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Use of algae and digital integration in improving agricultural value chain

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Abstract

Escalating population pressures and its effect on food security has led to use of costly fertilizer intensive agriculture is trying to cope with the increasing demand. This in turn is causing drastic deterioration of the ecosystems and climate. Therefore, it is time to consider alternate ways to overcome the wide- spread use of chemical fertilizers and improve productivity to shorten the gap between production and demand. This review paper provides in-depth perspective of the challenges in agricultural value chain, probable solutions, both biological and digital, alternate farming practices fortified with algae to increase productivity and uses of microalgae and their benefits to both soil health, increase in productivity, as fertilizer, in pest control and as growth regulator for crops.

Keywords: Value Chain; Biofertilizers; Algae; Productivity; Digitalization

1 Introduction

Although there are several problems in the improvement and scaling up of agriculture, it is still the backbone of the economy. According to statistics, approximately 65% of the world population are directly dependent on agriculture as their livelihood. Agriculture also accounts for around one fourth of the annual gross domestic product (GDP).

1.1 Agriculture value chain

The idea of agricultural value chain has been present from the start of the millennium, although no universally accepted definition for the term is present. What this generally means is the process where the whole range of agricultural goods and services needed for an agricultural product move from farm to its final receiver. The World Bank's definition of the term "value chain' describes the full range of value adding activities required to bring a product or service through the different phases of production, including procurement of raw materials and other inputs".

Modern agricultural practices are prompting an urgent question about the future sustainability issues associated with the value chain. The extreme weather volatility, growing food demand, and wide gap in the agriculture productivity between India and its peers in the region, and the need to manage food prices and import pulses to meet demand have all highlighted that developing countries needs to rethink its approach (1).

In a significant mindset shift, the governments of different countries are focusing is moving from increasing farm output to improving farmer incomes. It has set an aspiration to double farmers' incomes by 2022 through the following six key agendas: Improvement in crop productivity; Improvement in livestock productivity; Resource use efficiency or saving in cost of production; Increase in cropping intensity; Diversification towards high value crops; Improvement in real prices received by farmers (2). This will enhance productivity and have multiplied effects on the larger ecosystem.

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2 Challenges in the value chain

2.1 Resource scarcity

In today's farming practices resources like land, water, and soil health are badly lacking. The uncontrolled use of chemical fertilizers, pesticides and insecticides have caused tremendous deterioration in the ecosystems and exerts a challenge to human health and flora fauna where it reaches the ground waters or as runoffs from agricultural fields into surrounding water bodies. More than half the countries faces water shortage with withdrawals at 40 to 80 percent of available supply. The labor supply is also lacking, and the labor market is making a natural structural transition from farm to non-farm jobs. Agricultural jobs declined by 25 million between 2011 and 2015, while non-farm jobs rose by 33 million (1). The rising wages for farm labor make it imperative to improve farm productivity through mechanization and other measures.

2.2 Improving yield

Crop yields in developing countries are still significantly lower than averages in other developed countries. For example, the average rice yield in India is 3.6 ton/hectare compared to 6.7 ton/hectare in China, similarly Potato yield per hectare is 50% lower than that of US. Large quantities of crops are destroyed by pests reducing productivity and the fluctuations in environmental conditions like floods, and drought cannot be overlooked. This situation could improve by at least 40 to 70 percent with suitable interventions such as alternate farming methods requiring less water, biofertilization, improving soil health and pest control.

3 Some the key challenges in the downstream of agriculture value chain are:

3.1 Multiple intermediaries and lack of transparency and traceability:

In developing countries which are major contributors of food supplies mandis and FPOs that cater to the process need digitization to bring more transparency into transactions. Farmers need more sales options and ways. Data and market connections can enrich each stakeholder. India ranks among the top 5 countries in food processing. By 2024, the sector will employ 9 million and the organized sector has only 60% of the share (2). Streamlining and traceability can improve farmer income and exports.

3.2 Losses in the food chain

Around 60 percent of food loss and waste happens between the field and the end-consumer (1). There are many challenges like cold chain penetration and adoption, high cost of stable power supply, low-capacity utilization, and limited financing options. These challenges offer a significant opportunity to improve farmer incomes by addressing the storage and handling of food as well as creating market linkages to customers.

