# Phosphorus Waste Production in Fish Farming a Potential for Reuse in Integrated Aquaculture Agriculture

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***Abstract***— *The development of aquaculture in recent years to become the fastest growing food production in the world is accompanied by a secondary effect on the environment, since considerable quantities of waste can be produced and discharged into the environment, as these phosphorus-rich effluents, over time, can contribute to eutrophication phenomena in the aquatic environment. This pollutant is essentially of food origin and is a necessary macro-mineral for fish. However, current scientific and technical means are far from offering the solution to the environmental problems posed by aquaculture development. However, this effluent is a compound that is necessary for the soil as a fertiliser and has great potential for reuse. In this context, aquaculture systems must therefore be well managed to ensure the environmental sustainability of the sector by exploiting these phosphorus-rich discharges in the system of integrating aquaculture with agriculture. The integration of agricultural and aquaculture production systems is seen as a sustainable alternative and as a way to rationalise the use of water and fertilisers. However, for the optimisation of this integrated system to be justifiable in terms of the exploitation of phosphorus from aquaculture effluents, it is necessary to take ownership of the processes involved in the presence of food-borne phosphorus in these effluents and the possibility of its advantageous use both in aquaponics and in agricultural irrigation, the aim of which is to increase the efficiency and sustainability of both aquaculture and agriculture.*

***Keywords— Aquaculture, Agriculture, Integration, Phosphorus, Effluent, Aquaponics, Irrigation.***

## I. INTRODUCTION

The increase in the size of the world's population, together with the rise in average per capita fish consumption and the demand for fish, the role that aquaculture plays in ensuring food security, and to preserve marine resources has led to development of this sector in the world over the last few decades (FAO, 2020).

One of the consequences of the expansion of aquaculture is the significant increase in the production of faecal and metabolic waste from feed in farming systems. The main pollutants involved in these aquaculture effluents, are phosphorus (P), nitrogen (N) stand out as important contributors to the eutrophication process of the aquatic environment, leading to negative impacts on the environment, (Lazzari and Baldisserotto, 2008). Among the nutrients lost from diets, phosphorus is the most critical, is the main factor of pollution in aquaculture since it influences directly the eutrophication process (Carpenter *et al*., 20O8; Morales *et al*, 2015; Han *et al*., 2016; Wang *et al*., 2017, Sugiura, 2018).

In this context, this forces us to rethink waste management with a sustainable vision, operating systems that allow us to reuse nutrients from effluents generated by fish farming (Carpenter and Bennett, 2011), in order to take advantage of the phosphorus nutrients present in aquaculture effluents, especially as the growing global demand for food results in a steady increase in the demand for P, which is expected to increase the cost of P fertilizers in the future (Ashley *et al*, 2011; Scholz and Wellmer, 2015; Geissler *et al*., 2019 ).

From this need stems the concept of Integrated Multi-Trophic Aquaculture (IMTA) systems, which allow the co-production of food or other products through the recycling of aquaculture wastes in order to ensure the environmental sustainability of the sector (Troell *et al*., 2009; Barrington *et al*., 2009; Chopin, 2013).

The integration of fish farming systems with the production of vegetables or fruits are commonly cultivated by integrating aquaculture with agriculture; in agricultural irrigation or aquaponics, is already well established in freshwater, is a sustainable and productive approach, in line with the principles of Integrated Multi-Trophic Aquaculture (IMTA), applying ecological concepts and principles of agro-ecology, which can therefore play an important role in building resilience and adapting to climate change, in addition to food security (FAO, 2019). Integrating aquaculture into farming systems can improve productivity, water use efficiency and overall environmental sustainability (Ingram *et al*., 2000), reduce the use of chemical fertilizers (Rejesus *et al*., 2013), and promote ecological, social and economic benefits (Halwart *et al*., 2003; Aba Mustapha and El Bakali, 2020).

Fish feeds contain Phosphorus and are essentially the only significant source of P in aquaculture (Van Ginkel *et al*.., 2017; Strauch *et al*, 2018), although the importance of phosphorus nutrition is well known to fish nutritionists, mainly because of its effect on bone development and energy kinetics in the cell (Lall, 2002 ; NRC, 2011), in addition to its biological importance for fish, it is well established that excess phosphorus in fish feed can promote eutrophication of aquatic environments, few studies are available on phosphorus-rich aquaculture effluents used by plants by integrating aquaculture into agriculture in order to contribute to the sustainability of aquaculture production. Due to the lack of information on mineral nutrition, in particular phosphorus, and its importance for both fish and plants, and for the beneficial use of fish feed waste, we purpose this Review article which aims to gather, analyse and synthesise information on phosphorus nutrition in fish feed, with the aim of presenting guidelines for the use of this mineral responsible for aquatic pollution as a fertiliser in the integrated aquaculture agriculture system.

