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THE ESTIMATION OF MICROALGAE CULTIVATION PRODUCTIVITY FOR BIOFUEL PRODUCTION IN NIGERIAN CONDITIONS

Introduction

Renewable sources are the areas of interest for researchers of which biomass and biodegradable organic wastes have shown high potential to be used in the production of biofuels [1–9].

Nigeria is located between 4°*N* and 14°*N* latitude and hence, the country receives a vast supply of solar energy all year round. This energy can be utilized for the development of solar energy systems. With fossil fuel prices on the increase biofuel production from microalgae seems like Nigeria's way to increase energy production. Due to solar irradiance, Nigeria is divided into five parts. Daily satellite global irradiance data obtained from the archives of the National Aeronautics and Space Administration (NASA) was used for this study. The data set which was obtained at a screen resolution of 1° by 1° was validated using surface global irradiance obtained from the archives of the Nigerian Meteorological Agency (NIMET) for the corresponding years [10–11].

Analysis of the research and publication

The solar radiation is directly proportional to the production of microalgae biomass. Fig. 1 shows the average annual sum of solar radiation in different regions of Nigeria.

Microalgae are eukaryotic organisms that have no roots, leaves but with a nucleus and can carry out photosynthesis. Their simple unicellular structure and high photosynthetic efficiency allow for a potentially higher oil yield per area than that of the best oil seed crops. Algae can be grown on marginal land using brackish or salt water and hence do not compete for resources with conventional agriculture. They do not require herbicides or pesticides and their cultivation could be coupled with the uptake of CO_2 from industrial waste streams, and the removal of excess nutrients from wastewater [12–16].They have been used as food and drugs. The main components of algae cells are proteins, carbohydrates and lipids [17].This supports the further production of biodiesel, bioobutanol, bioethanol, hydrogen, biogas, vitamins, antioxidants, aminoacids.

Photoautotrophic cultivation. This form of cultivation takes place when algae utilize an energy source (light) and a carbon source (inorganic carbon) to form carbohydrates through a process termed as photosynthesis [18].

This is the most general method used for cultivating algae and results in the formation of algal cells with lipid content ranging from 5 to 68 % depending on the algal specie being cultivated. If algae are cultivated for oil production, then the prime advantage of using this cultivation technique is to utilize carbon dioxide to meet the carbon requirement.

