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Fish offal from aquaculture as fertiliser

Report to the Nordic Council of Ministers

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Usage of medium risk fish offal as fertiliser
Report to the Nordic Council of Ministers

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Summary

The aquaculture industry produces vaste quantities of fish offal. These amounts stem both from slaughter and from on-farm mortality and must be dealt with according to the EU Animal By-Product Directive. Using the fish offal as fertiliser is one of the approved methods, provided that certain precautions are taken and restrictions met.

This report puts forth some recommendations for use of the product, including considerations for vulnerable areas and plant growing time. Also it is recommendated to measure the content of nutrients and POPs, and to conduct germination tests to find an appropriate dilution of the fertiliser before application in order to avoid scorching of the vegetation.

Introduction

Aquaculture is a major industry in several Nordic countries. The industry produces large quantities of by-products, such as entrails from the slaughter of farmed fish. From time to time, diseases as well as for example algal blooms cause considerable fish mortality resulting in large amounts of fish offal.

There are strict rules how to deal with this offal, and all Nordic countries with aquaculture have accepted and put into force the EU Animal By-Products Directive (ABP), in which by-products are classified according to the risk they pose. Fish mortalities from aquaculture are classified as “Category 2” waste, which is waste considered as posing a medium risk. Fish waste from slaughter is classified as low risk waste, or “Category 3”.

There are several uses of products made from fish waste, such as animal feed, biodiesel/biogas, dietic products, food-packaging, cosmetics, enzyme isolation, Cr immobilisation, moisture maintenance in foods, and from some seafood waste it is possible to obtain natural pigments (Arvanitoyannis and Kassaveti, 2008). All fish waste not intended for human consumption, whether it is from landings of fish or from farmed fish, should be treated as waste according to the ABP Directive. However, waste from the fish capture industry is normally categorised as low risk material and accounts for greater amounts, and therefore more demand is for the waste from fish capture than for the waste from aquaculture.

There is a long tradition of using fish waste as fertiliser, but most of the methods previously used have been abandoned, due to several complications, from odour and scavengers to scorched vegetation and nitrogen run-off. Further there is a risk of applying environmental pollutants with this product and of spreading pathogens.

This report provides some guidelines for how to deal with these problems, allowing sustainable use of fish offal.

Use of fish waste as fertiliser

There is an old tradition of using marine organic fertilisers, in some cases by applying them directly on the ground, or burying them under the turf. The product could be either in fresh form, or in some form of compost.

A century ago a product called ‘fish guano’ was well known. This was dried fish ground to powder. Norwegian cod-fisheries dried the heads and backbones upon heated floors after sun-drying them on the rocks, then grinding them to powder. One ton of fish guano was said to equal 17 tons of farmyard manure. The annual production in 1911 of fish-guano from all sources was 75,000 tons (Beach et al., 1911).

The Nordic countries having extensive fish industries, both fish capture and fish farming, produce relatively large quantities of fish offal. Some of it can be used for fodder, but since the ABP Directive entered into force restrictions have been imposed on the use of fish offal, in particular on waste from the fish farming mortalities.

In general, fish residues are too valuable to be used as fertiliser, and in the Nordic countries most waste material from healty fish, both from catch and aquaculture, is utilized either as animal feed or as more advanced products, such as supplements, cosmetics and medicine. However, as there are strict guidelines for how to deal with fish waste from diseased, mortal and moribund farmed fish, there has been a very limited demand for the product, and one of the few options for this product is fertiliser. The alternative is to incinerate it, or bury it in approved landfill sites after appropriate treatment.

Problems of direct usage of fish waste as fertiliser

Considerable problems have been reported with scavengers such as seagulls and rats, and odour from rotting material. In addition new issues have arosen, such as organic pollution, where in particular nitrogen compounds have caused concern either as leached compounds to water resources, or due to volatilisation causing unvanted fertilising of natural areas (nitrogen deposition).