## II. PHOSPHORUS REQUIREMENTS

### 2.1 Minerals

Minerals are essential elements for the vital processes of all animals, including fish, which need minerals more than land animals for tissue formation, osmoregulation and other metabolic functions (Lall, 2002). Minerals differ from other necessary nutrients because they are not produced by the body and have to be provided by the diet. Minerals are of great importance because they perform various biological functions. These functions can be classified as structural, such as bone tissue and muscle protein; regulatory, such as cell replication and differentiation; physiological, such as its action on osmoregulation and membrane permeability; and they are and are part of energy storage molecules (Cho *et al*., 1985; Bureau and Cho, 1999; Roy and Lall, 2003).

Minerals are classified according to the amount required by the organism and are separated into macro and micromineral groups (NRC, 2011; Antony Jesu Prabhu *et al*, 2016).

- Macroelements are required in relatively high quantities in the body, the main examples of this group being calcium, phosphorus, potassium and sodium.
- Microminerals are relatively small elements required by the animal, such as: molybdenum, selenium, cobalt, copper, iron, zinc and manganese.

Fish have the physiological capacity to absorb some of these minerals from the aquatic environment through ion exchange in the gills. In freshwater, there is generally a sufficient concentration of calcium, sodium, potassium and chloride to meet their needs except for phosphorus, which must be present in the feed (Bureau and Cho, 1999).

### 2.2 Phosphorus

Phosphorus is a fundamental macromineral for the growth and reproduction of fish; it is widely distributed in all cells of the body, with important functions in several essential metabolic processes. This mineral is present in nucleic acids, phospholipids, enzymes and glycolic compounds. In oxidative phosphorylation, it acts as a covalent moderator, participating in the regulation of many metabolic processes, and being one of the main anions in the crystalline structure of bones (Lovell, 1988; Roy and Lall, 2003; NRC, 2011). In its phosphate form, Phosphorus plays an essential role in all the fundamental biochemical reactions of respiration, photosynthesis, muscle contraction, cell division, transmission of genetic information and fermentation (Lall, 1991).

In nature, phosphorus is widely distributed in combination with other elements. Phosphate is in equilibrium with phosphoric acid (H3PO4), with dihydrogen phosphate ($H_2 PO^-_4$) and with hydrogen phosphate ($HPO^{2-}{}_4$). The predominant form at neutral pH is hydrogen phosphate, as in an acidic medium, phosphoric acid predominates. Pentavalent phosphate is the most common form ($PO_4^{3-}$), being an essential component of protoplasm, present in plant and animal tissues (Strain and Cashman, 2002). Hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$ has the important role of being the main crystalline constituent of bones, giving them rigidity and strength (Lall, 2002).

Free phosphate is also called inorganic phosphate (inorganic phosphorus Pi). Phosphate that is covalently bound to sugars, proteins and other components of the cell is called organic phosphate (P) (NRC, 2011).

Although fish absorb many essential minerals directly from the aquatic environment, most of the phosphorus must be obtained from the feed, as the absorption of phosphorus directly from the water is very low, indicating the need for supplementation of this mineral in the diet (NRC, 2011; Chen *et al*., 2017).

### 2.3 Source and availability of phosphorus

In aquaculture, feed is the inly source of phosphorus in fish (Roy and Lall, 2003; Chen *et al*, 2017; Verri and Werner, 2019). Phosphorus can be found in different forms and concentrations in the ingredients used in feed formulation, such as: inorganic phosphate, bone phosphorus and organic phosphates of animal and plant origin.

#### 2.3.1 Organic Phosphorus

In order to improve the availability of P in aquaculture feed and to prevent P deficiencies, such as skeletal deformities and reduced growth, supplementation of organic P used in feed is necessary to accurately cover the needs of fish (Lall, 2002; Sugiura *et al*., 2004).

The availability and digestibility of this mineral is also different depending on the feed. Fishmeal has been the main source of protein especially for carnivorous species for many years and has the highest digestibility of phosphorus intake (66-74%). Its importance in the formulation of feeds has considerably decreased, but it still remains a significant ingredient. It is very rich in P in the form of hydroxyapatite and phospholipids (Kaushik, 2005; Vandenberg, 2001).

In the context of the sustainability of aquaculture and the gradual depletion of marine resources (FAO, 2020) the substitution of fish meal by a vegetable protein source is recommended, As an alternative to this ingredient, many authors have recommended the plant based protein ingredients specifically regarding the cost as they seem to be cheaper compared to fish meal ( Daniel, 2018).

