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Fish and fish waste-based fertilizers in organic farming – With status in Norway: A review

Ishita Ahuja [a], Egidijus Dauksas [b], Jannicke F. Remme [c], Roger Richardsen [d], Anne-Kristin Løes [a]

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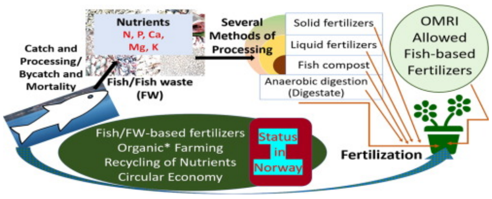
Abstract

This paper reviews relevant knowledge about the production and uses of fertilizers from fish and fish waste (FW) that may be applicable for certified organic farming, with a focus on crop and horticultural plants. Fish industries generate a substantial amount of FW. Depending on the level of processing or type of fish, 30–70% of the original fish is FW. Circular economy and organic farming concepts were used to evaluate the potential of production of fertilizers from captured fish. Fertilizers produced from captured fish promote the recycling of nutrients from the sea and back to terrestrial environments. Nutritional composition of FW is assessed to determine the potential to supply plant nutrients such as nitrogen, or a combination of nitrogen and phosphorous, or to enrich a compost. Methods used in processing of FW to produce fish- emulsion, fish hydrolysate/fish silage, fish-compost and digestate from anaerobic digestion/co-digestion are presented. Using information about commercially available fish-based fertilizers listed by the Organic Materials Review Institute (OMRI), we present a scenario for establishing fish/FW-based fertilizers industry and research in Europe. With Norway's 9th position among top ten global capture producers and focus in Norway on developing organic farming, we brief how FW is currently utilized and regulated, and discuss its availability for possible production of FW-based organic fertilizers. The amount of FW available in Norway for production of fertilizers may facilitate the establishment of an industrial product that can replace the currently common use of dried poultry manure from conventional farming in organic farming.

Graphical abstract



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Introduction

The fishery industry is economically important in many countries including China, India, Spain, the US, Canada, and Norway (Aster, 2018, FAO, 2020, Kazemi et al., 2017). From 2007 to 2017, the world's total production of fish (fisheries and aquaculture) increased with a compound annual growth rate of 2–3.5% (Aster, 2018). The world's total fisheries and aquaculture production in 2018 was 178.5 million tonnes, of which capture fisheries accounted for around 96.4 million tonnes (FAO, 2020). The increase in global capture fisheries (5.4% from the average of past three years) was mainly driven by marine capture fisheries, due to an increase in production from 2017 to 2018. In 2017, the production was 81.2 million tonnes, and in 2018, it was 84.4 million tonnes. The global capture fisheries (long-term) have been rather stable since late-1980s, with catches usually fluctuating between (86 million tonnes − 93 million tonnes per year), with exception in 2018 (96.4 million tonnes) (FAO, 2020).

After China, Norway is the second major exporter of fish and fish products (in 2018: China (14%) and Norway (7%). Catches by Norwegian fleet include big volumes of cod, herring, mackerel and other whitefish and small pelagic species (FAO, 2020, Richardsen et al., 2019, Richardsen et al., 2019).

Raising, catching, and processing of fish leads to vast amounts of wastes, which are of global concern (Caruso, 2016, Choe et al., 2020, Feltes et al., 2010, Harikrishna et al., 2017, Villamil et al., 2017). For each tonne of fish consumed, about the same amount of fish waste (FW) is discarded by ocean dumping or land disposal (Dao and Kim, 2011, Illera-Vives et al., 2015, Karim et al., 2015, Pfeiffer, 2003).

The term "fish waste" may include different materials such as whole fish (dead or damaged fish), fish trimmings, and specific tissues, such as heads, intestines, tails and fins, skins, scales, and bones etc. Different studies have used different terms, for example, "fish waste", "fish processing waste", "by-products", "raw materials" or "rest raw materials" (Choe et al., 2020, Dominy et al., 2014, Estevez et al., 2014, Ghaly et al., 2013, Kannan et al., 2017, Lopes et al., 2015, Olsen et al., 2014, Richardsen et al., 2019, Rustad et al., 2011; Sahu et al., 2014; Sahu et al., 2016; Shaviklo, 2015; Toppe et al., 2018). From the studies describing production of fertilizers from FW, we found "fish waste" to be the most commonly used term (Abbasi, 2011; Balraj et al., 2014, Carney et al., 2000, Dao and Kim, 2011, Illera-Vives et al., 2017, Radziemska et al., 2018, Toppe et al., 2018, USDA, 2019a). Therefore, in this review, mostly, we have used the term "fish waste", but at some places, by-products/raw materials/rest raw materials (as such have been also used).

