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Review Article

Fertilizers in Aquaculture: An Overview of its Types, Market Trends, and Future

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ABSTRACT

Fertilization is an important management activity which is followed in all aquaculture production systems, from extensive, semi-intensive to intensive aquaculture farms. Fertilization helps in sustaining the productivity of the pond by acting as a natural food web. Generally, fertilizers were classified as natural and synthetic based on their origin. Natural fertilizers have been used for ages and now their speed of primary production is being challenged by the advent of synthetic fertilizers. The results provided by the inorganic fertilizers led to various kinds of synthetic fertilizers in the market. Due to lack of knowledge about fertilizers, the farmers are pumping more money towards fertilization which is becoming an economic burden to them. At once, fertilizers were considered as friends of farmers and now they are draining the farmers profit during fish production. To reduce the burden further, fertilizers like biofertilizers and vermicompost are being popularized among the farmers. In overnight it cannot be achieved, as there is deep lacuna on the use of biofertilizers or vermicompost in aquaculture, which signifies the requirement of more studies on these fertilizers. The present article has critically reviewed the fertilizers, types, current marketing trends and their effect on pond ecosystem productivity.

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INTRODUCTION

Pond fertilization is an important protocol to be followed in all aquaculture systems, from extensive, semi-intensive to intensive aquaculture farms. Fertilizers contribute to establishing and maintaining the pond environment and allow microalgae to utilize the minerals and nutrition released by the fertilizers. Fertilizer is a synthetic or natural compound, which enhances the productivity of soil, water, or plants. Further, it boosts the natural fertility of soil and replaces the lost chemicals or minerals from previous crops. Unlike terrestrial animals, fish can take minerals from food or directly from water (Terech-Majewska *et al*., 2016). Organic fertilizers, usually animal manures or plant waste, are excellent fertilizers for fish ponds such as droppings of chicken, ducks, pig, cattle, etc. However, derivates from all living organism certain items like rice hull, sawdust cannot be called organic fertilizers, as they take enormous time to decay. Inorganic fertilizers (minerals or chemicals) are those in which the nutrients are obtained through extraction or industrial processes, while organic fertilizers use natural materials of a plant or animal origin (Roba, 2018). Inorganic fertilizers have been in various scientific sectors and been an epicenter for the last fifty years. As they depend heavily on synthetic or inorganic compounds, they can also be called mineral fertilizers (Scherer *et al*., 2009). Some properties of the soil are reduced or replenished while administering the inorganic fertilizers, whereas the organic manures maintain the properties of soil.

Inorganic fertilizers are generally rich in nitrate and phosphate and these kinds of fertilizers are commonly used in aquaculture ponds. In freshwater ponds the nutrient in demand is phosphorous, use of nitrate and phosphate fertilizers create a dual benefit to fish pond. Phosphorous, despite being an important component, is relatively insoluble in water. The most rapid way a fertilizer can be used for aquaculture is in a liquid form as it readily releases the necessary minerals and components. Algal growth in a freshwater pond can be increased exponentially using phosphoric acid or other forms of phosphorus. Fertilizers from animal origin are relatively better than those of plant origin (Green, 2015).

Pond fertilization, an important step in a semi-intensive

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or intensive pond management protocol, is applied to the pond in a limited and calculated method. Fertilization is important like aeration and water quality management (Hickling, 1971; Bardach *et al*., 1972). Primary production which kicks starts the entire productivity of ponds was 4 to 5 times higher in fertilized ponds than unfertilized ones (Hepher and Pruginin, 1981). Natural foods cannot be the only main provider of food in a semi-intensive or intensive pond but animals like shrimps, carp and tilapia use the primary producers as their food to a considerable level. Compound or formulated feeds are usually provided to the culture animals when the primary production after application of fertilizers, have reached a stand still as they are being used by the growing larval stage animals or when biomass is low (Hepher, 1962). Therefore, fertilization is necessary to support the primary production and there by the sequential food web (Green, 2015). However, fertilization is needed when fingerlings or larvae rely on primary producers, but as the feeding rate increases the fertilization can be gradually stopped or reduced as enough nutrients from feed is released for primary production.