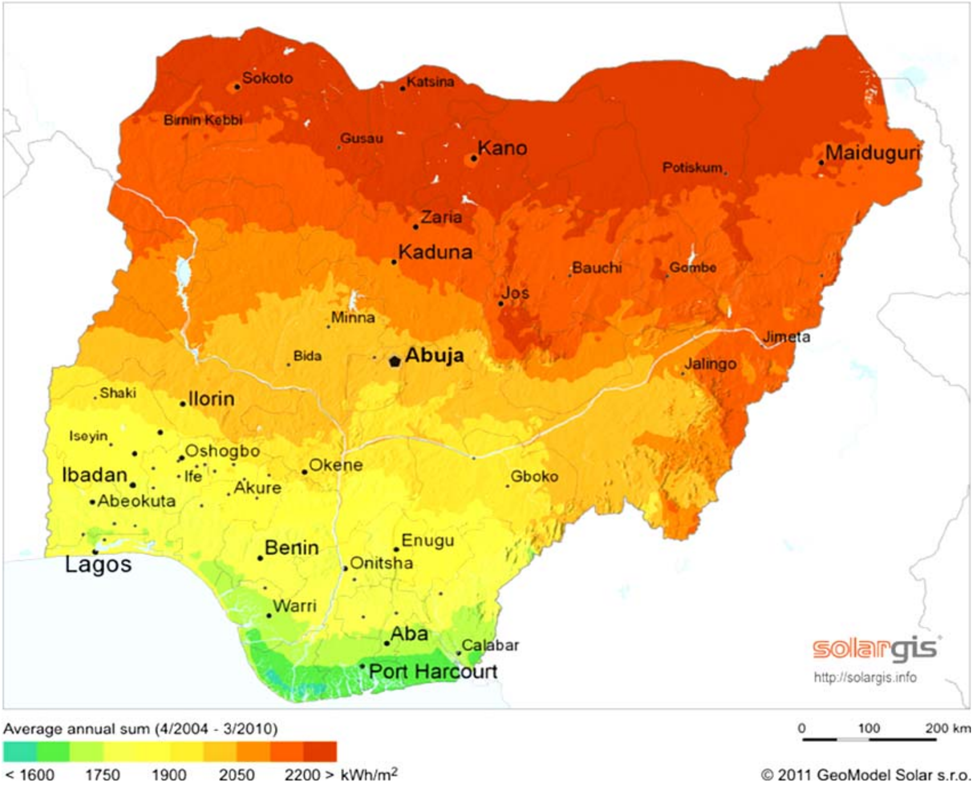

Fig. 1. Distribution of solar radiation in Nigeria

Heterotrophic cultivation. In this method, the algal specie is grown on a carbon substrate like glucose thus eliminating the need of light energy [19]. This process can be performed in a reactor with a small surface to volume ratio. A much higher degree of growth control is achieved and harvesting budget is lowered due to production of high-density cells. The set-up cost is negligible but more energy is used as compared to the process utilizing light energy because photosynthetic processes are utilized to form the carbon source on which the algae are grown. Studies have shown that heterotrophic method of biomass production has a higher yield and cells have higher lipid content (55 % as compared to 15 % in autotrophic cells).

Mixotrophic cultivation. Some algae have the capability to obtain nutrition by both autotrophic and heterotrophic methods [20]. This means light energy is not a primary need for mixotrophs as cell growth can occur by digesting organic material. These cultures are shown to lessen photo inhibition with enhanced growth rates as compared to autotrophic and heterotrophic cultures. This is because cultivation of mixotrophs utilizes both photosynthetic and heterotrophic elements, which decreases loss of biomass and reduces the quantity of organic substrate consumed.

Photoheterotrophic cultivation. This mode of cultivation refers to the process in which alga requires light energy and obtains carbon from an organic source. Unlike mixotrophs, photo-organotrophs [21] cannot grow without light energy. Although this process can enhance the production of certain useful light-regulated metabolites, this mode of cultivation is not preferred in case of procedures like biodiesel production.

The aim of this paper is to model the productivity of biomass and the accumulation of lipids in algae, as well as to calculate the productivity when cultivated under weather conditions in different regions of Nigeria.

Modelling the productivity of cultivation

The process by which green plants and algae form carbohydrates from carbon dioxide and water through the agency of sunlight acting upon chlorophyll is called photosynthesis. These organisms are able to harness the energy contained in sunlight, and via a series of oxidationreduction reactions, produce oxygen and carbohydrates, as well as other compounds, which may be utilized for energy as well as the synthesis of other compounds. The chemical equation (1) shows the energy available for photosynthesis is called Photosynthetically Active Radiation (PAR) which ranges from 400 to 700 nm of the entire solar spectrum. PAR varies with geographical factor, latitude, and seasonality, supplies the energy for photosynthetic conversion of carbon dioxide to carbohydrates. Not all of the solar energy is suitable for photosynthesis.

$$6CO_2 + 12H_2O + photons \rightarrow \\ \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O. \quad (1)$$

Eight photons are required for complete photosynthesis to capture or fix one molecule of CO_2 into carbohydrate (CH_2O_n) In equation (1), CH_2O represents the basic form of chemical energy captured by photosynthesis. Its actual form is triosephosphate ($C_3H_5O_3P$), but the energy content is often calculated from glucose ($C_6H_{12}O_6$).

The light energy absorbed by algae is first stored as intermediate bio-chemical reductants (*NAD* PH_2 and *ATP*) which are then used by the algal cells to produce new biomass (CH_2O) [3; 22]. Since, the energy content of one mole CH_2O is 468 kJ.

This maximum theoretical photoconversion efficiency of PAR energy applies to any photosynthesizing organism (carbohydrates) is 27 % (more specifically

$$468\ kJ \big/ (8\ photons \times 218\ kJ) = 26{,}9\ \%).$$

Table 1 shows the value and coefficient of variation (COV) of average monthly density of solar radiation in the main (typical) climatic zones of Nigeria.

Table 1

The average monthly density of solar radiation in the main (typical) climatic zones of Nigeria, kWh/m²·day with COV [23]

Region		Months											
		01	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**
Tropical rainforest	kWh/m²·day	19.88	20.4	19.98	18.97	17.68	15.89	14.16	13.83	14.73	16.49	18.52	19.37
	COV	0.12	0.11	0.12	0.12	0.13	0.15	0.16	0.17	0.16	0.14	0.12	0.12
Guinea savannah	kWh/m²·day	20.81	21.6	21.73	20.67	19.31	17.65	16.05	15.12	16.44	18.26	20.35	20.55
	COV	0.11	0.1	0.1	0.11	0.12	0.13	0.14	0.15	0.14	0.12	0.11	0.11
Sahel savannah	kWh/m²·day	20.32	22.9	24.5	24.64	23.71	22.82	20.54	19.2	20.66	21.22	20.56	19.29
	COV	0.09	0.08	0.08	0.08	0.08	0.08	0.09	0.1	0.1	0.09	0.09	0.1
Sudan savannah	kWh/m²·day	20.31	22.6	23.73	23.55	22.55	21.56	19.43	18.16	19.89	20.99	20.96	19.83
	COV	0.1	0.08	0.08	0.08	0.08	0.08	0.09	0.1	0.09	0.09	0.09	0.09
Mangrove swamp forest	kWh/m²·day	19.61	19.9	18.58	17.59	16.26	14.14	12.54	12.84	13.23	14.64	16.88	18.7
	COV	0.13	0.13	0.14	0.15	0.16	0.2	0.21	0.21	0.19	0.18	0.16	0.14