Large amounts of FW are produced in the main capture fisheries countries, such as Canada, USA, India, Republic of Korea, China, Spain and Norway (Balraj et al., 2014, Estevez et al., 2014, FAO, 2020, Ghaly et al., 2013, Kazemi et al., 2017, López-Mosquera et al., 2011, Sahu et al., 2016, Teh and Sumaila, 2013, Xu et al., 2017). FW, as a by-product of fish markets/fish processing industries, depending on the conversion, may represent 30–45% of the original weight of the product (Illera-Vives et al., 2015, Kazemi et al., 2017, Teh and Sumaila, 2013). FW depending on fish processing and non-utilization, most likely can represent about 30 – 70% of the original fish (Toppe et al., 2018). The amounts of FW that can be generated due to fish processing, as mentioned in different studies, are described in Table S1.

Utilization and further processing of FW are dependent on the local conditions and the structure of the industry. For food, feed, technical and pharmaceutical purposes, FW may be processed to proteins, amino acids, peptides, collagen, oil, minerals, enzymes, flavours, and other compounds (Eilertsen et al., 2017, Ghaly et al., 2013, Rustad et al., 2011). FW that does not meet relevant standards for food or feed, may be used for energy production or fertilizers (Dao and Kim, 2011, Fernandez-Salvador et al., 2015, Fernandez-Salvador et al., 2015, Fernandez-Salvador et al., 2015, Treadwell et al., 2011, Ward and Løes, 2011, USDA, 2019a).

The use of FW for production of fertilizers has received attention over the years to increase the economic and ecological sustainability of the fish industry (Aung and Flick, 1980, Beckley et al., 2007, Illera-Vives et al., 2013, Kinnunen et al., 2005, Lema and Degebassa, 2013, Sahu et al., 2016, Toppe et al., 2018). Fish and shellfish have a long tradition as fertilizers. In medieval France, shellfish debris was used along the coast to raise abundant crops (Wyatt and McGourty, 1990). Fish as fertilizer was used by Egyptians, Incas, and Mayans (Pennington, xxxx, PlimothPlantation, xxxx, Sigma Marine Products, xxxx). Fish residues were traditionally used to fertilize crops in coastal areas. For example, in Nordland county in Norway, the backbones and heads of cod, and left-over herring were used directly or after composting to fertilize both leys and row crops (Helland, 1907, 1908). Around 1880, increasing interest in commercial fertilizers lead to the establishment of several factories producing "fish guano" in Norway. Heads of cod and other FW were steamed or treated with sulfuric acid, dried, ground and exported, for example to Germany (Helland, 1907, 1908).

Commercial fish-based fertilizers are available for both agricultural and horticultural crops, but not commonly applied in Northern Europe, at least not in organic*[1] agriculture where one may expect a relatively more interest in such fertilizers (Løes et al., 2018). These fertilizers are available in many formulations, such as meal, bone meal, liquid fertilizer, and compost, possibly also mixed with seaweeds. As updated on 25 January 2020, 157 fish-based fertilizers were listed by the Organic Materials Review Institute (OMRI), and allowed for use in organic* agriculture (OMRI, 2019b, OMRI, 2020b, OMRI, 2019a, OMRI, 2020a), as discussed in 5.1 About OMRI, and the OMRI's Canada program, 5.2 Commercially available fish-based fertilizers listed by OMRI. The broad availability of commercial fish-fertilizer products indicates that this is a profitable industry.

In this review, we present an overview of knowledge, that will be useful for increasing the utilization of FW as fertilizers. We focus our research on the applicability of such fertilizers in organic* farming, and hence, this review deals mainly with FW from captured fish, and not from aquaculture. Fish raised in aquaculture are usually not certified organic*, and the aquaculture industry has developed quite advanced utilization of FW.