Inorganic fertilization was first used in aquaculture especially in freshwater sector during 1990s (Culver, 1991; Culver *et al*., 1994) and has become a reliable method to rear live foods in the aquaculture (Tew *et al*., 2006). The copepods cultured with inorganic fertilizers have shown better growth results when compared to commercial zooplankton products and are also pathogen free and cheaper cost of production (Hong and Tew, 2022). The study conducted by Jian *et al*. (2011) has revealed that use of supplement feed in rice cum fish culture ponds applied with low quantities of fertilizers have shown greater growth and even reduction in fertilizers subsequently has no effect on the overall production of rice cum fish culture unit. The objective of the study is to review and understand the various fertilizers available in the market and its usage in the aquaculture sector, the benefits of inorganic and organic fertilizers over each other, different types of the fertilizers readily available for the consumers and their market trends and along with the rising use of bio-fertilizers. Primary aim is to understand the several fertilizer types being used for centuries and the potential new fertilizers which can make an impact in the market for years to come. This is a bibliographical review of the selected topic with sources obtained from Google scholar, research gate and other aquaculture and agriculture related websites. The papers are selected based on the reliability and similarity to the topic at hand.

WHAT ARE FERTILIZERS?

Fertilizers are either natural or synthetic substances used to increase phytoplankton or zooplankton production. They increase the nutritional content of the ponds and thus act as a primary source for phytoplankton production in large numbers and zooplankton load which feeds on the phytoplankton.

CURRENT TRENDS IN FERTILIZER USAGE IN AQUACULTURE

The global fertilizer usage in aquaculture market had been in a dwindle since COVID has affected the entire world, it was experiencing lesser than a staggering demand overall declining to a 24.7% of drop in 2020 compared to 2019, which although is set to rejuvenate in the coming years, the aquaculture is expected to rise to a US$ 27.44 million in 2028 a rise compared to US$ 10.72 million in 2021. With recent Ukraine-Russia war has slammed the global economy post-pandemic and the regular supply of necessities even like crude oil was very much affected. The unstable supply chain issues, shattering trades, and thereby the prices as both nations are important exporters of agri products especially fertilizer (IFA, 2023).

The observations made by Naylor *et al*. (2021), pointed out that the Global aquaculture is on its own race as it has tripled in the volume since 1997 to 2017 from 34 Mt (metric tons) to 112 Mt (metric tons) and Asia still dominating the aquaculture accounting for 92% of the overall production. Fertilization in combination with supplementary feeds is still the viable way to keep production in pace with the global demand.

During the times of war in Ukraine, with Russian invasion over the land, fertilizer prices which were already sky high in history, the prices were increasing from 2020 because of various reasons. The demand for fertilizers did reduce in the COVID era, and it rebounded after 2020-2021 as export restrictions imposed were lifted and the crop prices increased. The price increase for natural gas and coal, the key feedstocks and energy sources for production of fertilizer, impacted production and added pressure on prices (Hebebrand and Glauber, 2023).

The effort to revitalize the fertilizer industry has been taken as an imitative from countries across the globe, especially by Asian countries. The Chinese government had imposed a steady price and stable supply of fertilizers and priority to agriculture related demands in 2020 (Ministry of Finance the People's Republic of China, 2021). The government of India has allotted a staggering 70,000 crores (US$10.5 billion) along with subsidies and Government of India GOI paying the individuals the price difference in cost of production going above the MRP (maximum retail price) (Fortune Business Insight, 2023) These actions and initiatives are expected to increase the production of fertilizers and encourage new manufacturers'

entry into the industry. By March 2023, the Food and Agriculture Organization has delivered 36,000 tons of Triple Super Phosphate to the Ministry of Agriculture of Sri Lanka for distribution to farmers (USAID,2023).

The fertilizer industry in the aquaculture sector is preparing itself to hit a major revenue of 27.4 million in US dollars by 2028 and thereby the overall aquaculture production (The Insight Partners, 2022). The major companies like URALCHEM (Moscow, Russia), Sinofert holdings limited (China), Luxi Chemical (China), Yara International (Norway), Saudi Basic Industries (Saudi Arabia) and others (Fortune Business Insight, 2023).

Factors affecting the fertilizer industry

Though the fertilizer demands are skyrocketing every year, the fertilizer industry is facing multiple challenges and hurdles thereby affecting the output and consistency in output. The following are the factors which have caused a setback. (i) The unstable price of fertilizers every year, which are due to the logistical constraints faced seasonally and high fuel price which in-turn affects the local transportation to shift fertilizers from one point to another. (ii) The lesser or below pars average quality of fertilizers in the market tend to be a problem of its own as the end production result obtained is not desirable (Khor and Zeller, 2015). (iii) The domestic production, imports of fertilizers and extended subsidies have affected the supply of fertilizers in India (Jadhav and Ramappa, 2021).

