# Embracing the Green Shift

## The Multifaceted Role of Algae & Fungi in Reducing GHG Emissions

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The 2023 Emissions Gap Report of the UN Environment Programme reveals that *current pledges under the Paris Agreement are insufficient to prevent global temperatures from rising by 2.5-2.9°C above pre-industrial levels this century.* The world is sliding towards disaster, and it is our lifestyle choices – the products we use, the way we produce, and what we eat -- that are responsible. For instance, plastic waste and chemical fertilizers, two omnipresent aspects of today's civilisation, have a significant carbon footprint and can alter the delicate balance of soil, which is crucial for the survival of all dependent organisms. Along the same lines, while beef and veal are preferred food staples in many cultures, their production process leads to environmental impacts and emissions.

To reduce our GHG emissions, can we therefore shift from commonly used but environmentally degrading products to new products that are natural resource-based? Can algae and fungi-based alternatives substitute conventional products in terms of functionality and environmental impact, potentially mitigating climate change and promoting sustainability? Let us examine three alternatives: bioplastics, biofertilizers and mycoprotein.

Algae and mushrooms are transformative agents, known for their versatility and use in market applications for reducing carbon footprints. Research by Bhola *et al* (2014)(we need a full reference here) highlights the remarkable carbon capture potential of microalgae at a rate 50 times greater than that of terrestrial plants. After generating nearly 280 tonne of dry biomass per hectare per year, microalgae absorbed an impressive 513 tonne of carbon dioxide during the growth period. Mushrooms, popular for their mycelium component, have a typical meat-like structure that unlocks diverse, cost-effective meat substitutes, while their affinity for agricultural waste starkly contrasts with the resource-intensive nature of beef production.

Microalgae and macroalgae offer sustainable solutions for food, fuel and other applications, while mushrooms can cater to growing dietary trends and health consciousness. With increasing global trade and rising consumer interest, these markets are poised for significant growth. With a market size of US $11.8 billion in 2023 and a projected growth of US $25.4 billion by 2033, boasting a steady 7 per cent compounded annual growth rate, the business in microalgae holds promise. Macroalgae follows a similar trajectory**,** starting at US $9.3 billion in 2023 and reaching US $18.3 billion by 2033, with a slightly higher CAGR of 7.8 per cent. Compared with algae, the mushroom market is already huge and valued at US $50.3 billion in 2021. It is projected to reach a staggering US $115.8 billion by 2030, with a robust CAGR of 9.7 per cent.

## MACROALGAE AND MICROALGAE

More commonly known as seaweed, **macroalgae** is composed of a group of cells arranged in colonies or as an organism. They are packed with protein, minerals and vitamins and have the capacity to prepare environmentally friendly market products such as biofuels, bioplastics and biofertilizers. Macroalgae are chlorophyll-containing organisms existing in three main categories: green (Chlorophyta), brown (Phaeophyta), and red (Rhodophyta) algae. Green macroalgae can be found in saltwater and freshwater; they are extensively used in the food and cosmetic industries. Brown macroalgae are a nutritious food source; they are used in the production of alginates for the purpose of manufacturing and are also employed as food thickeners. Red macroalgae is a rich source of dietary fiber.

Macroalgae are produced in optimal sunlight at temperatures ranging from 25°C to 30°C. Spore or vegetative propagation methods are typically employed to build seaweed farms, minimising ecological stress. After maturity, macroalgae is harvested using either of the two methods: rope culture systems floating in open water or pond-based cultivation in controlled environments. To maximise capacity and ensure quality, harvested seaweed undergo a rigorous cleaning process that removes debris and unwanted organisms. This can be done manually or by using machines, depending on the scale of the operation.

After cleaning, the harvested seaweed is exposed to an air-drying process to reduce moisture content and prevent further growth. The previous step is crucial as it acts as a bridge between farming and processing, preparing the seaweed for its range of industrial applications. Additionally, dried seaweed can undergo purification procedures, or specific compounds can be extracted for product development.

**Microalgae** -- single-celled organisms performing photosynthesis -- constitute the base of the aquatic food chain. They are adaptable to their surroundings and act as nature's carbon capturers, absorbing $CO_2$ and helping mitigate climate change. They also contribute to the development of complex microhabitats within aquatic ecosystems, fostering biodiversity. Additionally, some species serve as a direct food source for various organisms. Certain microalgae boast an impressive protein content and favorable amino acid profiles, making them a viable and sustainable alternative to traditional protein sources.