Animal By-Products Directive

All Nordic countries with aquaculture have put into force the Animal By-Products Directive (EC) 1774/2002, including several later amendments, of which in this context (EC) No 93/2005 and (EC) No 181/2006 are of particular relevance.

This Directive aims to guarantee a high standard of health and safety throughout the food chain by laying down rules for collection, transport, storage, handing, processing, and use or disposal of animal by-products not intended for human consumption.

It was put into force following by the food crises in the 1990ies with certain infectious diseases, in particular Transmissible Spongiform Encephalopathy (TSE) – a group of prion diseases that might have evolved due to the administration of feed made of proteins obtained by processing carcasses of the same species as those fed with the protein. The goal of the Directive is that products that at any chance might pose a risk should not enter the food chain.

The EU Animal By-Products Directive classifies the different animal by-products into three categories. Category 1 (high risk) consists of material from animals suspected or confirmed infected with a TSE, as well as from pet animals, zoo or circus animals, experimental animals, or wild animals suspected of being infected with a communicable disease.

Category 2 (medium risk) includes material such as manure and digestive tract content, and otherwise material from animals other than Category 1 that have not been slaughtered for human consumption. Material containing residues of veterinary drugs and contaminants in concentrations exceeding the Community limits also belong to Category 2.

Category 3 (low risk) comprises parts of slaughtered animals which are fit – but of commercial reasons not intended – for human consumption, or the material can of other reasons be rejected as unfit for human consumption, yet not affected by any signs of a communicable disease.

Aquaculture by-products can be classified as follows (Table 1), which shows that the main concern is over Category 2 waste:

Table 1. *Categorisation of aquaculture by-products*

Source of waste	Waste category		
	1	**2**	**3**
On-farm mortalities		x	
- where no disease has been confirmed		x	
- where controls have been applied because of the presence or suspected presence of notifiable disease		x	
- as a result of jellyfish attack		x	
- as a result of algal bloom		x	
- as a result of adverse weather conditions		x	
- due to a compulsory slaughter notice		x	
Mortalities at the processor			
- where the fish are dead on arrival		x	
- show clinical signs of disease and are not processed		x	
Processing waste			
- where source is subject to disease controls (but fish show no clinical signs of disease)			x
- where source is not subject to controls			x

From Mack et al. (2004)

Accepted methods to deal with Category 2 and Category 3 material

There are several restrictions to Category 2 material.

This material can be dealt with in accordance with some approved methods on special approved plants. In particular, apart from direct incineration, the only accepted method is using *Method 1*, which requires, that the material is reduced into pieces less than 50 mm. After size reduction the material must be heated to a core temperature of more than 133°C for at least 20 minutes at a pressure of at least 3 bar. This method applies to all Category 2 material, other than manure, digestive tract content, milk and colostrum destined for a biogas or composting plant or intended for use as organic fertilisers or soil improvers.

This method also applies to Category 2 material to be disposed off in a landfill.

For Category 3 material there is a specific method approved for fish offal (EC) No 93/2005 – *Method 6*. Here it is considered sufficient to boil 50 mm pieces at

90°C for at least 60 minutes, and if the pieces are further reduced to 30 mm or less, then at 70°C for 60 minutes.

According to the ABP directive it is prohibited to apply organic fertilisers and soil improvers, other than manure, to pasture land. This is further described in commission regulation (EC) No 181/2006 regarding organic fertilisers and soil improvers other than manure.

This regulation states, that processed products derived from the processing of animal by-products in a processing plant in accordance with Regulation (EC) No 1774/2004 shall not be applied as such directly to land where farmed animals might have access. However, 21 days after the last application of organic fertilisers and soil improvers, farmed animals may be allowed to the area. The same restrictions apply to harvested fodder, as no grass or other herbage may be cut for use in feedstuffs until 21 days after the last application of organic fertilisers other than manure.

The Nitrates Directive

(Council directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources [91/676/EEC])

Some EU countries have experienced considerable problems of elevated values of nitrates and therefore efforts are made to limit the emissions in particular from agriculture. The Nitrates Directive is in force in all the Nordic countries but Faroe Islands and Greenland. The Directive regulates the allowed amount of nitrogenous fertilisers and manure. The goal of the directive is that there should not be applied more fertiliser than the soil and vegetation are able to use.