Status of fertilizer in Indian aquaculture

The development of technologies in carp farm and advent of precise induced breeding technique in the last decades made the overall freshwater aquaculture, Indian major carps to be exact, the country is set to face increased fertilizer use in freshwater aquaculture sector and brackish water aquaculture focusing on the giant tiger prawn as the potential candidate species. The growth of White leg shrimp *(Penaeus vannamei*) in the Indian aquaculture industry, especially in coastal sectors, is encouraging the farmers to fertilize the ponds for better growth output.

Indian market scenario- fertilizers

Indian market for fertilizer is valued at INR 990.4 billion and is expected to reach INR 1459.95 by the year 2029 growing at 5.7% as Compounded Annual Rate Formula (CAGR) (IMARC, 2023). The production output of fertilizers in the year 2019-21 was 462.15 LMT (lakh metric tons). With 32 large scale urea plants and 19 DAP units the nation is expected to reduce its dependence on Chinese market for fertilizers sooner.

The new fertilizer policy in 2003 allowed manufactures of urea to sell 25% of the produce internally and 50% outside the range of distribution channel (Mala, 2013). To meet the demands of ever-growing population and food needs in the country, the government had set up various production units for fertilizers and urea units (Pathak *et al*., 2014). Introduction of neem coated Urea in India by Government during 2015, had significantly contributed for more yields and reduce production cost because of lower urea usage (Ramappa *et al*., 2022).

Imports have risen by 78% during the last five years, especially in fertilizer requirement. The government in the past few years has taken quite a few initiatives to reduce the urea demand in India. The government of India has taken initiatives with regards to fertilizer usage and its flow in the Indian market like Neem coated urea distribution in market since 2015, limiting urea bags as 45 kgs from 50 kgs to reduce wastage (Singh *et al*., 2022) and cut demand and launching liquid "Nano Urea" and Liquid nano urea plant at Kalol, Gujarat developed by Nano Biotechnology Research Centre (NBRC) (Kiran and Samal, 2021).

GENERAL CATEGORIES OF FERTILIZERS BASED ON MARKET

The fertilizer available in the market is generally categorized by their chemical source, target water body during its application, market geography, etc. Urea, triple super phosphate, potassium sulphate and other forms of chemical fertilizers are classified based on their chemical source or chemical makeup. The fertilizers are further categorized upon the type of aquaculture it is being applied into like freshwater aquaculture, seawater aquaculture and brackish water aquaculture. Based on the geography of fertilizer market, it is divided into North America, Asia pacific, South America, Middle east and Europe.

ORGANIC AND INORGANIC FERTILIZER

The major two important types of fertilizer which are categorized based on the source of its origin are either organic or inorganic fertilizers (Griengo *et al*., 2020). Organic fertilizers are those which are obtained from organic sources i.e., natural or without artificial means (El-Sayed, 2020). Inorganics are those which are synthesized in standard or formulated by artificial means. Most commercially available inorganic fertilizers are urea, triple super phosphate and potassium sulphate and important types of inorganic fertilizers are phosphate, nitrogen and potassium (Eddine *et al*., 2022).

INORGANIC FERTILIZERS

Inorganic fertilizers or synthetic fertilizers are ready

to use nutritional products for plants, soil or water system, they are highly soluble products in general compared to organics where the decomposition is needed to break the organic fertilizers. Synthetic fertilizers are available in a single or multiple nutrient formats. With the advent of a chemically uniform and granulated fertilizers which are high in nutrient content like urea, ammonium nitrate and ammonium sulphate, there was a drastic reduction in labor as the time taken for applying organic fertilizers (Cabrera, 2003).

The inorganic fertilizer market is primarily urea centric; it is most widely used in aquaculture activities due to its ability to boost aquatic phytoplankton growth in a short span of time. By 2012, China was the largest consumer of urea by 70% followed by India and USA, Australia exported AU$ 321.5 million primarily to Pakistan, India and New Zealand (Milani *et al*., 2022). Urea consumption rose by over a third since 2009-10 in India, SSP and AS which dominated in 1960s have taken back seat for Urea (Mala, 2013) and thereby in evident increase in price at 16.5% from 4830 to 5628 per ton.

Triple superphosphate (TSP) had a global production of 4.98 million metric tons in 2021, this was the lowest figure in the past decade. TSP is a major source of phosphorous for plant growth (Statista Research Department, 2023). Triple super Phosphate is generally manufactured by countries like China, Morocco, Bulgaria, Egypt and Tunisia and primarily consumed by Brazil, Bangladesh and USA. With the global increase in diammonium phosphate price, the price of triple super phosphate is also likely to go higher. Urea and triple super phosphate are the most used commercial fertilizers in aquaculture and potassium fertilizers are pretty much used less, though they might aid in some ponds for phytoplankton growth (Boyd, 2016).

