

Oral paper

Utilisation of seafood processing waste – challenges and opportunities

Ian Knuckey¹, Clive Sinclair², Aravind Surapaneni³ and William Ashcroft³

¹Fishwell Consulting, 22 Bridge St, Queenscliff, Vic 3225.

Sieber New Zealand Ltd, Waiuku, New Zealand

³Primary Industries Research Victoria, Department of Primary Industries, Tatura Centre, Ferguson Rd, Tatura, Vic, 3616.
WWW.dpi.vic.gov.au Email: Aravind.Surapaneni@dpi.vic.gov.au

Abstract

During the processing of fish, it is generally only the fillets that are retained while the bulk of the product is discarded (about two thirds of the whole weight is comprised of guts and frames). Across the seafood industry in southeastern Australia alone, there is an estimate that well over 20,000 t of fish product waste is produced each year. In some instances this fish waste may be taken from the processing site to be rendered, but usually it is dumped to landfill at a cost to the processor of up to \$150/t. This practice is coming under increased scrutiny due to environmental issues and is becoming an increasing cost burden for the whole industry.

Hydrolysed fish waste can be composted with rock phosphate to form an organic/biological solid-phosphate fertiliser. To enable this, relationships need to be formed between seafood industry and fertiliser manufacturers.

The seafood industry can process the fish offal through a cost effective hydrolysis system into a stable liquid fish concentrate. This can then be efficiently transported to fertiliser manufacturers, who then can blend this stable liquid fish concentrate with rock phosphate. The mixture can then be inoculated with bacteria and fungi using advanced composting technology. This technology has shown that temperatures around 60°C are achieved to produce a pathogen free compost blend, which builds up the populations of microorganisms and enables more minerals to be bound within. These bound minerals are considered to be readily plant available. Such a product has the dual advantages of providing needed nutrients to agricultural crops as well as utilising waste materials that are otherwise costly to dispose of. Three field trials (tomato, irrigated pasture and dry land tritacle) are under way to assess the agronomic effectiveness of a fish waste based rock phosphate fertiliser. Processing tomato crops appear to benefit from the application of the fish based P fertiliser to the same extent as traditionally used superphosphate.

Overview of seafood processing waste

Within the Australian seafood industry, thousands of tonnes of fish waste are produced each year by processors and retailers (Gavine *et. al.* 2001), as well as the catching sector (Knuckey *et. al.* 2001). In processing fish, it is generally only the fillets that are retained and although yields may vary widely (Crapo *et. al.* 1993), the fillets of many of the Australian commercial species only usually comprise 30-40% of the whole weight of the fish (Australian Fisheries Management Authority unpublished). Subsequent to processing, the bulk of the product (60-70%), consisting of head, guts and frame is usually discarded. In some instances this waste product may be taken away from the processor at no cost, but usually processors pay for its removal as garbage that is dumped to landfill at costs up to \$150/t. Due to its high organic content, fish waste is often classified as a certified (prescribed) waste which is even more costly to dispose. This practice is coming under increased scrutiny due to environmental issues (Jespersen *et. al.* 2000, Anon 2002) and is becoming an increasing concern and cost burden for the whole seafood industry. At the 2001 Seafood Direction Conference, the Australian Seafood Industry Council highlighted that the utilisation of fish waste was one of the high priority areas that needed to be addressed in the next

two years. In south eastern Australia alone, there are estimates that well over 20,000 t of fish product waste is produced by the seafood industry each year (Knuckey 2004).

With most of Australia's fish stocks near or at full exploitation, it is unlikely that the seafood industry will expand and develop through increased wild-capture harvests. One of the main options for increased profits to the seafood industry is through value-adding the current catch. The Fisheries Research and Development Corporation (FRDC) set up the South East Fishery Industry Development Subprogram to specifically explore such options. The main focus of this Subprogram over the last two years has been to find a solution to the large amounts of fish waste that are discarded by the seafood industry each year.

Options for utilisation of seafood processing waste

At a FRDC workshop in 2001, seafood industry leaders discussed ways to improve the utilisation of fish waste by investigating techniques to process the waste into products such as aquaculture feeds, silage, fertilisers, fish mince, and fishmeal. After considering a variety of options, it was agreed that processing the waste into valuable fertiliser products was the option that was most feasible at that point in time. This option suited the particular characteristics of the processors and the raw product that they produce: it could utilise the bulk of the fish waste and prove cost-effective given the relatively low volume and wide geographical area covered by Australia's seafood industry. It was acknowledged that if the utilisation of fish waste were to be successful on a broad scale, it would require a considerable level of coordination and cooperation, both within the seafood industry supply chain and across a range of different areas. It would also require the sensible use of the current resources and investment into infrastructure of the seafood industry towards waste utilisation.

