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USE OF MICROALGAE FOR CIRCULAR ENERGY ECONOMY FOCUSED ON AGRIBUSINESS

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Abstract. *Energy is essential for the development of humanity, regardless of the development of the region, due to its influence directly linked to the pattern of population consumption. As society's standard of living evolves, there is an increase in the supply of goods that require more energy, but their use mostly comes from non-renewable resources. Maintaining the growing curve of fossil fuel consumption has a harmful effect on the environment, increasing the unprecedented risk of climate change, as well as the rapid and critical depletion of natural resources. Research progress is increasing in favor of alternatives to meet these needs, leading to the adoption of more sustainable technologies. Great emphasis is given to microalgae, which are unicellular photosynthetic organisms that occur naturally in various aquatic/humid environments and are easily conducted when in a controlled environment. These microorganisms are capable of providing carbohydrates, lipids and proteins, consequently resulting in the generation of electricity through the incineration process, or generating biofuels, such as biodiesel, biokerosene or bioethanol. They also help in the treatment of effluents, as bioremediation agents by capturing CO_2 and other toxic emissions. The process of obtaining energy through microalgae is promising, generating biomass as a by-product, which can be used as biofertilizers for agribusiness. Biofertilizers are substances that contain living microorganisms that colonize the rhizosphere or the interior of plants and promote growth, with an increase in the nutritional supply for host plants and are used to reduce the use of chemical fertilizers, which in addition to having high added value , generate dependence on the external market for the acquisition and surplus of mineral elements in groundwater, due to leaching when applied to the soil. Microalgal biomass, when linked to agriculture, promotes increased productivity, high efficiency in carbon capture, increased starch and lipid content, general increase in the germination index (GI) of treated seeds, development of longer roots and greater tolerance to drought and salinity. Therefore, the commercial cultivation of microalgae has become a sustainable alternative for the integration of different production chains. The factors considered during the development of the study attributed the benefits of a renewable option for energy production, reconciling the effects of microalgal biomass in agriculture, one of the sectors that proportionally consume more* *energy, forming a cycle of use that seeks to address two major global problems: generation of renewable energy and reduction in the use of products that degrade the environment.*

Keywords: *renewable energy; microalgae; agronomy; biofertilizer; circular economy chain*

1. INTRODUCTION

According to estimates by the Food and Agriculture Organization of the United Nations, the world population in 2050 will be 29% greater than in 2017, with the majority living in urban areas, which may lead to increased scarcity and poor distribution of food. Currently, around 800 million people already suffer from malnutrition, mainly in underdeveloped regions. In addition to the food demand, the increasing use of energy by man accompanies its development.

The processes involving industrial production, from its creation to the present day, generate waste that ends up being unused and/or having an incorrect destination. The use of natural resources is a key issue when it comes to sustainability and the circular economy. The agronomic scenario is no different, many of the resources used in agriculture are not renewable and cause damage to the environment when used improperly.

A common practice to meet the nutritional demand of plants to grow and achieve good productions is the use of chemical fertilizers, but this practice negatively affects soil-water-air resources. The use of microorganisms associated with agriculture that promote plant growth, called biological inoculants. An example of a bioinoculant is microalgae, which are microorganisms that, in addition to being potential energy generators, also offer benefits when inoculated to agricultural crops, thereby making this process more sustainable and cyclical.

2. ENVIRONMENT AND AGRICULTURE

Human activity on a global scale has led to a variety of issues, both social and environmental, while the demand from consumers, society, governments and the market for enterprises with more sustainable practices is growing. This situation directly impacts the strategic formulation of organizations (BARBOZA et al., 2021).