Types of inorganic fertilizers nutritional makeup

Based on the presence of single or multiple nutritional loads, the fertilizers are broadly classified as (a) straight fertilizers-provides one nutrient to soil or water, (b) complex fertilizers- two or more essential nutrients and (c) mixed fertilizers - two or more straight fertilizers mixture.

Besides that, the other two major types of inorganic fertilizer forms which are common in use are (a) solid fertilizer (b) liquid fertilizer.

Solid fertilizer

Usually broadcasted in ponds with depth not more than 2m most preferably which are 1 m depth. Boyd (1981) stated that phosphorus is not soluble at depths more than 2 m whereas nitrogen and potassium are soluble at a quick pace. Boyd *et al*. (1981) further stated that liquid phosphorous fertilizers were more effective in increasing phytoplankton production compared to broadcasting of triple superphosphate and diammonium phosphate.

Liquid fertilizers

Relatively ease of handling and its ability to be mixed with herbicides, they are widely accepted. Usually much denser than water and commonly used fertilizer in liquid form are phosphorous and ammonium polyphosphate The solid fertilizer and liquid fertilizer are in many versions, like solid fertilizers are classified based on their physical form and since liquid fertilizers are the same physically, they are differentiated by presence of phosphorous or ammonium (Table I).

Table I. Solid and liquid fertilizers: common types.

Type/ Physical form	Fertilizers
Solid fertilizers	
Powder	Single super phosphate
Crystals	Ammonium sulphate
Prills	Urea, Diammonium phosphate
Granules	Holland granules
Super granules	Urea super granules
Briquettes	Urea briquettes
Liquid fertilizers	
Phosphorous	Super phosphoric acid
Ammonium polyphosphate	Anhydrous liquid ammonia, aqueous ammonia, nitrogenous fertilizers, ammoniates

Factors determining usage of chemical fertilizers

Water source

Brackish water and seawater must be incorporated only with nitrogen source fertilizers whereas in freshwater sources only phosphorus fertilizer should be used. According to the experts (Wen *et al*., 2016) suggest the addition of both source of fertilizers (nitrogen and phosphorous) in maize grain resulted in greater results and stimulated growth in roots.

Water flow and solubility of fertilizers

It is also a determining factor in choosing the fertilizer as excessive water flow washes away nutrients for phytoplankton to develop into bloom. Ponds with water retention less than two weeks is not recommended and ponds with no aeration leads to stratification. Therefore, solubility of fertilizers must be understood while choosing the apt fertilizer for the pond of choice as phosphate fertilizers are insoluble and liquid phosphate fertilizers are used instead of granular fertilizers.

Composition of fertilizers

The contents of the fertilizers which are composed of are usually in the form of nitrogen, phosphorous and potassium. The composition varies and usually urea and triple super phosphate are fertilizers which are rich in nitrogen content with over 45% of nitrogen (Table II).

Table II. Chemical composition of commonly used inorganic fertilizers.

Fertilizer	N_2 (%)	P_2O_5 (%)	KO_2 (%)
Urea	45-46	0	0
Ammonium nitrate	33	0	0
Ammonium sulphate	21	0	0
Calcium nitrate	16	0	0
Sodium nitrate	15	0	0
Diammonium phosphate	18	46	0
Monoammonium phosphate	11	48	0
Super phosphate	16-20	0	0
Triple superphosphate	46-50	0	0
Ammonium polyphosphate	10-13	34-38	0

ORGANIC FERTILIZERS

Organic fertilizers or manures which are made by rotting animal dung, residues of crop and peels of fruit and vegetables, upon decomposition provides wide range of nutrients to plants and water (Verma *et al*., 2021). The common sources of manures applied for aquaculture are cow manure, pig manure, poultry droppings and night soil.

Organic fertilizers include the derivates from plants or animals in form of manure or litter and by products of agriculture (Wohlfarth and Schroeder, 1979). The nutritional profile of organic fertilizers varies according to the source and the degree of its readily degradable materials. Organic manures when available is easy and consistently, the use is recommended with a proper production strategy. Manure products from animals are more nutritious than products from agricultural origin (Green, 2015).