4 Solutions of improvement of agricultural value chain

4.1 Use of Algal Biofertilizers to improve farming practice and crop productivity.

Microalgae are found in almost all ecological niches on earth. The first known algae on earth are the cyanobacteria or blue green algae that appeared some 2.4-3.6 billion years ago, and todays oxygenated environment is largely due to the photosynthetic activity of these microbes. Microalgae are endowed with great adaptability to tolerate all sorts of fluctuations in environmental parameters and can tolerate a variety of conditions including a wide range of pH levels, temperatures, salinity, and light intensities. Because of their great versatility in nature, simple cellular structure, high photosynthetic efficiency, ability for heterotrophic growth, ability to grow on domestic and industrial wastewater, and production of biomolecules like plant growth promoting substances, microalgal use is becoming popular in agriculture as an alternate biofertilizer (3). In agro-ecosystems, microalgae have been primarily used to improve paddy cultivation, but in recent times also in grains such as wheat, corn, sunflowers, peas, and chickpeas; cotton; sugar beets; sugarcane; produce crops such as lettuces, cabbage, peppers, tomatoes, and radish; ornamental flowers and trees; and other crops. Studies have shown increases in plant root/shoot length, dry weight, yield, germination rate, cellular respiration, floral production, photosynthesis, chlorophyll production, and/or resilience to pests, diseases, and climate stressors (4,5). Overall, rice yields have increased by up to 50% with microalgal addition (4,6,7). This yield increase has occurred primarily due to cyanobacteria performing free-living and symbiotic atmospheric nitrogen gas fixation. The fixed nitrogen, in the form of ammonia, may be converted into polypeptides, free amino acids, vitamins, and auxin-like substances which add fertility either by secretion or through microbial degradation after cell death. Studies have shown that this nitrogen fixation may account for up to 100 kg N ha^{-1} yr^{-1} (8).

5 Why algae?

Most of the countries in Asia have agricultural productivity less than other developed countries due to lack of proper and appropriate farming resources, and practices.

Microalgae play a very important role in improving the fertility of soils due to their nitrogen fixing properties, phosphate solubilizing action, plant growth substance release into the soil, and natural biopesticide action. These advantages of algalization increase sustainability and increase resilience. (6). Detailed below are the different aspects of agriculture that are brought about by algal addition.

5.1 Health of soil

Some of the main reasons for poor agricultural productivity are compressed soils, low fertility, saline, sodic, non-aerated low water retention and easily eroded soils. (6). Microalgae play a very important and positive role in reclamation of these soils by making physio-chemical changes in soil properties like soil stability such as soil stabilization leading to increased pore space and aeration.

5.2 Organic matter

With a high photosynthetic capacity of 10-50 times faster than terrestrial plants (6) microalgae are an important source of organic matter to soil. In addition, some biochemicals released by these microbes cause significant sequestration of soil organic matter thus enriching the soil further.

5.3 Climate resilience and mitigation

Climatic properties such as resilience and mitigation are significantly impacted by increases in organic matter by microalgae. Algae are generally known to be potential bioindicators but in some cases they prove to be strong mitigators well depicted in situations of waste treatment, water pollution and increase in water temperature.

5.4 Plant fertility and soil

Microalgae have the same cellular constituents as higher plants and therefore contribute to the overall nutrient requirements needed by plants for their growth and development. Microalgae are known to release cellular nutrients into the medium that are similar to plant growth hormones causing an increase in root/shoot, number of leaves and yield of plants (**6**). In poor usar soils with high/low pH, salinity/high $CaCO_3$ content, so macro and micronutrients needed to support plant growth may be lacking in the soil. Addition of microalgae to such soils not only mitigates the unavailability's and drawbacks of the soil but improves the quality of the soils by the release of mucilage to bind soil particles together and N& P and growth promoting compounds, enzymes and organic acids to break down complex organic molecules to easily available simple products and chelators to remove unwanted molecules in the soil (9).

5.5 Acidic and saline soil conditions

Saline and acidic soils contribute to over one billion hectares of land in nature (10). Both these conditions have a negative impact on soils and are responsible for damaging plant development at the seedling stage mainly and in later developmental processes. Microalgae are known to be tolerant to high levels of salinity/acidity and when added to soils act as a buffer and lower the damaging effect on plants.

5.6 Management of water

Most microalgae have a mucilaginous sheath around them, and some are embedded in slime. These 2 extracellular products connect soil particles to form aggregates which in turn improves its water holding capacity due to their hygroscopic nature which has a positive effect on plant development. Soil aggregates then become less likely to be affected by wind and water erosion. Immobilized algae which form biocrust have been found to absorb 10 times more water than ones without algae (11,12,13,8). However, hydrophobicity in some of the biochemicals released by algae can contribute to scaling (14).