Microalgae biomass production by cultivating in open area BM_{algae}, g/m²·day, can be determined by the formula

$$BM_{algae} = \frac{S_{illum} \times \eta_{transmission} \times \eta_{capture}}{E_{algae}}, \text{ (g/m}^2\text{·day)}, \quad (2)$$

where S_{illum} — solar irradiance falling on a horizontal surface of photobioreactors (kJ/m²·day); E_{algae} — amount of energy stored in the biomass, (MJ/kg); $\eta_{transmission}$ — efficiency of light transmission to microalgae; $\eta_{capture}$ — efficiency of conversion of incident sunlight to biomass in microalgae.

Lipids production by cultivating in open area BM_{lipid}, g/m²·day, can be determined by the formula

$$BM_{lipid} = \frac{f_{ilipid} \times BM_{algae}}{p_{lipid}}, \text{ (g/m}^2\text{·day)}, \quad (3)$$

where f_{lipid} — microalgae lipid fraction usable for biodiesel production; MB_{algae} — microalgae productivity, (g/m²·day); ρ_{lip} — density of lipids usable for conversion to biodiesel (kg/l).

Efficiency of conversion of incident sunlight to biomass in microalgae can be determined by the formula

$$\eta_{capture} = \eta_{photosynthesis} \times \eta_{photoutilization} \times (1 - r), \quad (4)$$

where $\eta_{photosynthesis}$ — photosynthesis efficiency; $\eta_{photoutilization}$ — fraction of captured photons utilized by microalgae; r — fraction of energy consumed by respiration in microalgae.

Efficiency of light transmission to microalgae can be determined by the formula

$$\eta_{transmission} = \eta_{light\ distributuin} \times \eta_{land\ use} \times \alpha \times PAR_{component}, \quad (5)$$

where $\eta_{light\ distributuin}$ — the optical light distribution efficiency; $\eta_{land\ use}$ — land-use efficiency; $PAR_{component}$ — photo synthetically active radiation of the sun; α — light absorption coefficient of microalgae.

Fraction of captured photons utilized by microalgae can be determined by the formula

$$\eta_{photoutilization} = \frac{I_S}{I_L}\left[\ln(I_L / I_S) + 1\right], \quad (6)$$

where I_S — saturation light photosynthetic photon flux density on microalgae (μmol/m^2·sec), quantum of energy at which microalgal photosynthesis attains saturation; I_L — incident light photosynthetic photon flux density incident on microalgae (μmol/m^2·sec) quantum of energy available in natural sunlight.

Table 2 shows the monthly biomass productivity of five regions in Nigeria divided by the area of cultivation calculate according to the proposed model.

Mangrove swamp forest is found in places near the coast that is under the influence of brackish water commonly found in the Niger Delta.

Tropical rainforest area is characterized with a prolonged rainy season.

Guinea savannah zone has a unimodal rainfall distribution with the average annual temperature and rainfall of 27.3 ºC and 1051.7 mm respectively where the wet season lasts for 6–8 months. The Sudan Savannah zone is found in the Northwest stretching from the Sokoto plains in the West, through the Northern sections of the Central highland. Sahel savannah is the last ecological zoological zone with proximity to the fringes of the fast-encroaching Sahara desert. Occupies about 18 130 km^2 of the extreme Northeast corner of Nigeria and is the last vegetation zone in the extreme northern part of the country. Fig. 2 is the graphical representation of the monthly biomass productivity of five major regions of Nigeria.