The application of organic manures increases the heterotrophic bacterial load and thereby promotes the secondary producers to feed upon primary producers (Schroeder, 1978; Colman and Edwards, 1987; Qin *et al*., 1995; Barkoh *et al*., 2005). The primary role of organic manures is decomposing and releasing carbon dioxide, ammonia, and other nutrients which promotes growth of phytoplankton and acts as a substrate for microbial growth. Manure based on solid content (Lorimor, 2004) are classified into four categories i.e., liquid manure with less than 4% of solids, slurry manures are ones with 4 to 10% solids, and semi solids with 10 to 20% and solids manures are with over 20% of solids in manure content. During night, heavy plankton blooms deplete the oxygen available and create a heavy biological oxygen demand in the system when huge quantities of organic manures are used to compensate the effect which can be achieved while using Inorganics (Boyd and Lichtkoppler, 1979).

Based on the origin of manure, the main types are (a) Plant based- from plant or plant derivates materials e.g., compost fertilizer and oil cake and (b) Animal based- from animal droppings or litters e.g. poultry droppings, swine excreta.

Other Important organic fertilizers used in aquaculture

Green manure

Are crops that can serve as nutrients for economic crops thereby improving overall soil productivity grown as pure crop or intercrop with main crop. These includes both legumes and non-legumes for example Chinese milk vetch and barley, respectively. Green manure in aquaculture increases the amount of nitrogen in ponds and the productivity and is mainly used for nursery ponds. The most prevalent green manures are Sun hemp, Dhaincha and Guar.

Compost fertilizer

Cow dung mixed with different plants and leaves which is used to control the pH of the pond.

Oil cake fertilizer

Mustard, badam, ground nut and other are extracted for its oil and the remaining residue is made into oil cakes.

Non edible oil cakes

Like Neem, castor oil and mahua oil cake.

Mahua oil cake-the unique organic fertilizer

Bassia latifolia or mahua is being used as pesticide and industrially as foaming and surface-active agents, and to a limited extent also as a feed (Chahar *et al*., 2021). Mahua oil cake acts as both fish poison and then as fertilizer by killing the unwanted fishes in the pond before the fishes to be stocked. Mahua oil cake is a non-conventional feed ingredient acting as growth stimulator in fish and as immune booster (Chahar *et al*., 2021). Later, the cake disintegrates and becomes a fertilizer and increases nutrition load and aids the zooplankton growth. Mahua oil cake with components like saponin (mowrin), eradicates unwanted fishes in the pond preparation phase (Rath *et al*., 2017).

Pros and cons of organic and inorganic fertilizers in use

The fertilizers, both organic and inorganic, have their own advantages and disadvantages against one other. Multiple factors like storage, availability, price, mineral and organic content are taken into consideration for determining the best advantage and disadvantage (Table III).

APPLICATION OF FERTILIZERS IN AQUACULTURE POND

Watson and Cichra (2006) suggested the more resourceful methods of applications like (1) dripping of fertilizer in propeller of boat, which gets mixed and fertilizes the water. (2) using garden hose sprayer in surface of water and (3) dilution of fertilizer in a tub before adding into the water. Farmers, while applying the fertilizers, need to have environmental responsibility**,** otherwise they may end up causing eutrophication by enriching the nutrients in ecosystem (Oldham and Jones, 2020). The nutritional management of the fertilizers must be used by focusing on four R's as suggested by Oldham and Jones (2020), bringing in the importance of responsible fertilizer application for environment safety (Fig. 1). This is carried out to reduce the detrimental effects of using excessive or improper fertilizers in the ecosystem. Proper nutrient management studies are required to analyze all the possible nutritional sources, the soil makeup, crop management and environmental risks, to utilize the correct fertilizer and in the required amount. However, fertilizers are normally applied by farmers in two main methods: (1) Broadcasting and (2) Platform method.

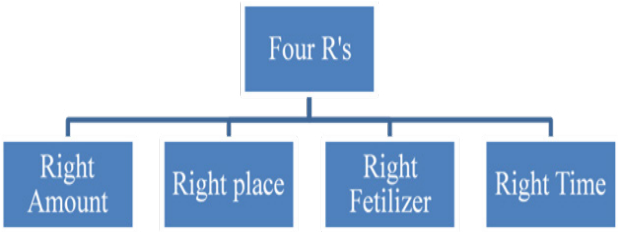

Fig. 1. Four R's as suggested by Oldham and Jones (2020) for environmental safety while applying fertilizers.