5.7 Management of pests

The exopolysaccharides from algae, hydrophobic biomolecules and hormones that are typically released into the surroundings have properties like antibacterial, anti-fungal, antiviral, anti-protozoan, nematicides etc.

The production of these compounds is typically dependent on culture conditions such as medium, pH, light intensity, temperature used during growth. The release of these compounds varies within different microalgal species and those with more hydrophobic molecules such as polyketides, amides, alkaloids, fatty acids, indoles, and lipopeptides being most effective (5). The production of anti-fungal compounds also varies in different species of algae but a significant number of these have been reported against soil-borne or foliar fungal pathogens (14).

5.8 Promotion of plant growth

A wide range of microalgae from diverse habitats have been known to release biomolecules that are like plant growth promoters that cause improvement in photosynthesis, leaf chlorophyll content, cellular respiration, nitrogen assimilation, anti-oxidant synthesis and uptake of ions (5,15,16). The plant growth promoters are like the auxins gibberellins cytokines amino acids vitamins betaines, polysaccharides, and polyamines (5). Brassinosteroids, protein hydrolysates and polyamines have also been reported from microalgae(17). Presence of these bio actives increases plant growth and development, helps overcome abiotic stress injuries, influences root and shoot growth, leaf senescence, breaking bud dormancy, seed germination, photosynthesis, respiration, nucleic acid synthesis and nutrient uptake. The presence of amino acids like tryptophan and arginine affect the development and yield of crops being the metabolic precursor of secondary metabolites, polyamine auxin and salicylic acid synthesis (3).

5.9 Interactions with other organisms

Microalgae in combination with other nitrogen fixing/phosphate solubilizing bacteria or other microbes that release plant growth molecules produce cumulative benefits for plant growth and development. Examples are mycorrhizae and Rhizobium with microalgae activated high levels of rhizosphere activity, nutrient uptake and cycling and aggregation of soil. (18). Phosphate-solubilizing bacteria, *Bacillus megaterium, Bacillus circulans, Bacillus subtilis, Bacillus mucilaginous and Pseudomonas striata,* act in consortia with microalgae to mobilize phosphate (4).

6 Alternate farming method for efficient crop production without soil

6.1 Algal aquaponics

Aquaponics, a branch of hydroponic farming is a sustainable farming system that utilizes water without any chemicals and soil to produce sources of organic nutrition for crop cultivation. This can be further enriched by adding algal cultures to the water which adds nutrients and natural growth hormones produced by algae to the water. By this method both fish and green vegetables grow together.

Aquaponics provides many benefits compared to traditional farming and hydroponics. Some of the most important ones:

- Production of fresh and organic fish and vegetables.
- Tastier vegetables and faster growth of plants.
- Aquaponic systems are easy to build and cheaper to run.
- Less space requirement than traditional farming.
- 90% less water requirement than classical farming.
- Aquaponic systems are easily expandable for commercial purposes.
- It is a sustainable and eco-friendly way of food production.
- Aquaponics is an efficient way to produce out of season products.
- It is employing the whole family in sustainable farming.
- No problems of weeding from time to time.
- No chemical nutrients added therefore environmentally safe.

This emerges as one of the best ways of increasing crop productivity and this can be further enhanced by using the microalgal cells in the water from which the fish feed and plants benefit.

6.2 Algal aeroponics

Aeroponics is a term used to describe a method of growing plants without soil and using extraordinarily little water and is a variation of hydroponics and aquaponics Aeroponics Plants grown in an aeroponic system are suspended in air, with their exposed roots receiving essential nourishments from a nutrient-laden mist/ microalgal culture spray. Unbelievably valuable in areas where there is water scarcity.