Faced with the increasingly urgent challenges faced by the linear economic model, arising from the Industrial Revolution, based on "take-make-dispose", the circular economy (CE) has aroused the interest of these organizations (Assunção, 2019). CE offers a viable approach to redefine the concept of economic growth, with an emphasis on efficient use and management of resources, as well as preservation of environmental quality, social inclusion and well-being of populations (Cotec, 2016). It is an economic model based on shared values and a long-term systemic vision (Confederação Nacional da Indústria [CNI], 2018). When implemented, CE has the potential to create sustainable value by minimizing negative impacts and promoting the adoption of new business practices (Buren et al., 2016). In addition, CE has a direct connection with sustainable development and contributes to achieving the Sustainable Development Goals (SDGs) established by the United Nations (UN) (Schroeder et al., 2018).

The environmental impacts reflected in the scarcity of natural resources, soil degradation, overpopulation and, in particular, climate change, which society has been facing, are directly linked to the increase in greenhouse gas (GHG) emissions, as pointed out by the IPCC (2018). These emissions are the result of various activities, especially those related to the use of fossil fuels, and a significant factor in this consumption is the constant global population growth. This growth causes an increase in the demand for food and energy, which contributes significantly to emissions, since food production is associated with the intensification of the agricultural sector to meet this need (Barboza et al., 2021).

Furthermore, although gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are naturally emitted into the atmosphere, human activities have altered their concentrations. In general, CO2 is the dominant gas, however, non-CO_2 emissions such as methane (CH_4) and nitrous oxide (N_2O) account for more than 34% of total GHG emissions, including land use change. (UNEP, 2019). In addition, agricultural sources are among the main global sources of non-CO_2 emissions, accounting for 65% of anthropogenic N_2O emissions, mainly due to changes in land use, use of synthetic fertilizers and application of manure (Cornejo; Willie, 2010).

2.1. Macronutrients

In the scenario of agriculture, for plants to reach the maximum potential of final productivity, they depend on all the nutrients to be in adequate amounts in the soil for absorption of the agricultural cultures, as established in the "Law of the Minimum" in the seventeenth century, by Liebeg. (Souza, 2021). The most sought-after nutrients for use in agribusiness are nitrogen (N) and phosphorus (P), which in addition to being essential elements for crop development, N and P are macronutrients, reflecting on the precision of the elements in large quantities for achieving high yields.

Nitrogen (N) plays a fundamental role in plants, as it is present in important biomolecules such as ATP, NADH, NADPH, chlorophyll, proteins of several enzymes (Miflin; Lea, 1976; Harper, 1994, Bredemeier; Mundstock, 2000). In many production systems, nitrogen availability is often a limiting factor, affecting plant growth more than any other nutrient. Due to its importance and high mobility in the soil, nitrogen has been the subject of intense research to maximize the efficiency of its use. Efforts have been made to reduce soil nitrogen losses and improve N uptake and metabolism within plants (Tavares et al., 2023).

Among the macronutrients, phosphorus (P) is the least abundant in the soil solution, and increasing its concentration to make it more available to plants through fertilization is a challenging agricultural practice (Bredemeier; Mundstock, 2000, Marchetti, 2022).

Although absorbed in smaller amounts, phosphorus plays a key role as a primary macronutrient in plant growth and production. It is essential for biological processes such as photosynthesis, respiration, energy storage and transfer, cell division and cell growth (Araújo; Machado, 2006, Muhl et al., 2022). Due to its importance in biological processes, adequate availability of phosphorus is essential from germination to plant development. This nutrient has little mobility in the soil, but is highly mobile within the plant, with greater absorption occurring in young plants, during rapid and intense root development (Moreira, 2004, Muhl et al., 2022).

In general, Brazilian soils have considerable levels of N and P in the soil, but only a small percentage is available for direct absorption by plants, which means that most of it is retained with other elements in the soil. Therefore, the nutritional needs of plants are mostly met with the use of chemical fertilizers, however, losses from the application of nitrogen and phosphate fertilizers, whether due to surface runoff, soil leaching and/or losses due to volatilization, also lead to the degradation of water resources, soil and air (EMBRAPA, 2021).