Broadcasting

The broadcasting has an impact on environmental effects based on the excessive use of fertilizers. The excessiveness is at 1% and 10% for young farmers and traditional broadcasting methods end up in severe fertilizer loss due to rain, irrigation, or sublimation by sun radiation (Rahman and Zhang, 2018). The dry granules of fertilizers are cast in the water body or soil, in such a manner that it gets distributed almost throughout the water or soil. This is usually best opted for ponds with depth not less than 1 metre (Boyd, 2017). When the water body is infested with aquatic weeds, even then the broadcasting is not suited as the weeds first and foremost absorb the fertilizer's effect leaving nothing or minimal for the water to use.

Table III. Pros and cons of organic and inorganic fertilizers in use.

Factor	Organic fertilizers	Inorganic fertilizers
Storage	Short time storage with more difficulties	Longer time with ease management
Distribution	Larger scale transport is difficult	Easily it can be shifted
Mineral content	Slightly lower	High level
Organic matter	Present	Absent
Effect on soil structure	Improve the structure	No connection with structure
Direct food for fish	Yes sometimes	No
Decomposition process	Possible with oxygen supply	Not possible
Price	Very low	Comparatively high
Cost per nutrient unit	Slightly higher	Bit lower
Availability	Easily procured from nearby farms	Commercial or imported suppliers
Direct pond fertilization	Easily done by erecting shed over the pond	Not feasible
Antibiotic transmission	Possible through animal to fish	No
Off-flavor in fish	Yes	No

Platform

The best method for application of fertilizers is by use of raised platform which is placed at 30 cm depth of water. Fertilizers when placed in these platforms get released into the water body gradually by the water current by dissipation. Phosphate fertilizers are usually applied by this method as they are generally insoluble, and this method avoids the settling of phosphate fertilizers in the pond bottom. The platform method also reduces the usage of fertilizers by 30 to 40% thereby reducing the cost (Swingle, 1965).

Solubility of fertilizers

Most of the fertilizers which are in the granular or pill form are generally easily soluble upon application and fertilizers like phosphorous settle down in pond bottom before it dissolves (Boyd, 2003). It is crucial to dissolve the fertilizers earlier to be utilized in water rather than letting it settle down in soil and to be used only by the bottom soil (Boyd *et al*., 1981). Liquid fertilizers are denser and hence must be used along with water as a mixture to avoid settling in pond bottom (Boyd, 2003).

VERMICOMPOST AND AQUACULTURE

Plankton, like the other artificial feeds, has a protein range between 40 to 60% which is suited for culturing any fishes. Vermicompost manure is a potential choice because of its nutrition profile favorable to plankton growth. According to Kumar *et al*. (2007) the relationship between phytoplankton biomass and zooplankton abundance and diversity with rotifers ranging over 68%. Vermicompost utilization in *Caspian kutum* fry was studied by Habibnia and Bahram (2020) observed improved plankton growth after vermicompost application at rate of 10,000kg/ha/year. Deolalikar and Mitra (2004) recorded increased overall productivity when vermicompost was used as fertilizer in *Labeo rohita* pond at application rate of 10,000/kg/ha/year. Rahman *et al*. (2020) observed reduced supplementary food usage with increased zooplankton growth due to vermicompost in ponds of monosex *Oreochromis niloticus*. The weight gain in *Cyprinus carpio* was observed by Kaur and Ansal (2010) when fish ponds are fertilized in vermicompost for 120 days at 15,000 kg/ha/year and 2% supplementary diet.

BIO FERTILIZERS

Preparations containing certain strains of micro-organisms which aid in plants nutrient uptake in rhizosphere. The important categories of bio-fertilizers are (1) symbiotic nitrogen fixers, (2) non-symbiotic free living nitrogen fixers, (3) algal bio fertilizers, (4) phosphate solubilizing bacteria, (5) mycorrhiaze and (6) organic fertilizers.

The fluoroquinolone resistance was increased when applied to *Vibrio parahaemolyticus* isolated from aquaculture units (Zhao *et al*., 2020) by controlling PMQR (plasmid mediated quinolone resistance) genes in the bio-fertilizers and oqxB was spread horizontally from biofertilizers to *V. parahaemolyticus*. Cyanobacteria fed as bio-fertilizers has been in use as food and as bio-fertilizers (Chittora *et al*., 2020).

Types of bio-fertilizers

Bio fertilizers are widely understood that they are live organisms which aid in enriching the environment in which they are applied. They are generally classified based on the role it takes part in, like nitrogen fixing or plant growth promoting or phosphorous mobilizing, etc. (Table IV).

