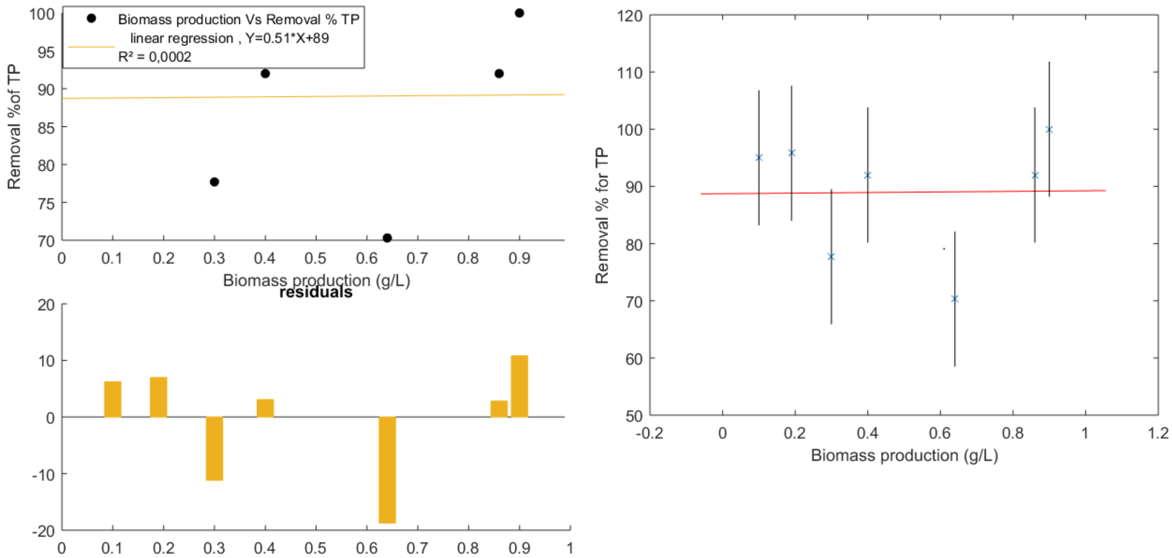

Fig 8. Linear regression analysis of percentage removal of TP by various algal biomass and its uncertainity

4. Conclusions

Regression equations between algae biomass production and different wastewater variables were developed during algal biomass production from differernt types of wastewater. Lipid productivity contributes 93.7% of the variability to the dependent variable of biomass production. Other independent variables such as COD, TN, TP and CO_2 can explain 66.7%, 66.5 %, 66.7% and 48% of the variability of our dependent variable, biomass production. In supplementary to that biomass production has 41.5%, 32.7 % effect on the variability of COD removal, TN removal. The general form of the equation to forecast biomass production from COD, TN and TP concentration is:

$$Predicted\ biomass\ production = -920{,}535 + (0{,}041 \times COD) + (9{,}102 \times TN) + (3{,}910 \times TP).$$

The uncertainty of regression equation has been quantified using Monte Carlo method. The efficiency of main phototrophic technologies for removal of nitrogen and phosphorus along with energy potential of phototrophic systems were discussed in this research review. The influence of physical parameters on algal biomass was also investigated.

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