2.2. Microbial and microalgae inoculants with a focus on agribusiness

In order to face the environmental challenges affected by conventional chemical fertilization, more sustainable agronomic practices have been adopted, including the use of biofertilizers and microbial inoculants (Conley et al., 2009). Microbial inoculants are biological products containing live microorganisms that, when applied to soil, seeds or leaves, have the ability to promote plant growth and development, as well as increase resistance against external agents. Its application in agriculture has been shown to be effective in increasing the final agricultural yield and in reducing the environmental impacts caused by the excessive use of herbicides, pesticides and chemical fertilizers. Thus, the use of these microbial bioinoculants represents a promising alternative to improve the nutritional efficiency of plants and reduce dependence on chemical inputs, contributing to more ecologically correct agricultural practices aimed at preserving the environment (Santos et al., 2019).

Microalgae are unicellular or colonial photosynthetic organisms, their growth occurs naturally in various aquatic/humid environments (Trichez et al., 2019) and they have the ability to produce compounds such as carbohydrates, lipids and proteins, which can be used for energy generation electricity, through the microalgae incineration process or as a raw material for the production of biofuels, such as biodiesel, biokerosene or bioethanol (Dantas et al., 2019). In addition, these microorganisms play an important role in the treatment of effluents, acting the bioremediation agents, capturing CO_2 and other toxic emissions. The use of microalgae to obtain energy is a promising approach, and the residual biomass resulting from this process can be used as a biofertilizer for the agricultural sector, contributing to sustainability and the circular economy in agribusiness. (Lopes, 2017).

Microalgae biomass, when linked to agriculture, provides an increase in the final productivity of crops, high efficiency in carbon capture, a general increase in the germination index (GI) of treated seeds, development of longer roots, with a high content of starch and lipids (Ferreira et al., 2021), greater tolerance to drought and salinity, providing better absorption of nutrients from the soil (Ronga et al., 2019).

In view of the population increase, which aims at greater consumption of energy and food, combined with the search for alternatives that are less abrasive to the environment, this present work has an option for the production of renewable energy and biofuels through the process of burning microalgae Tetradesmus obliquus, which, thinking about the circular economy, uses the residual biomass from this process as a bioinoculant applied in agriculture.

3. MATERIALS AND METHODS

The agronomic experiment was conducted in the city of Curitiba - PR, in the greenhouse of the Campus Ciências Agrárias, of the Federal University of Paraná (UFPR) located next to the Department of Soil Science, whose coordinates are 25°24'46.0"S 49°14'57.3"W, with approximately 915 meters of altitude (GOOGLE EARTH, 2023). According to Köppen's classification of climate types (1948), the localized region of the experiment is determined as a temperate climate, with mild summer (Cfb) (EMBRAPA, 2023).

The soil used in the experiment comes from the Canguiri Farm, experimental at the Federal University of Paraná - UFPR, located in the municipality of Pinhais - PR, whose coordinates are 25° 23' 08.8" S 49° 07' 29.4" W, with approximately 908 meters of altitude and the same climatic classification mentioned in the city of Curitiba. (EMBRAPA, 2023; Google Earth, 2023).

The soil was classified as Cambisol, in terms of fertility, soil texture and total levels, demonstrating the need for correction with liming and fertilization. The soil was initially sieved through a 4 mm diameter sieve and subsequently corrected for liming with quicklime with a PRNT of 90%, based on Nepar (2019), to achieve a base saturation above 60%, correction with liming was used, reaching a value of 5 g dm^{-3}. The fertilization for P was 200 mg/dm, using triple superphosphate fertilization, in the proportion 1.5 g dm^{-3} and for K in 150 mg dm^{-1}, being then used potassium chloride in the proportion 0.5 g dm^{-3}, following the fertilization recommendation for experiments in Malavolta pots (1980 and 1981) and leaving the soil piled up, to react for 3 months. Fertilization and liming were carried out so that normal nutritional levels did not interfere with the yield of the crops used.