To achieve the above, the Subprogram formed Australian Seafood Co-products (ASCo) during 2002. The goal of ASCo is to add value to the seafood supply chain through the sustainable utilisation of fish and fish co-products that are not traditionally utilised or marketed. ASCo shareholders include the FRDC and numerous major Australian seafood companies from Queensland, New South Wales, Victoria, Tasmania and South Australia. Their initial shareholder contributions have been used alongside Federal government funding to run a number of projects to help get ASCo off the ground. Some of the projects that have been completed to date include a feasibility study on installation of a fish silage plant at central fish processing sites, development of a business network plan for ASCo and development of an agreed structure for the operation of ASCo. Although it considered a number of uses for fish waste, ASCo decided that processing of the fish waste into a valuable organic fertiliser was the option that was most feasible at this point in time. As a consequence, ASCo Fertilisers was formed – a partnership between ASCo and Sieber, a New Zealand company that has the proven technology and experience to process fish wastes into fertilisers. Through this partnership, ASCo Fertilisers intends to utilise large quantities of fish waste from across south-eastern Australia to produce fish-based fertiliser products that can be potentially used by the farming sector for agricultural crops and can be certified for use in the rapidly growing organic (farming) market. Any research in this area will be an exciting proposition given it is a potential win for the seafood industry, the agriculture industry and the environment.

Fish nutrient

Fish nutrient is an inert liquid produced by enzymatic hydrolysis. It is manufactured by grinding whole fish or fish waste, which is then transferred to a tank or vat where an acid is added, and the whole mixture agitated until the enzymatic hydrolysis process is complete. A variety of acids are suitable, but in this case concentrated sulphuric acid (H_2SO_4) is used, as it is readily available, relatively easily handled, inexpensive and the sulphur (S) content is beneficial to the crop. The H_2SO_4 added (2% by weight), helps initiate hydrolysis of the fish, but its primary purpose is to reduce the pH to prevent microbial spoilage. The hydrolysis process proceeds as the endogenous enzymes in the fish are released from the cells and digest the fish tissue. This process is controlled by temperature and is preferably carried out in an insulated and jacketed tank. As this process is exothermic (heat producing), the insulation enables heat to

be retained, which accelerates the process. The water jacket enables heating of the tank if required to keep the temperature to desired levels. A temperature of 30°C provides rapid breakdown of the fish, but higher or lower temperatures will provide good results without degradation of the product. Temperatures higher than 50°C should normally be avoided to prevent destruction of the enzymes which drive the process, or degradation of the amino acids in the fish nutrient.

Careful control of the pH is essential to avoid bacterial spoilage. This is usually achieved by use of an automatic pH meter and acid dosing pump, which will maintain the process at a pH of 3.0-3.5.

Depending on the temperature, the hydrolysis process is usually complete after 48 hours. The liquid fish nutrient is then passed through a 1 mm screen to remove any solid material. From a batch of 10 tonnes of fish byproduct there is usually only about 50 kg of solid waste (more than 1 mm in size).

Fish nutrient can be stored indefinitely in agitated steel or some plastic containers without spoilage, if the pH is at the correct level.

Biologically activated rock phosphate fertiliser

There are numerous naturally occurring soil microorganisms that are capable of extracting the phosphorus (P) from soil or minerals including phosphate rock, (Agnihotri *et. al.* 1970) and making it available to plants (Mclaren *et. al.* 1990) . However, when phosphate rock is added to the soil, this process usually proceeds very slowly.

Addition of biological material, such as fish nutrient, and inoculation with bacteria and fungi will result in acceleration of the biological breakdown of rock phosphate (During *et. al.* 1984). The bacteria and fungi feed on the fish nutrient and produce acids (Mckenzie *et. al.* 1995), which in turn break down the rock phosphate into more biologically available forms. This process can occur in the soil but is relatively slow when compared with its application in a factory environment which results in a biologically activated phosphate fertiliser (Chitralkha *et. al.*).