Table 2

Monthly biomass productivity of microalgal cultivation in typical regions of Nigeria, kg/m^2

Region	Months											
	01	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**
Tropical rainforest	0.049	0.050	0.049	0.048	0.046	0.043	0.040	0.039	0.041	0.044	0.047	0.048
Guinea savannah	0.050	0.051	0.051	0.050	0.048	0.049	0.051	0.052	0.053	0.054	0.055	0.056
Sahel savannah	0.049	0.052	0.054	0.054	0.053	0.052	0.050	0.048	0.05	0.051	0.050	0.048
Sudan savannah	0.049	0.052	0.053	0.053	0.052	0.051	0.048	0.047	0.049	0.050	0.050	0.049
Mangrove swamp forest	0.048	0.049	0.047	0.046	0.044	0.040	0.037	0.038	0.038	0.041	0.045	0.048

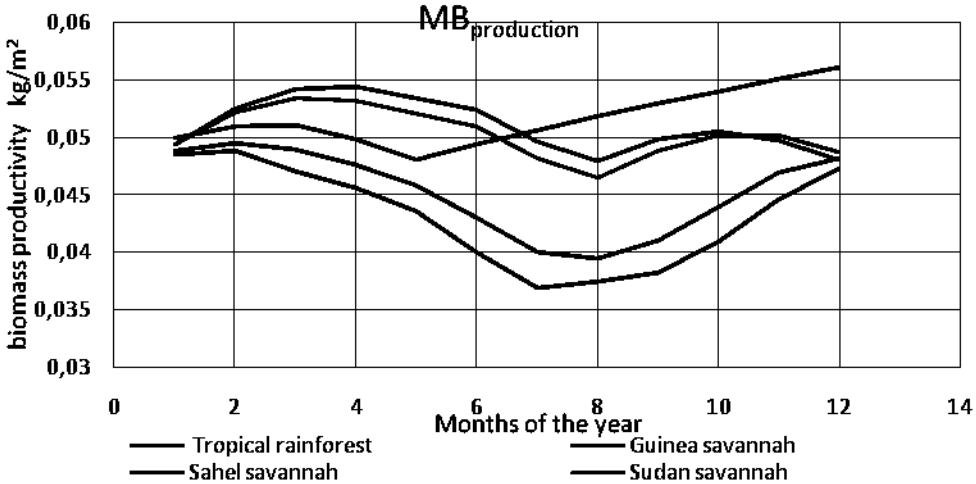

Fig. 2. Monthly biomass productivity of microalgal cultivation in typical regions of Nigeria, kg/m^2

Conclusion

The result shows the amount of algae biomass potential in the five regions. Guinea savannah having the highest amount for biomass potential of 0.052 in December because of the high Irradiance and the lowest is the mangroove swamp forest at 0.037 in July.

Generally, the month of December have the highest amount of biomass potential, therefore the highest amount of biofuel also.

The algal cultivation for biofuel production would require sustainable conventional algal culture technologies.

Enormous quantities of freshwater or wastewater, nitrogen, phosphorus, and potassium comparable to the current global consumption would be needed to produce enough algal biofuel to meet 30 % of the transportation fuel demand. Research shows that Nigeria has the potential for biofuel production but would require a vast amount of resource to accomplish.

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Бойченко С. В., Шаманський С. Й., Адений К. О.

ОЦІНЮВАННЯ ПРОДУКТИВНОСТІ КУЛЬТИВУВАННЯ МІКРОАЛЬГИ ДЛЯ ВИРОБНИЦТВА БІОПАЛИВА В УМОВАХ НІГЕРІЇ

Мікроводорості являють собою основне джерело матеріалів, які можуть бути використані як сировина для багатьох високопродуктивних біопродуктів, найбільш відомих з яких це вітаміни, ліпіди, хлорофіл і каротиноїди. Ключем до економічного виробництва біомаси та біопродуктів з мікроводоростей є оптимізація їх умови росту. Мікроводорості вимагають оптимальних умов освітлення для ефективного фотосинтезу.

Стаття присвячена умовам вирощування мікроводоростей здебільшого chlorella sp. Фотоперіод, інтенсивність світла і довжина хвилі світладеякі з важливих факторів, що впливають на швидкість фотосинтезу. Світлові умови безпосередньо впливають на зростання, вміст пігменту та кількість білка в мікроводоростях. Метою даної роботи є моделювання продуктивності біомаси та накопичення ліпідів у водоростях, а також розрахунок продуктивності при культивуванні в погодних умовах у різних регіонах Нігерії. Інтенсивність сонячної радіації на добу зазвичай є однією з змінних, зібраних метеорологічними станціями в Нігерії. Було отриманосупутниковевипромінення в 25 точках в 5 кліматичних зонах Нігерії (тропічний ліс, саванна Гвінея, саванна Сахель, саванна Судан и болотний ліс мангрових лісів).У статті аналізується перспектива виробництва біопалива третього покоління з використанням мікроводоростей біомаси в погодних умовах типових регіонів Нігерії. Враховуючи середньомісячну щільність сонячного випромінювання в основних регіонах Нігерії kWh / m2.day, можна оцінити можливість досягнення врожайності біомаси мікроводоростей на квадратний метр оброблюваних територій в погодних умовах Нігерії.