The experimental design used was completely randomized (DIC), the study was divided into 4 treatments, with 6 repetitions each. Two of the main agronomic crops in Brazil were grown, soybean (Glycine max (L) Merrill) and corn (Zea mays), the description of the treatments is presented in Table 1. The soil was distributed in 7 L pots, and in 4 soybean seeds of the Zeus-Brasmax 55I57RSF IPRO cultivar were sown in each pot, in the “S C” and “S To” treatments, and 4 corn seeds, BRS 4103 cultivar, in the “M C” and “M To” treatments, inserted with 4 cm deep, but during the initial stages of crop development, 2 plants were thinned in each pot, leaving 2 plants per pot.

Table 1. Description of treatments used in the study.

TREATMENTS	DESCRIPTION
S C	Soybean without inoculation (Soybean Control)
S *To*	Soybean inoculated with *T. obliquus*
M C	Corn without inoculation (Control corn)
M *To*	Corn inoculated with *T. obliquus*

The production of the microalgae *Tetradesmus obliquus* was carried out at the Sustainable Energy Research and Development Center - (NPDEAS), Polytechnic Center Campus, Federal University of Paraná, UFPR. The cultivations were carried out under ambient conditions of luminosity and temperature, in compact tubular photobioreactors built with transparent PVC tubes and operating volume of 10 m^3, which presents a high production density. The culture medium used for the growth of microalgae was composed of biodigested swine manure, in batch growth mode.

All the productive processes that the *T. obliquus* microalgae can go through, both for the production of renewable energy, biofuels, effluent treatment and production of microalgal residual biomass are represented in Figure 1.