Microalgae can be turned into marketable products like organic energy booster tablets (made with Spirulina or Chlorella) or green crude (biofuels) through the following three steps.

- Cultivation: Careful strain selection, tailored to the desired growth rate and nutritional profile, is of the utmost importance. Depending on economic costs and production scale, either photobioreactors offering controlled environments or open pond systems with ample sunlight can be used.
- Harvesting: Density-based filtration is practiced through screens to gently release the algae from its growth medium.
- Processing: Drying and concentration are performed to amplify the algal biomass. Be it solvent extraction, trans-esterification or any other refining process, each step unlocks the inherent potential of microalgae to be used as a green alternative to energy-intensive products that harm the environment.

## SHIITAKE MUSHROOMS

Mushrooms are fungi that come in a wide variety of shapes, sizes, and colors. They can be found growing in the wild or cultivated on farms. In particular, Shiitake mushrooms are known for their rich, earthy flavor and meaty texture. They have one of the highest protein contents amongst other commercially available fungi and are more economical for consumer needs.

As one would expect of fungi, shiitake mushrooms are cultivated on the sawdust of broad-leaved trees, requiring a mixture of sawdust, wheat bran, and calcium carbonate. The first step of production consists of soaking the sawdust for 16-18 hours and the wheat bran for three hours. After thorough mixing, the ingredients are sealed into polypropylene bags. These bags are subjected to an autoclave sterilisation process at 22 psi for 1.5 to two hours, which ensures sterility.

Post-sterilisation, mushroom seeds, also known as spawn, are put in bags and incubated in a controlled environment with a four-hour light/20-hour dark cycle at 22-26°C for 60-80 days. During this period, the mycelium (the vegetative part of the fungus) is allowed to grow and colonise the substrate. After the incubation period, a cold-water shock treatment is applied to induce the formation of the fruiting body, also known as frutification. Finally, the shiitake mushrooms are harvested at an early stage of development, ensuring optimal quality and flavor. Every step, from prepping the substrate to the final flourish of fruiting, demands meticulous attention.

The potential expands beyond the mushroom itself. Mycelium, the versatile root system of the fungus, can be transformed into a sustainable and protein-rich meat alternative. Available in ground form or even shaped into various meat-like textures, it presents a promising avenue for future food production. The spent mushroom substrate, formed as a byproduct, contains organic matter that can be broken down by anaerobic microbes to produce biogas.

**CASE STUDY: BIOFERTILISERS**

Macroalgae (or its extracts) have potential uses in horticulture as a soil supplement or fertiliser. Among the three macronutrients used in NPK fertilisers, ‘N’ affects organic structure and physiological characteristics. Insufficient supply impairs the structure and function of photosynthesis. Similarly, ‘P’ deficiency in plants can reduce leaf area and alter carbon metabolism. ‘K’ is the most abundant cellular cation, regulating osmotic adjustment.

This brings us to the question: to what extent can replacing the use of traditional chemical fertilisers with algae-based organic fertilisers/additives reduce GHG emissions when compared on the basis of their NPK compositions?

To begin with, let us consider the NPK composition of the two types of fertilisers. Urea 46, a white crystalline fertiliser, is composed in the ratio 46:0:0, with 46 per cent nitrogen. Brown seaweed, a natural fertiliser that provides all the vital nutrients, growth hormones and other essential elements required for sustenance, is composed in the ratio 1:0:4 -- lower in nitrogen and higher in potassium compared to Urea 46. In the market, brown seaweed exists in the form of kelp meal as well, which is hand-harvested and milled into powder. Kelp meal is a soil conditioner and has a higher water-holding capacity.

The other variable used in this assessment is carbon emissions ($CO_2$ eq), defined as a metric measure used to compare emissions from greenhouse gases on the basis of their global-warming potential. We have used the variables given above to ascertain emissions caused by Urea 46 and algal-based fertiliser.

For calculating GHG emissions during use of these fertilisers, we take the kg $CO_2$ equivalent of 1 kg each of N2O (nitrous oxide) and K2O (potassium oxide) – this amounts to 298 and 0.7 kg $CO_2$ eq, respectively.