Table IV. Types of Bio-fertilizers.

Bio fertilizer	Group	Example	Function
Nitrogen fixing (Nosheen *et al*., 2021)	Free living, symbiotic and associative symbiotic	*Clostridium, Azospirillum* sp, *Rhizobium, Anabena , Azollae*	Increase N_2 in soil by fixing atmospheric nitrogen
Phosphorous mobilizing (Nosheen *et al*., 2021)	Mycorrhiza	*Arbuscular, Mycorrhiza, Sclerocystis* sp, *Glomus* spp	Phosphorus transfer from soil to root cortex.
Potassium solubilizing (Etesami *et al*., 2017)	Bacteria	*B.edaphicus, Arthrobacter* spp., *Bacillus, Mucilaginosus*	Produce organic acids degenerate silicates and remove metals to solubilize potassium
Plant growth promoting (Nosheen *et al*., 2021)	Plant growth-promoting rhizobacteria	*Agrobacterium, Pseudomonas fluorescens, Arthobacter, Erwinia, Rhizobium, Pseudomonas* spp.	Produce hormones aid in root growth, nutrient availability and crop yield.
Micronutrient (Kamran *et al*., 2017)	Zinc-solubilizing	*Pseudomonas* spp, *Mycorhiza* and *Bacillus*	Protons, chelated, ligands, acidification and oxidoreductive

Functions of Bio-fertilizer

The bio-fertilizers provide a better-quality nutrient to plants and thereby resulting in a higher crop production, decreased growth of pathogens which are soil borne and improving fertility of soil. The usage of Bio-fertilizer also maintains better microbial diversity in soil (Zainuddin *et al*., 2022).

Market trends of bio fertilizer

Globally, bio-fertilizers are about 2.15 billion USD in 2022 and the numbers are expected to reach a massive USD 6.83 billion by 2032 (Precedence Research, 2022). This is by the ever-growing CAGR at 13.4% from 2023 to 2028. The North American mark*et al*one was valued at potential 1.24 billion USD in 2022.

With the recent trends in chemical fertilizers indicating the huge gap in supply and demand globally and increasing environmental concern, it is important to note the role of bio fertilizers as an ideal choice in coming years. The market for bio fertilizers was about 440 million USD in 2012 and growth at 10% per annum (Owen *et al*., 2015). *Azospirillum* is a promising strain to be used as a product alternative to traditional fertilizers and *Rhizobia* was a popular bio fertilizer constituting 79% of world demand in bio-fertilizer. Around 167 million hectares are being utilized in China and one lakh hectare in India are using bio-fertilizer as part of organic farming (Sekhar *et al*., 2016).

Why choose bio fertilizers?

Bio-fertilizer, micro-organisms which support growth of plants through nutrient supply enhancement to the plant (Kumar *et al*., 2018; Malusa and Vassilev, 2014; Malusá *et al*., 2012). Bio-fertilizers are cheaper (Zainuddin *et al*., 2022) and more ecofriendly than their chemical counterparts which harm the soil or ecosystem upon continuous overuse, bio-fertilizers can deceive the farmers or buyers as the application of bio-fertilizers is always narrower and more specific rather than broad spectrum. Microbe and the ecosystem interaction must be understood and analyzed in advance before the usage of bio-fertilizer as factors like pH, moisture, temperature and other physical parameters affect the effects of the bio-fertilizer in use. With researchers and scientists firmly believe that in coming 30 years with excessive use of chemical type fertilizers will pave a road to a problematic environment because of chemicals with heavy metals (cadmium and chromium) and radionuclides (Savci, 2012).

Limitations in biofertilizer

Despite its proven advantages it carries to environment the bio-fertilizer is not without its list of serious limitations like availability of required strain, soil and environmental conditions, pollutants, skilled technicians and funds, lack of awareness from farmers, etc. (Nosheen *et al*., 2021).

Further research and studies must be placed in full force if bio-fertilizers are meant to be the future of fertilizers in the following decades. Bio-fertilizers are environmentally friendly and with sufficient awareness among users and the scientific community can nosedive into further studies to make biofertilizers as a best fertilizer overall.

BIODIVERSITY OF FERTILIZED POND ECOSYSTEM

As primary production is needed for the food cycle to begin in a pond, the nutrients unavailability is taken care by fertilizers, but water quality usually begins to deteriorate with increase in nutrient input and further affecting the culture animals by stress. Unfertilized ponds are low producers of culture stocks between 50 kg/ha/crop to 500 kg/ha/crop (Boyd, 2018). Production of unfertilized ponds with proper aeration has increased its production after fertilizer usage which indicates the increased nutrient availability from fertilization has greater potential to boost the harvest.