The Directive focuses on designated vulnerable areas, for example surface freshwaters, intended for drinking water, and on groundwater reservoirs. The Directive also applies to freshwater lakes, other freshwater bodies, estuaries, costal waters and marine waters found to be eutrophic. Thus the Nitrates Directive should be relevant to all the Nordic countries.

The Directive points out a number of codes for good agricultural practice that should be used. These include application during appropriate periods, taking into consideration run-off from steeply sloping grounds, and avoiding application on water-saturated, flooded, frozen or snow-covered grounds.

The Nitrates Directive limits how much nitrogen fertiliser can by applied, requiring that soil conditions, type and slope are measured together with climate conditions, rainfall and irrigation. Also the amount of nitrogen present in the soil at the end of the winter, the net mineralisation of organic nitrogen reserves in the soil, additions of nitrogen compounds from chemical and other fertilisers and the additions of nitrogen compounds from livestock manure, which includes both the amounts applied by the animals themselves, and what is applied as manure.

In vulnerable areas the Directive limits the application of manure to a quantity corresponding to a maximum of 170 kg/N per hectare annually.

Phytotoxicity

Fresh fish offal, as well as many other fresh organic fertilisers may be phytotoxic, and can have a harmful effect on plants or germinating seeds, as well as on soil life. Phytotoxic effects of organic waste are the result of a combination of several factors. Heavy metals, ammonia, salts and low molecular weight acids all have been shown to be responsible for inhibitory effects. Ammonium-N in solution can also be toxic to plant growth. This toxicity mainly results from ammonia (NH_3) affecting plant growth and metabolism at low concentration levels at which ammonium (NH_4^+) is not harmful (Hoekstra et al., 2002).

Volatilisation of ammonia can also lead to direct damage of plants, microbes and soil animals because cell membranes are highly permeable to ammonia and the pH rise in the cell is too rapid for normal compensation mechanisms to operate. Generally, reduction of soil microbial population due to the toxicity of volatilised ammonia will be short lived, but ammonia damage to plants may be irreversible (Killham, 1994).

Ammonia can have such a strong effect on microorganisms such as bacteria, parasites, and some viruses, that ammonia treatment can be used to stabilise and sanitise biowaste (Albihn and Vinnerås, 2007). Thus following an incident where ammonia has inactivated the soil microbes, changes of the mineralisation rate are to be expected.

There are some indications that the choice of acidifier for sanitising the fish offal has an impact on the toxicity of the fish emulsion, which is first boiled, then filtered and stabilised, typically with sulphuric or phosphoric acid. Phytotoxical studies of formic acid, sulfuric acid and other acids have demonstrated, that even though formic acid had phytotoxic effects on plants, it was also 7 times more toxic to pathogens than acetic acid (Abbasi et al. 2009). On the other hand, phosphoric acid is the preferred stabiliser when producing commercial fertilisers (Baker, 1996), providing the plants with additional phosphate as well.

Seed germination tests have shown, that both fresh feedstock and digestates collected during anaerobic digestion (biogas) and also the early stages of aerobic post-treatment were phytotoxic, but this phytotoxic effect disappeared after an aerobic post treatment of 10 weeks and with diluted digestates (Abdullahi et al., 2008).

Germination index

To test for phytotoxicity a germination test can be used, where the effects on seed germination and primary root growth is determined in petri-dishes with filter papers wetted with a solution of fertiliser at different concentrations, and a known number of seeds added. The control is wetted with distilled water, and the germination index is calculated relative to the control after incubation for typically 72 hrs at 25°C (depending on plant species), see Hoekstra et al. (2002).

A germination index lower than 100 indicates an inhibitory effect on the germination, while a value greater than 100 indicates a stimulatory effect.

A germination index of less than 70% has been suggested to be phytotoxic (McLachlan et al., 2004).