However, these plant ingredients contain anti-nutritional factors, such as phytic acid, which form complexes with minerals, proteins and lipids, reducing their digestion and bioavailability in the digestive tract (Vielma *et al*., 2002).

One of the minerals trapped by phytic acid is phosphorus, which is the main representative of the structural components of skeletal tissue and is directly involved in energy processes (Akpoilih *et al*., 2017). According to (Kumar *et al*., 2012; Cangussu *et al*., 2018), the incorporation of a synthetic enzyme called phytase could counteract the anti-nutritional factors of phytic acid and improve the bioavailability of minerals and their absorption in the intestinal tract. The opposite, ruminants can produce phytase in rumen by phytate hydrolysis but monogastric animals don’t have phytase available during digestion (NRC, 1993), but for fish, according Hardy (2010), reported that majority of the phosphorus in plant protein cannot be utilized by fish, which are monogastric animals.

Phytase also plays a role in improving the digestibility of plant proteins and the bioavailability of certain minerals, particularly phosphorus (Kémigabo *et al*., 2018). The fish nutrition researchs have suggested the increase of phytase in the feed formulation to increase bioavailability and utilization of the phosphorus in fish feed (Dauda *et al*, 2019).

#### 2.3.2 Inorganic Phosphorus and Food Additives

To ensure the sustainability of aquaculture and the availability of P in fish feeds, inorganic additives to P (Pi) such as monocalcium phosphate (MCP), dicalcium phosphate (DCP) and tricalcium phosphate are generally added to the diets of fish and terrestrial animals to meet P requirements for maximum growth (Yoon *et al*, 2015). Feed manufacturers often add mono or dicalcium phosphate to feed to supplement phosphorus from other feed ingredients (Chatvijitkul *et al*, 2017).

### 2.4 Phosphorus requirements

Of all minerals considered essential for fish, requirement for phosphorus (P) is the most extensively studied (Antony Jesu Prabhu *et al*., 2013). P is a macro element that is essential for several physiological functions in fish (Kaushik, 2005). Unlike ammonia, phosphorus is not toxic to farmed fish (Wong, 2001).

According to Amirkolaie (2011), information on the dietary phosphorus requirements of each fish species and the availability of this nutrient in the diet is essential for the formulation of diets. In the context of mineral nutrition of fish species of aquaculture importance, the main four groups; salmonids (trout and salmon), cyprinids (carp), cichlids (tilapia) and silurids and (catfish) are well studied compared to the other groups, whose most was widely used old method for estimating the phosphorus requirement in fish nutrition is to study the excretion of metabolic discharges, the level of requirement being the one where an increase in phosphorus excretion is observed.

Currently , that the phosphorus requirement of the fish should be estimated by using the method who use the combination the excretion of metabolic discharges, and digestibilty of phosphorus reported in the works Sugiura (2000) and Kaushik (2005), as a tool to estimate the content of this ingredient in aquaculture feed formulation (Hua and Bureau, 2010).

Most of the required phosphorus (P) is supplied to farmed fish through feeding (Stickney, 1979; Hardy and Gatlin, 2002 ; Roy and Lall, 2003), and the requirement may be variable according to the life stage, phosphorus source and the statistical approach used to estimate the requirement (NRC, 2011). Additionally, that digestive tract differences among fishes may influence the quantitative requirement of phosphorus (Hua and Bureau ; 2010). Data available for teleost fish show that requirements vary between 0.5 and 0.9% (Kaushik, 2005; NRC, 2011) and 0.4 to 0.7% of total P (Hardy and Gatlin, 2002; Kaushik, 2005).

### 2.5 Digestion and retention of phosphorus

This mineral is present in virtually all food ingredients, in a mixture of inorganic and organic forms. Intestinal phosphatases hydrolyse the organic form, so most absorption is in the form of inorganic phosphorus, with a higher percentage of total absorption in young animals than in adults (McDowell, 1992).

The digestibility of phosphorus depends on its origin: phosphorus from fishmeal is 60% digestible because the digestive enzyme complex of most teleosteans is better adapted to the digestion of products of animal origin, while vegetable phosphorus, in the form of phytic acid, is little useable by fish (0 to 20%) because the latter do not have the enzyme phytase to digest it (Dosdat, 1992). In this context, feeds formulated from plant ingredients are supplemented with inorganic sources of phosphorus to meet the metabolic requirements of the mineral by fish. This strategy increases the cost of production in addition to allowing greater excretion of the mineral into the environment (NRC, 2011; Araújo *et al*., 2012).