The paper is organized as follows: Section 2 briefs about fundamentals of organic* farming systems, recycling of nutrients, and circular economy. Section 3 explains the nutritional composition of different species of fish, various fish parts, and some kinds of FW. Section 4 shows how various FW materials are/can be processed to produce different kinds of fertilizers, including digestates from biogas production. Section 5 lists currently available commercial fish-based fertilizers allowed by the OMRI, while briefly presenting OMRI's organic standards and the OMRI Canada program. Section 6 discusses the effect on plant growth from application of some of the commercial fish-based fertilizers on plants. Section 7 reviews some studies about production of fish-based fertilizers and their growth effects on a diverse range of plants. Finally, Section 8 presents the current utilization of FW in Norway and the potentials for increasing the volumes of FW available for fertilizer production. Throughout this article, our emphasis is on the utilization of FW to produce FW-based fertilizers applicable in organic* farming, and to recycle nutrients from sea to land by this practice.

Section snippets

Organic* farming, nutrients recycling and circular economy

According to the US Department of Agriculture (USDA), organic* farming production are based on the use of biological, cultural, and mechanical practices, to promote the cycling of on-farm resources, maintain ecological balance, and conserve biodiversity. Some of the examples of such practices are maintaining or enhancing soil and water quality, and excluding use of synthetic fertilizers, pesticides, growth regulators and livestock feed additives, sewage sludge, and genetic engineering (…

Nutrients in fish and FWs suitable as crop fertilizers

Crop plants contain about 30g of minerals per kg of fresh plant material (Mengel and Kirkby, 2001). Six macronutrients [nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), and sulphur (S)] constitute a significant part of this amount. Fertile soils may deliver a substantial portion of these elements; however, most soils are dependent on regular input of fertilizers containing all macronutrients, and preferably also thirteen micronutrients required for successful growth.

…

Processing of fish/FW for use as feed or fertilizer

Fish/FW can be processed into stabilized liquid or solid forms of fertilizers and be combined with other materials to produce fish compost (Fig. 1A and B) or applied as a substrate in anaerobic digestion (Table S2), which has been discussed later in this section.

Depending upon the method of processing, several terms are used to describe FW products, including fish solubles/fish emulsion, fish soluble nutrients, hydrolysed waste/fish hydrolysate (also called fish silage), fish meal, and fish…

About OMRI, and the OMRI's Canada program

The Organic Materials Review Institute (OMRI) is a non-profit organization creating trust and integrity in the organic* sector. OMRI reviews various products for their suitability for use in organic* production and provides a platform for listing accepted products on their website https://www.omri.org/↗. Fertilizers, pest controls, and livestock care products that comply with organic standards are "OMRI Listed®". The "OMRI Listed®" products follow the USDA National Organic Program (NOP) (USDA,…

Scientific studies related to commercially available fish-based fertilizers

There are 154 commercial fish-fertilizer products that are allowed by OMRI (Tables S3 and S4), of which very few have been investigated in scientific research (Table 6). The referred studies were performed with commercially available fish-based fertilizers, such as fish- meal, fish-scale meal, fish pellets, fish-derived protein hydrolysates, hydrolysed fish extracts, fish emulsion, and fish bone formulations. Significant results related to growth effects on agricultural and horticultural…

Effect of FW-based non-commercial fertilizers

on plants

As per literature search, a limited number of studies have been carried out that used FWs to develop non-commercial fish-based fertilizers and also reported the effects of FWs on plants.…

Norwegian fishing industry

The Norwegian fishing industry includes value chains based on the harvesting of cod varieties, pelagic species, flatfish, and benthic species, shellfish, and other molluscs. These value chains include collection, processing, and sales/export activities (Eurofish International Organisation, 2019, Olafsen et al., 2012). In the past 30–40years, the fishing industry has changed significantly, from a situation with almost free access to fishing – towards highly regulated fishing, with fewer fishers …

Conclusions

Taken together, we have brought forward how FW, especially solid FW, can be processed to produce fertilizers for organic* farming, advancing sustainable management of FW and organic* agriculture. Different studies both on commercial and non-commercial fish/FW based fertilizers and in different countries demonstrate a positive impact on plant growth. However, fish/FW based fertilizers have been tested mostly on horticultural plants. The OMRI institute provides a comprehensive overview of…

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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