Fish emulsion an effective fertiliser

Although there is a long tradition for the use of organic fertilisers and composts, few studies have evaluated the efficacy and rates to applied. However, Murray and Andersen (2004) compared fish emulsion (acidified fish tankage, urea, phosphoric acid and potassium chloride), and a digested fertiliser (microbe digested organic fertiliser derived from blood meal, bone meal and sulfate of potash) with an inorganic fertiliser with 20-10-20 NPK. This study was done in 3" pots with tomato and pepper plants.

The fish emulsion contained 5-1-1 NPK, while the blood and bone meal contained 6-6-6 NPK.

Also compost from worm castings, cow manure and horse manure were compared with inorganic 20-10-20 NPK fertiliser.

It turned out that both fish emulsion and blood and bone fertilisers were effective fertiliser treatments. Compared with the inoganic fertiliser with a ratio of NPK of 20-10-20, the nutrient content of the fish emulsion was 5-1-1, and thus considerably lower concentration than the inorganic fertiliser. This difference in concentration was not fully compensated for, as the inorganic fertiliser was only provided with half the dose of the fish emulsion, and thus the inorganic control obtained twice the amount as the pots with fish emulsion. Even so, the plants fertilised with fish emulsion increased dry weights between 200 and 300% over the unfertilised control. The inorganic fertiliser increased plant dry weights by approx. 200 to 700%.

Yet plants from pots with the composted products were considerably smaller than the unfertilised controls. This indicates that the compost was not mature when used, and therefore the microbes involved in the composting process used soil nutrients in competition with the plants.

Experiment: Unmatured fertilisers inhibit germination

An experiment on germination showed that germination was totally inhibited by the adicified fish offal, but to a lesser extent also by horse manure. The few seedlings that managed to germinate were all scorched and withered soon (Olsen, 2010).

Especially the ratio of ammonium (NH_4^+) seems to be interesting in this context, as both had a low amount of ammonium relative to total nitrogen. This ratio would change if the product is allowed to mature – towards a higher proportion of ammonium, that is directly available for the plants.

The nutrient composition in the soil and nutrients used in the germination experiment are shown in Table 2. The table indicates that the nitrogen content of fish fertiliser, whether it is acidified or composted, is great, but also shows, that in the compost, which did not inhibit germination, a large fraction is converted to ammonium (NH_4^+) while a large fraction in both the acidified fish offal and in the horse manure is of unidentified nitrogen-compounds. This indicates, that the acidified fish offal, which was not composted, is not mature, and a much better result could have been achieved, if it had been composted before use.

Table 2. *The chemical composition of soil and nutrients in germination experiment compared with Danish and Norwegian manure from cattle.*

	DM %	Total N Kg/T	NH_4^+ Kg/T	P Kg/T	K Kg/T
1. Soil	60	1.4	0.12	0.3	0.3
2. Fish offal, acidified (Category 2)	48	19.0	1.43	2.7	1.6
3. Fish offal, composted, matured 2-3 mts	40	16.3	4.94	2.2	1.7
4. Fish offal, composted, matured >6 mts.	48	14.7	6.63	2.9	1.9
5. Horse manure mixed with hay	22	4.3	0.59	1.2	1.6
6. Danish norm 2010 cattle (Jersey)	9	5.6	3.25	0.9	5.3
7. Average Norway	7	2.3		0.4	2.0
8. Norwegian Westcoast	4.5	1.1		0.2	0.8

1. Soil without any fertiliser. 2. Fish offal, has been acidified, then heated to 133°C with a pressure of 3 bars for 20 minutes (method 1, ABP). 3.-4. Composted and matured fish offal. 5. Unmatured horse manure.

Source: 1.-5. Olsen (2010). 6. Miljøstyrelsen, DK. 7.-8. Bjarnason (1997).