6.3 Vertical cropping systems for sustainable agriculture with algal amendment

Vertical agriculture addresses food security of the present day with enormous potential of growth and utilization. Vertical farms do not use soil and are therefore not bound to one geographical location. Instead, plants can grow hydroponically, aeroponically, or even aquaponically in a vertical fashion. This means that plants' roots are suspended in nutrient-rich water. The use of algae to provide nutrients is an approach that needs to be tried out to make this system even more efficient and ecofriendly. Beyond providing fresh local produce, vertical agriculture could help increase food production and expand agricultural operations as the world's population is projected to exceed 9 billion by 2050. And by that same year, two out of every three people are expected to live in urban areas. Producing fresh greens and vegetables close to these growing urban populations could help meet growing global food demands in an environmentally responsible and sustainable way by reducing distribution chains to offer lower emissions, providing higher-nutrient produce, and drastically reducing water usage and runoff. Some of the greatest advantages of vertical farming are:

- Reliable year-round crop production.
- Unaffected by adverse weather conditions.
- Better use of space.
- Minimize water usage.
- Environmentally friendly.
- No chemicals or pesticides.
- Reduce transport costs.
- Highly energy efficient.
- Safe for staff.
- Low labor costs.

7 Digital solutions for improvement of the agricultural value chain

There are many digital technologies in place, but they must be scaled up to meet the increasing demand in agricultural production and supply. A great example of this is the most efficient soil health management systems where you get every detail of the soil characteristics with the click of the button. The agricultural sector is now looking forward to using many digital technologies that are at the pre-production stage, in production and in the postproduction stage.

Some of the key opportunities that can create value and boost farmer income are:

7.1 Digital and analytics

The use of digital methods and analytics will play a critical role in building farms of the future. Potential disruptions that could unlock value through the food chain are:

- Digital farming includes integrating field data, weather patterns to drive agronomic advice to farmers, and yield forecasting.
- Use of electronic applications in farm money lending, disbursal of loans, insurance payouts linked to weather, field data, direct benefits transfer in agriculture.
- Creation of a central platform that integrates farmers and wholesale markets, to provide timely information for price realization.
- IoT-based advanced analytics in manufacturing plants to improve availability, throughput, and save costs.

7.2 Financing and crop insurance

- Provide innovative equipment: financing models to farmers through partnerships with manufacturers, weather forecast agencies, and digital partners.
- Offer easy financing for FPOs for community infrastructure for storage and transportation.
- Create digital ecosystems for financing and crop insurance.

7.3 Establishing market linkages between farmers and buyers

This will establish transparency in pricing and better value, especially for perishable products. It could also help to increase farmer incomes by at least 8 to 10 percent. In addition, it will enable the downstream players to source more effectively by eliminating intermediaries. Farmer-producer organizations (FPOs) are already aggregating supply and supporting farmers towards this goal.

7.4 Investing in cold storage

Use and access of cold storage is a big challenge, but this segment is expected to significantly grow because of rising food demand, supply deficits, and improved market economics. The cold chain market is expected to double in size to reach $7 billion to $9 billion in future years. Cold chain players could invest in alternate energy technologies like solar-powered systems, or biofuels, they can explore chemical treatments to extend the shelf-life of produce, set up pack houses, and reefer transport. They could also optimize the use of existing facilities by opening them up for multiple crops instead of a single crop or product.

8 The digital ecosystem in agriculture

The aggrotech stakeholder ecosystem is rapidly growing and maturing. There are ~450 aggrotech start-ups in developing countries and they are growing at 25% year on year. Every 9th aggrotech start-up in the world is from India. The is a huge opportunity to target all the sections of the agriculture value chain.

8.1 Better access to inputs

Providing better access to agricultural inputs at the doorsteps of farmers, to understand the best input to increase yield and productivity.

8.2 Financing

Big drawback for farmers to work at their full potential but aggrotech-based start-ups helps such community of farmers to get loans quickly.

8.3 Digital Agriculture

Digital/ precision agriculture-based business offers innovative technology solutions to increase farm productivity and farming process efficiency.

8.4 Improving the Supply chain

Market linkage provides a digital platform which connects farm output with consumers.

8.5 Farming as a service

Offers affordable technology solutions for farmers by providing easy access to expensive equipment, converting the fixed costs to variable costs.

9 Conclusion

This paper discusses the importance and use of algae in agriculture as an environmentally friendly method of increasing agricultural yield which is the need of the day to balance population explosion all over the world. In addition, rapid increase in pollution caused by extensive use of chemical fertilizers is a great threat for the world which can be controlled to a great extent by replacing chemical fertilizers with algal fertilizers that are non-toxic, easy to use and with greater benefits to the crops. Coupled to this, modern techniques of digitalization will enhance the success of agricultural yield by providing the farmers with a platform where they can find solutions to their problems while farming thus improving the value chain of agriculture.

Compliance with ethical standards

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Disclosure of Conflict of interest

There is no conflict of interest.

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