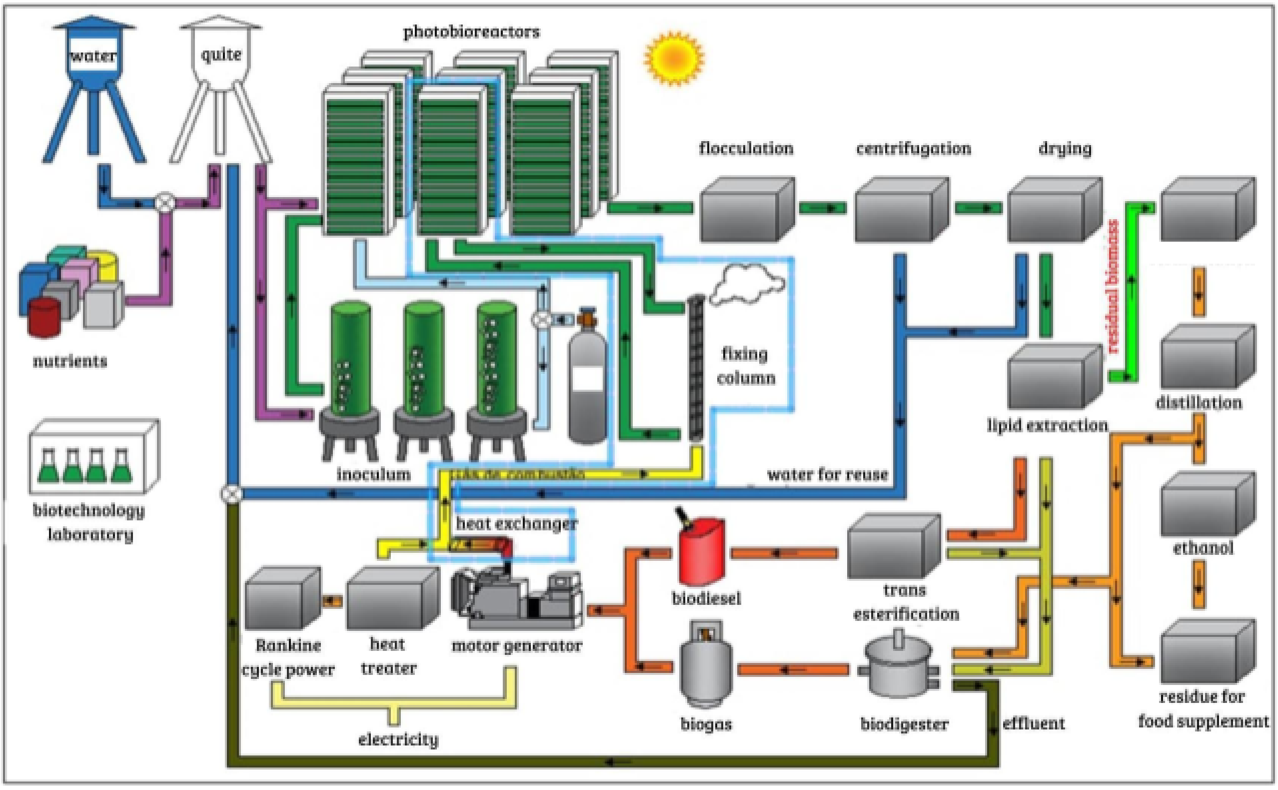

Figure 1. Microalgae production processes at NPDEAS.
Source: Adapted from Taher (2019).

In order to recover the microalgae biomass, at the end of the species' cultivation period, flocculation was performed using a commercial polycationic organic polymer, which is a tannin-based coagulant (Tanfloc®), followed by centrifugation, filtration and drying in oven at 60 °C until constant weight is maintained. The dry biomass was macerated, stored in a freezer for later composition analysis and use in biological activity assays.

The addition of microalgae biomass in the experiment was done following the preparation of a solution containing approximately 1.5 g of microalgae biomass that was macerated again in a mortar with a pestle until most of it was in fine powder, to increase the surface of the microalgae. contact and consequently increase the dilution. Subsequently, this powder was dissolved in 500 mL of water, in a beaker. From this biomass solution, the distribution in the pots, dividing into 15 mL of the dilution on the soil surface of each pot, right after sowing, as shown in Figure 2.