Крім того, обговорюються переваги та сучасні обмеження виробництва біодизеля, кількісна та якісна доцільність використання біодизелю мікроводоростей та його економічна доцільність.

Ключові слова: біопаливо; мікроводорості; біомаса мікроводорог; опромінення; сонячне випромінювання.

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THE ESTIMATION OF MICROALGAE CULTIVATION PRODUCTIVITY FOR BIOFUEL PRODUCTION IN NIGERIAN CONDITIONS

Microalgae constitute the main source of materials that can be used as raw materials for many high value bioproducts, the most prominent ones of which are vitamins, lipids, chlorophyll and carotenoids.The key to economic production of biomass and bioproducts from microalgae is to optimize their growth conditions. Microalgae require optimal lighting conditions for efficient photosynthesis. This article focuses on the conditions for growing microalgae mostly chlorella sp. Microalgae require optimal lighting conditions for efficient photosynthesis. Photoperiod, light intensity and wavelength of light are some of the important factors affecting the rate of photosynthesis. Light conditions directly affect the growth, pigment content and protein amount in microalgae. The aim of this paper is to model the productivity of biomass and the accumulation of lipids in algae, as well as to calculate the productivity when cultivated under weather conditions in different regions of Nigeria.The intensity of solar radiation per day is usually one of the variables collected by meteorological stations in Nigeria. Satellite derived solar irradiance over 25 locations in the 5 climatic zones of Nigeria (tropical rainforest, Guinea savannah , Sahel savannah , Sudan savannah , and Mangrove swamp forest) was analyzed.

This article analysis the prospect of production of biofuel of the third generation using microalgal biomass in the weather conditions typical regions of Nigeria. Taking into account the average monthly density of solar radiation in the main regions of Nigeria kWh/m^2.day to estimate the possibiity of achieving crop yields of microalgal biomass per square meter of cultivated areas in the weather conditions of Nigeria.

In addition, advantages and current limitations of biodiesel production, quantitative and qualitative feasibility of microalgal biodiesel, and its economic feasibility are discussed.

Keywords: Biofuel; Microalgae; Microalgal Biomass; irradiance; solar radiation.

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ОЦЕНКА ПРОДУКТИВНОСТИ КУЛЬТИВИРОВАНИЯ МИКРОРАЛГОВ ДЛЯ ПРОИЗВОДСТВА БИОТОПЛИВА В НИГЕРСКИХ УСЛОВИЯХ

Микроводоросли являются основным источником материалов, которые могут быть использованы в качестве сырья для многих биопродуктов высокого качества, наиболее выдающиеся из которых витамины, липиды, хлорофилл и каротиноиды. Ключом к экономическому производству биомассы и биопродуктов из микроводорослей является оптимизация их условия роста. Микроводоросли требуют оптимальных условий освещения для эффективного фотосинтеза.

Статья посвящена условиям выращивания микроводорослей в основном хлореллы sp. Микроводоросли требуют оптимальных условий освещения для эффективного фотосинтеза. Фотопериод, интенсивность света и длина волны света некоторые из важных факторов, влияющих на скорость фотосинтез. Условия *освещения напрямую влияют на рост, содержание пигмента и количество белка в микроводорослях. Целью работы является моделирование продуктивности биомассы и накопления липидов в водорослях, а также расчет продуктивности при культивировании в погодных условиях в различных регионах Нигерии. Интенсивность солнечного излучения в день обычно является одной из переменных, собираемых метеорологическими станциями в Нигерии.*

Проанализировано спутниковое излучение солнечного излучения в свыше 25 мест в 5 климатических зонах Нигерии (тропические леса, саванна Гвинея, саванна Сахель, Саванна Судан, и мангровые болота). В данной статье анализируются перспективы производства биотоплива третьего поколения с использованием биомассы микроводорослей в погодных условиях, характерных для районов Нигерии. Принимая во внимание среднемесячную плотность солнечной радиации в основных регионах Нигерии, кВтч / м 2, день, чтобы оценить возможность достижения урожайности микроводорослевой биомассы на квадратный метр посевных площадей в погодных условиях Нигерии.

Кроме того, обсуждаются преимущества и текущие ограничения производства биодизеля, количественная и качественная осуществимость биодизеля из микроводорослей и его экономическая целесообразность.

Ключевые слова: биотопливо; микроводоросли; биомасса микроводорослей; облучение; солнечная радиация.

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