1. For 1 kg of Urea 46, carbon emissions in the proportion of nitrogen are calculated by finding 46 per cent of 298 kg $CO_2$ eq for 1 kg of nitrogen.

*Total Carbon Emission from 1 kg Fertilizer= proportion of N2O * CO2eq of per unit N2O + proportion of K20 * CO2eq of per unit K2O*

**proportion of phospohorus in both the fertilizers (traditional and alternative) is 0%*

2. Similarly, for 1 kg of brown seaweed, carbon emissions in the proportion of nitrogen and potassium are calculated by finding 1 per cent of 298 and 4 per cent of 0.7, respectively.

This gives us the following tables:

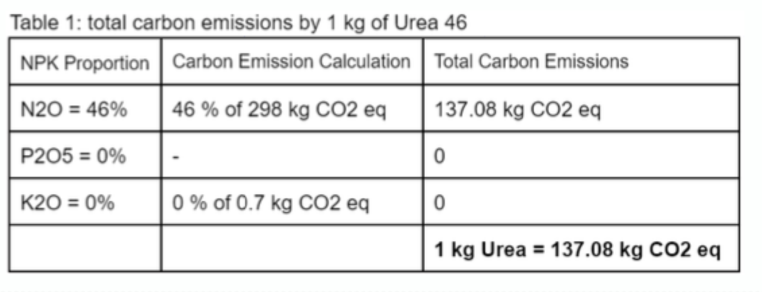

Table 1: total carbon emissions by 1 kg of Urea 46

| NPK Proportion | Carbon Emission Calculation | Total Carbon Emissions |
|---|---|---|
| N2O = 46% | 46 % of 298 kg CO2 eq | 137.08 kg CO2 eq |
| P2O5 = 0% | - | 0 |
| K2O = 0% | 0 % of 0.7 kg CO2 eq | 0 |
| | | **1 kg Urea = 137.08 kg CO2 eq** |

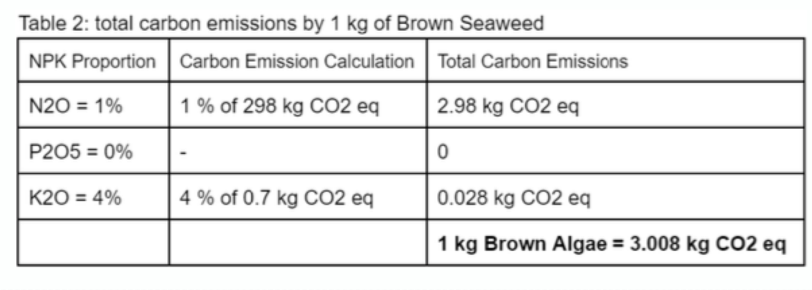

Table 2: total carbon emissions by 1 kg of Brown Seaweed

| NPK Proportion | Carbon Emission Calculation | Total Carbon Emissions |
|---|---|---|
| N2O = 1% | 1 % of 298 kg CO2 eq | 2.98 kg CO2 eq |
| P2O5 = 0% | - | 0 |
| K2O = 4% | 4 % of 0.7 kg CO2 eq | 0.028 kg CO2 eq |
| | | **1 kg Brown Algae = 3.008 kg CO2 eq** |

The tables show that when in use as fertilisers, 1 kg of urea (NPK composition) emits 137 kg $CO_2$ eq, while 1 kg of brown seaweed emits 3 kg $CO_2$ eq. Algal-based fertiliser prepared from brown seaweed is an organic matter with an ability to perform functions such as soil conditioning and root growth, and has a per kg emission which is over 45 times less than that of urea.

## CONCLUSION

Through this study, we have analysed the untapped potential of two ubiquitous organisms—algae and fungi (specifically, mushrooms)—as green catalysts towards climate change mitigation and a sustainable tomorrow. It can be deduced that brown seaweed fertiliser, when compared with Urea 46, can downscale agricultural sector emissions. However, there are certain limitations. These range from consumer acceptance to research and administrative hurdles, all of which pose a crucial question vis-a-vis the regulatory viability and mass adoption of these sustainable alternatives. The algae industry is upcoming, but water scarcity and the high cost of production are some of the main constraints for expanding its scale in India. Similarly, mushroom horticulture is a profitable activity for developing countries, but setting up a smooth-running processing unit comes with its own set of specialised infrastructure and training.

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