The Sieber group (now known as Kagree Holdings Limited) has previously manufactured biologically activated phosphate fertiliser using 5% by weight of fish nutrient in a composting process. However, this process was typically partly anaerobic, which at times resulted in off-odours and had the potential to produce pathogenic bacteria. One particular problem that has been experienced in commercial production of biologically activated phosphate fertiliser in the past was contamination by *Clostridium perfringens*, a spore-forming anaerobe (widespread in the soil), some strains of which can cause enterotoxaemia and "pulpy kidney" in sheep. These problems have been overcome by development of a controlled aerobic low moisture (<10%) composting process, which achieves temperatures higher than 55°C for a period of several days in order to kill potentially pathogenic bacteria. The key aspects of this process are maintaining aeration of the material throughout production, and achieving the critical temperature for a sufficient period to destroy pathogenic bacteria .

This patented process, is initiated by mixing ground rock phosphate with 5% by weight of fish silage (produced as above) to which a mixture of beneficial microorganisms have been added. These microorganisms include actinomycetes including *Streptomyces*, fungi including *Zygomycetes*, phosphate- and other mineral-fixing bacteria including *Thiobacillus*, selected archaeobacteria, autotrophic bacteria including *Glomus tenuis*, aerobic composting bacteria including *Theobacillus*, *Alkaligenes*, *Azotobacter*, and *Pseudomonas*, acidophiles and lactic-acid bacteria.

As well, 5% by weight of a porous organic material (usually sawdust) is added to the phosphate rock to improve aeration. The presence of coarse sawdust immediately assists circulation of air through the relatively fine rock phosphate, but circulation is progressively enhanced as the sawdust is partially

digested, leaving voids in the mixture. The organic timber also is able to “fix” free ranging elements including nitrogen.

The mixture is then held in a (preferably insulated) concrete bin, where air is forced through from the bottom of the bin to ensure the aerobic process is maintained. It is important to maintain moisture content below 10%, to avoid development of anaerobic zones and avoid loss of valuable nitrogen (as ammonia).

Proliferation of bacteria in the early stage of the process will result in the mixture reaching temperatures of around 60°C, which can be maintained for several days. The temperature then gradually decreases, during which phase there is a proliferation of fungal mycelia through the phosphate mass. These fungi partially absorb phosphate released during production.

The end product from this process comprises a free-flowing powdery or sandy material with 5% to 10% moisture content, containing a variety of dead or living micro-organisms and some secretions, at a pH of about 7 to 7.2 (sometimes pH 6.5 to 7.5, depending on the rock phosphate used). The microorganisms have already begun to solubilise or digest the phosphate rock while being supported by a community of other microorganisms that are converting the nutrients into cellular material.

Depending on the source of rock phosphate the analysis is high (Table 1) due to the relatively low (10% by weight) addition of composting ingredients. The end product can be handled through conventional fertiliser storage and distribution facilities and is applied to farms using conventional spreading methods.

The Biologically activated rock phosphate fertiliser (BioPhos in short) is currently marketed to farmers in New Zealand who are looking to establish a biological mineral delivery system (enzymic phosphate) through the soil to the plant. The product has organic certification in New Zealand Biogro # 0171.

Table 1 Typical analysis of biologically activated rock phosphate (Ben Guerir) fertiliser

Analyte	Typical fish waste based rock phosphate fertilizer
Total P (%)	12.5
P as water soluble	n/a
P as citric soluble (%)	3.85
Converted to total product (%)	30.7
Total K	Nil
Total S (%)	0.71
Total Ca (%)	38.3
Total N (%)	Up to 3
Organic matter (loss on ignition at 550°C)	5

Agricultural trials

The seafood industry in south eastern Australia is currently developing BioPhos fertiliser in Australia. This has the potential to reduce environmental impact by utilising problem wastes and could also generate significant financial returns to the seafood industry. The farming sector would also gain an alternative P fertilizer.

Australian soils are generally deficient in phosphorus (P) in their native state. They require the application of P fertilisers to satisfy the crop and pasture requirements for P. Two-year field trials were established at Tatura (northern Victoria) and Dutson Downs (Gippsland) to examine the effectiveness of BioPhos in comparison with traditional P fertiliser (Superphosphate) on processing tomatoes (Tatura), irrigated pasture (Tatura) and dryland tritacle (Dutson Downs). Results from two-year tomato trail will be presented here.