The methods of producing natural stock of live foods for fishes that are to be cultured are by application of manure, fertilizers and liming. Fresh manure is more effective than dried ones.

The rate in which the phytoplankton, rotifers and chironomids are developed varies from fertilizer even the variation is observed in organic manures. The production level found from chicken manure showed a high rotifer production as compared to cattle manure and in control conditions (No manure) there was significant production of live organisms, but it was nowhere near the levels obtained from using the manures (Table V).

Table V. Live food production from different organic manures.

Type of manure	Phytoplankton (1000 per liter)	Rotifers (Specimens per liter)	Chironomids (Specimens/0.1m^2)
Chicken manure	16.4	1000	680
Liquid cattle manure	5.6	867	163
Corral cattle manure	3.1	247	38
No manure (control)	2.5	170	59

Source: Hepher and Pruginin (1981).

OVERVIEW OF RESULTS

Fertilizers are external agents which are used to enrich the soil or water where the essential components would have been replenished or never available. The fertilizers are either organic or inorganic in its origin and organic being the agents from animal or plant source and inorganic are synthetic form. Inorganic fertilizers are usually rich in N:P:K nutrients which are readily available to be used by plants or soil or water, whereas organic fertilizers possess lower nitrogen sources due to its high moisture content. The concentrated organic manures have a higher nutritional profile than bulky manures which are applied in large quantities to cope up with the lack of better nutritional value.

Inorganic fertilizers are either granular or liquid or water soluble, where phosphorus-based fertilizers are usually in liquid form because of their insolubility when applied to water system. Aquaculture systems require a basic micro algal built water system which is in turn used for feeding in larval stages of any fishes and in most important way fixation of oxygen in the water. When organic manures are used, to boost phytoplankton production and heterotrophic bacterial development, which indirectly trigger s the secondary production in the system.

The best method of distributing or applying the fertilizers are broadcasting and platform. The former method is used for granular fertilizers and the raised platform method adopted when fertilizers like insoluble nature are applied.

In storage point of view, the inorganic fertilizers bag the victory as they can be stored for months and even years when storage condition is perfect which cannot be said so for the organics as their excessive moisture load makes it a worse product for storage unless they are dried up and kept away from moisture. Not only in storage, but also other criteria like distribution or application of fertilizers, higher nutritional load and cost per unit nutrition, the inorganic fertilizers are unanimous winners. But the organics are a better option when factors like higher soil improvement, as direct feed to fishes when applied, cost effectiveness and ease of availability and possibility of self-manufacture when enough animals are used which thus can drop more of these organic manures.

Overall, the choice and application of manure or inorganic fertilizers are individual preference and must take into consideration; the points like transparency of ponds, presence of aquatic plants, ponds with chance of eutrophication, these factors are primarily applicable to inorganic fertilizers.

CONCLUSION

Fertilizers are friends of farmers which boost the nutritional content of soil or water and the choice of using organic and inorganic fertilizers is purely on aqua farmers, as both types of fertilizers have their own advantages and disadvantages. Inorganic fertilizers are being opted as the best choice for the aquaculture unit as the production potential and rate of growth per unit application of fertilizer is superior to that of organic fertilizers viz. manure. The important take away point is that organic fertilizers are needed in larger quantities to reach similar effect of inorganic counterpart and it is also labor intensive for preparation and maintaining the animals. Inorganic fertilizers are high cash demanding and ease of procurement or availability is always an issue as the product is purely exported or manufactured by large players in the business and the reliability to abundance is not an option. The most viable option would be to use the combination organic and inorganic in a calculated and required levels to tackle the disadvantages of each fertilizer possess. The alternative to the chemical fertilizers with the efficiency equivalent is organic fertilizers as they have ecofriendly nature. But the studies must be done deeper and the existing awareness towards the organic fertilizers is increasing the bio-fertilizers can be promoted among the future generation and removing the constraints involved in bio-fertilizer industry. Similarly, vermicompost role and results are much more evident than bio-fertilizer as the ability to multiply phytoplankton and zooplankton in the ponds is far better and hence the usage in aquaculture is further recommended.

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The Review Board of Tamil Nadu Dr J Jayalalithaa Fisheries University, Nagapattinam-611 002, Tamil Nadu, India has reviewed and approved the study.

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The authors have declared no conflict of interest.

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