Fish assimilate only 20-40% of the applied P (Gross *et al*., 2020), and the ability of fish to digest phosphorus can vary depending on various factors such as the rearing phase, fish species, various organic ingredients and inorganic sources (Quintero-Pinto *et al*., 2011).

The digestibility of P depends on multiple factors and the association between variables, including pH, the anatomy and physiology of the gastrointestinal tract of TIG fish, the interaction between Pi and divalent minerals, and the presence of feed additives (Hua and Bureau, 2006; Hua and Bureau 2010).

The digestibility of P in the diet varies between fish species (Satoh et al., 1997; Hua and Bureau, 2010), the level of dietary inclusion of P (Satoh *et al*., 1997), the interaction with other dietary nutrients (e.g. Ca) and the presence of feed additives (e.g. phytase) (Hua and Bureau, 2006).

Phosphorus from plants is mainly found in forms of phytic acid (inositol exaphosphate), which is poorly hydrolysed in the gut, with low absorption and excreted via the faeces (Steffens, 1987).

## III. PHOSPHORUS AQUACULTURE EFFLUENTS

The food provided to the fish on a daily basis is usually based on a ration. The amount of feed depends on the energy and nutritional requirements of the fish. However, fish generally do not regulate their consumption on a daily basis, but rather over longer periods of time depending on their developmental stages (Madrid *et al*., 2009).

But Feed is the main source of waste and is also responsible for most of the environmental impact of aquaculture (Roque d'Orbcastel *et al*. 2009). The quantity and quality of the waste excreted by fish depend on intake, digestion and metabolism of dietary compounds (Bureau and Hua, 2010).

Environmental problems arise when much of the dietary P, because it is not bioavailable or exceeds the physiological needs of fish, ends up in fish farm effluents and is eventually discharged into receiving watercourses (Sugiura *et al*., 2000).

### 3.1 Phosphorus discharges in aquaculture effluents.

it is well documented that 15-40% of the applied P is retained by the fish, while the rest is excreted and released into the water (Trépanier *et al*., 2002;Roqued'Orbcastel *et al*., 2008; Sugiura, 2018;). There are several routes of P release in fish farms: faeces, uneaten feed, gill and urine excretion, and fish excrete P in soluble and particulate form (Lall, 1991).

#### 3.1.1 Forms of phosphorus excretion

Phosphorus (P) is found in fish farm effluents in two forms, namely (i) a solid or particulate form and (ii) a soluble or dissolved form.

- **Solid Waste**

Solid waste is mainly derived from uneaten feed and faeces from farmed fish excreta (Akinwole *et al*., 2016). The magnitude of the impact of solid waste depends mainly on the amount of faeces produced and the stability/decay rate of the ingested faeces (Brinker, 2007). It has been shown that diet composition can also change the consistency of faecal solids and other physical characteristics of fish faeces (Kokou and Fountoulaki, 2018).

These phosphorus solid wastes, therefore, are the P that has not been ingested and the P that has been ingested but not assimilated. This solid fraction represents the majority of phosphorus discharges from fish and this is confirmed by several studies concerning different fish species (carnivores and omnivores), which have revealed that phosphorus solid wastes represent between 60 and 70% of food discharges in tilapia (Alves and Baccarin, 2005; Montanhini Neto and Ostrensky, 2015;), trout (Boujard *et al*, 2002l, Roque d'Orbcastel *et al*., 2008) and catfish (Nwana *et al*., 2009).

The particulate form settles to the bottom of basins and reservoirs or accumulates in the sediment (Tundisi and Tundisi, 2008; Canale *et al*., 2016), and the average dietary conversion of diets has a major influence on the excretion of the amount of solid P produced by the fish (Bureau and Hua, 2010).

- **Dissolved Waste**

The dissolved form comes indirectly from the food in the sense that it represents the fraction of the portion of P absorbed in excess and then released in the urine primarily and through the gills (Bureau and Cho, 1999b; Ouellet, 1999; Hardy and Gadin, 2002).

Dissolved wastes, both in organic and inorganic forms, result from the excretion of fish and the decomposition of solid wastes (faeces and uneaten food) in the water column (Gowen *et al*., 1991; Yokoyama *et al*., 2009). These wastes are quantitatively more abundant than particles.

According to Numery (2018) dissolved P includes mineral forms of orthophosphate ions, and organic forms in the process of mineralisation of dead matter (phosphoproteins, phospholipids). Phosphorus excretion at the gills contributes to osmoregulation and acid-base equilibrium in fish (Bucking and Wood, 2006), while renal excretion of phosphate is more important than gill excretion and accounts for 90% of excreted blood P (Dosdat, 1992).