Table 3. *Calculated amounts of nitrogen applied when using a dilution of 5% dry mass, and an application rate of 40 tonnes of solution per hectare.*

	Dilution factor to obtain 5% DM	Undiluted Kg/T	Diluted ppm	Total amount N applied per HA kg/HA
1. Manure danish norm (DM 10%)				
Total nitrogen	2	6	2820	120
2. Fish offal norm (DM 20%)				
Total nitrogen	4	18	4500	180
3. Horse manure (DM 20%)				
Total nitrogen	4	4	1000	40
4. Fish compost (DM 45%)				
Total nitrogen	9	15	1667	80
5. Fish acidified (DM 50%)				
Total nitrogen	10	19	1896	80
6. Norway (DM 7%)				
Total nitrogen	1.4	2.3	1643	66
7. Norway west (DM 4.5%)				
Total nitrogen	4.5	1	1100	44

Source: 1. Miljøstyrelsen, 2.-5. Olsen (2010) 6.-7. Bjarnason (1997).

In Table 3 the nitrogen content of fish fertiliser is compared with that of manure, and the estimated amount of nitrogen is calculated, assuming a dilution of 5% dry mass, and an application rate of 40 tonnes of solution per hectare. The Nitrates Directive limits application rates to a maximum of 170 kg/ha annually, but to avoid foliar burns it would be appropriate to apply for example fish emulsion 3-4 times per year rather than all at once. Also this would prevent run-off of soluble mobile nutrients.

Pollution

Fish offal can contain relatively high levels of Persistent Organic Pollutants (POPs). However, analyses of both fish meal and fish for human consumption have shown that the products contain POPs well below the current European threshold limits. Even so, as these pollutants tend to a accumulate in the ecosystems, it is important to identify the pathways to the food chain, so to avoid further distribution if possible, for example by spreading contaminated fertiliser on cultivated or pasture land.

Since POPs bind to lipids, removal of the lipid phase of the acidified offal prior to spreading would remove this obstacle, because these pollutants are mainly found in the lipid phase. Therefore only the water phase should be utilised as fertiliser.

Recommendations

General recommendations

- Vulnerable areas of conservational interest should be exempted from fertilisation, in particular during bird nesting time.
- Fertilisation should only occur during the plant growing time.

Recommentations to the producer

- The material in the tanks/compost typically is not uniformly distributed, and the sampling should take this into account.

Acidified fish fertiliser

- Before extraction and distribution as fertiliser, the lipid layer should be removed and used for other purposes, or incinerated in approved plants (to remove POPs).
- The components of the fish offal tend to separate into horizontal layers, which should be taken into account when sampling, f.ex. by vivid stirring prior to or if possible during sampling.
- The acidic solution should be sieved and only the liquid should be distributed (to avoid scavengers). The greaves could be composted or used for biogas.

Nutrients and pollutants analyses (applies for all types of fish fertiliser)

- Fish fertiliser should not be distributed without analyses of N, P and K, and a germination test to find the correct dilution and recommended application rate. As these products are not uniform, it is necessary to measure the nutrient content in each batch or tank before releasing it as a fertiliser.
- Given potential pollutants in fish offal, a monitoring scheme as well as guidelines should take into consideration such components in the fertiliser.
- Dead and diseased fish may contain high levels of antibiotics, and the fertiliser should be analysed for this and the results reviewed by a competent body with authority to impose restrictions.

Recommendations to the user

- Fertilisers made from fish offal contain much nitrogen. Therefore care must be taken not to apply unneccessary amounts of such fertilisers, but rather to adhere to the codes for good agricultural practice, outlined in the Nitrates Directive, including limiting the amount of nitrogen to a maximum of 170 kg per hectare annually.
- To avoid plant scorching and leachage of nitrogen compounds the fertilizer should be diluted according to the nutrient content, which can vary considerably from batch to batch.
- With regard to possible accumulation of POPs, repeatedly sprayed fields should be sampled and analysed for POPs with relevant intervals.
- Farmed animals should not have access to the fields before 21 days after last application of fish fertiliser.
- Fodder should not be harvested before 21 days after last application of fish fertiliser.

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