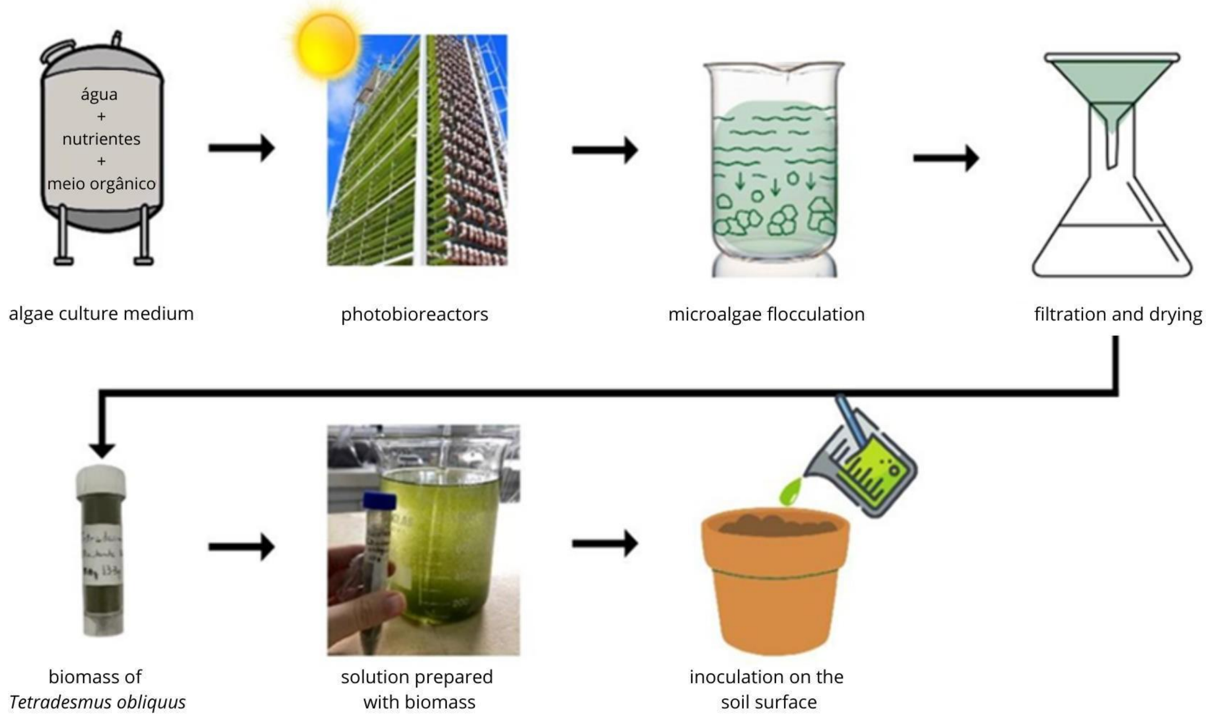

Figure 2. Use of microalgae biomass as inoculant.

The variables to analyze the objective of the research is to perform the measurement of root length, total chlorophyll content and available P.

On the day of harvest, the chlorophyll content was measured, which is directly related to the N content, using the Falker ClorofiLOG 1030 device, standardizing the measurement by the average of two points on the last leaf, in the middle third, face adaxial of each plant. For available P analyses, the rhizospheric soil (soil wrapped in the roots) was used, following the methodology of the Manual of Soil Analysis Methods, from Embrapa Solos (Teixeira et al., 2017) using the UV-VIS spectrophotometer equipment, to see the amount of P usable by the plant and the root length was performed with the aid of a millimeter ruler.

The collected data were submitted to analysis of variance with the application of the "F" test and using the SISVAR 5.3® program (Ferreira, 2011), evaluating separately the application of microorganisms in the two scenarios of soil aeration.

4. RESULTADOS E DISCUSSÕES

The obtained results demonstrated that the application of the solution containing the biomass of *T. obliquus* presented a significant positive difference in the evaluated parameters, for the two evaluated cultures, when compared with the control treatments, as shown in Tables 2 and 3. Such results corroborate with the results found with the study presented by Ferreira et al. (2021), which reports on the efficiency of microalgae, when linked to agriculture, as well as presented by Paiva et al., (2021), which found an increase in the availability of essential nutrients for plants. For the statistical analysis, the data obtained from the different cultures were separated by culture, so as not to interfere in the analysis, given the different morphology between the two.

Table 2. Soybean culture parameters evaluated, with statistical analysis.

Treatments	Root length (cm)	Total chlorophyll content	Available P (mg dm^{-3})
S C	54,8 b	51,0 b	2,559 b
S To	68,1 a	63,1 a	3,182 a

Table 3. Parameters evaluated for the soybean crop, with statistical analysis.

Treatments	Root length (cm)	Total chlorophyll content	Available P (mg dm^{-3})
M C	44,8 b	40,7 b	2,751 b
M To	57,9 a	53,6 a	3,219 a

5. CONCLUSION

With the results obtained, it was possible to verify the efficiency of the inoculation of the biomass of the microalgae *Tetradesmus obliquus*, promoting the root growth of the plants, increasing the availability of water and essential macronutrients N and P, acting as a bioinoculant allied to agribusiness, both when applied in corn and soybean crops.

Therefore, it is relevant to consider that microalgae, in addition to presenting potential for the production of renewable energy and biofuels, can be aggregated as a viable and effective product of agricultural microbiological inoculant, taking advantage of a residual by-product of the energy production process of these microalgae. Concluding then that the benefits of using *T. obliquus*, from its production focused on energy to the use of biomass in agriculture, adhere to the concept of circular economy.

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