Soluble P would be the most problematic form, as current effluent treatment methods would be unable to remove it effectively (Bureau and Cho, 1999b; Lellis *et al*, 2004), but has an advantage as a fertiliser in the system for integrating aquaculture into agriculture (Aba Mustapha and El Bakali, 2020).

#### 3.1.2 Factors influencing phosphorus discharges

According to Bureau (2004), the production of metabolic P waste by fish is determined by many endogenous (biological) and exogenous (dietary, environmental) factors. Nutrition and feeding remain the main factors that have a determining effect on the amount of metabolic waste produced. However, endogenous factors, such as fish species and size/age, can also have very important impacts.

Several factors influence the excretion of P in the body (NRC, 2011). According to Araripe *et al* (2006) and Koko (2007), the 4 main ones are :

- The quality of the feed, which depends on the content and digestibility of the P, on the one hand, and on the balance of the different nutrients and the physical form of the feed, on the other hand.
- The quantity and distribution method of the feed.

- The adequacy of the diet to meet the actual needs of the farmed fish species;
- The physiological state of the fish: in particular the age and state of health.

Phosphorus excretion is favoured by high doses of calcium carbonate, high concentrations of aluminium in the diet or lower water temperature (Lall, 2002). Metabolic wastes of P are mainly excreted as phosphate in the urine (Bureau, 2004), and phosphate excretion is proportional to the increase in plasma phosphate (Bureau and Cho, 1999).

In addition, fish density has a great influence on N and P excretion (Verant *et al*, 2007). Another factor favouring P excretion is that P is excreted in the farmed water mass in stomachless fish species such as carp (Kim and Ahn 1993).

## IV. RELATIONSHIP BETWEEN PHOSPHORUS AND PLANTS

Phosphorus is a vital, but limited and non-renewable resource for life on earth. The constant increase in the world's population and the need to feed the billions of people has put the global availability of P at risk (Cordell *et al*. 2011). Of the 89% of the world's phosphorus resources that are used for food production, 7% is used in animal feed and 82% is used as fertilizer (GPRI, 2010).

P plays an essential role in energy storage, respiration, and photosynthesis in plants (Zeitoun and Biswas 2020). With the prospects of a growing world population and the need to increase food production for food security, the agricultural sector requires the application of fertilizers containing phosphorus, nitrogen and potassium on agricultural fields in order to increase crop yields.

Phosphorus (P) is an essential nutrient for a growing agricultural industry (Morawicki, 2012). In the context of agricultural sustainability, a more integrated and effective approach to managing the phosphorus cycle is needed. To this end, over the last decade, fish has become more integrated into an overall agricultural system, where wastes from one system are recycled as inputs into another, resulting in reduced pollution (Corner *et al*, 2020). This nutrient is acquired by plants from the soil solution mainly in the form of $H_2PO_4^-$ and $HPO_4^{2-}$. Some soils, however, particularly volcanic soils, possess a high capacity to fix phosphate, thus limiting the bioavailability of P (Morales *et al*, 2011)

Systems that integrate agriculture with fish production are gradually being recognised as environmentally friendly practices that combine aquatic and terrestrial crop production while promoting waste recycling (Jamu and Piedrahita, 2002), thereby increasing farm productivity and optimising the use of limited water resources (Ingram *et al*., 2000; Stevenson *et al*., 2010). P-rich aquaculture effluents are causing growing concern worldwide about possible environmental pollution, so the integration of aquaculture into agriculture, through aquaponics (Cerozi and Fitzsimmons; 2017) and the integration of aquaculture into irrigation (Aba Mustapha and El bakali, 2020), holds promise for improving nutrient and water use efficiency and overall environmental sustainability.

Phosphorus deficiency leads to stunted plant growth, while excess phosphorus can lead to antagonistic interactions with micronutrients, particularly zinc (Barben *et al*., 2010). Therefore, to remedy this problem, the fish farmer is obliged to monitor phosphate concentrations in aquaculture ponds in order to determine the values of this mineral.

## V. CONCLUSION

The demands of food to ensure food security are combined with the demands for sustainable agricultural production models that consider production systems that have a low environmental impact and require less water or make its use more efficient. Therefore, the aquaculture-agriculture integration system has the potential to reuse aquaculture effluents rich in phosphorus, responsible for the eutrophication of aquatic environments, as fertilizer, and capable of improving the productivity, water use efficiency and overall environmental sustainability of both aquaculture and agriculture for agro-ecology.

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