Tomato trial

Materials and methods

The experiment comprised 3 treatments. These were an unfertilized control (T1), superphosphate (T2) and fish based P fertilizer product (BioPhos) (T3), replicated 12 times (3x12=36 raised beds) over 4 blocks. Each block comprised 9 raised beds 1.5 m wide x 72 m long. Experimental plots were 8 m long and 3 beds wide with all measurements taken from the central bed. Tomatoes were grown on these beds for 2 consecutive seasons (2002-03 and 2003-04). P was surface applied each year (hand spread and raked into the top 10 cm of soil) at the recommended rate (120 kg P/ha) before seedling were transplanted. Table 2 shows the analyses of P fertilizers applied.

Table 2 Fertilizer analyses (w/w)

Analyte	Superphosphate (T2)	Fish based P fertilizer (T3)
Total P	7.52%	9.6%
P as water soluble	6.84%	<0.5%
P as citrate soluble	0.51%	1.6%
P as citrate insoluble	0.17%	7.6%
Total K	6.02%	8%
Total S	11.87%	6.4%
Total Ca	16.24%	25.6%

Soil samples (two per bed) were taken from each plot prior to application of treatments during the first season (2002-03) to assess the initial levels of Olsen-P in the 0-30 cm depth. Seedlings of the standard processing tomato cultivar Heinz 9035 were transplanted with 30 cm spacing between plants during both the seasons. Irrigation and N fertiliser were applied according to commercial practice, through a buried drip system installed at a depth of approximately 15 cm. Leaf samples were taken to determine P levels during crop establishment and early fruit set stages for the 2 seasons. Fruit samples were taken to determine P levels at harvest for the second season crop only. Total ripe yields of tomatoes from the plots at harvest were converted to t/ha using a factor 3.3. Soil samples (0-30 cm depth in the middle of each plot) were taken at the end of each season to determine Olsen P. Additional 30-50 cm depth soil samples were taken at the end of 2003-04 season.

Results

The data during the first season was analysed by treating 3 'outlying' values as missing (Table 3). The initial Olsen-P levels (0-30 cm depth) ranged from (4-25 mg/kg) and were more variable on T2 plots. This was not known prior to the random allocation of treatments to the beds. There was no relationship between initial Olsen-P and total yield. Average plant P levels at the crop establishment stage were highest for T2 and lowest for T1. Early fruit stage samples showed highest average P levels in leaves for T3. There was no relationship between total leaf P (at either sampling dates) and total yield. When three 'outlying' values were treated as missing, there was a significant effect of treatment on total yield ($p<0.01$) with mean yield significantly lower for the control treatment (T1) by over 15 t/ha. There was no significant difference between the two fertilizer treatments.

Table 3 Treatment means from ANOVA (2002-03 season) with three 'outlying' values treated as missing¹ (n=33)

Assessment	Units	T1	T2	T3	sed	lsd (5%)
Total yield	t/ha	99.7	115.2	115.4	5.30	10.88
Total leaf P (Crop establishment stage)	%	0.283	0.468	0.368	0.016	0.032
Total leaf P (Early fruit set stage)	%	0.174	0.180	0.216	0.009	0.018
Final Olsen-P (0-30 cm)	mg/kg	7.0	5.5	7.0	0.74	1.5

¹one plot from T2 and one from T3 (both in block 1) excluded due to observed irrigation problems, an additional one plot from T1 (block 2) excluded due to exceptionally high total yield (147.6 t/ha)

The data during the second season was analysed with no 'outlying' values as missing (Table 4). Average plant P levels at the crop establishment stage were highest for T2 and lowest for T1, similar to first season. However, early fruit stage leaf samples and fruit samples at harvest showed no significant differences between the treatments. There was no relationship between total leaf P (at all sampling dates) and total yield. There was a significant effect of treatment on total yield ($p < 0.01$) with mean yield significantly lower for the control treatment (T1) by over 22 t/ha. There was no significant difference between the two fertilizer treatments, similar to first season's results.

Table 4 Treatment means from ANOVA (2003-04 season) with no 'outlying' values treated as missing (n=36)

Assessment	Units	T1	T2	T3	sed	lsd (5%)
Total yield	t/ha	69.1	87.3	95.9	7.39	15.08
Total leaf P (Crop establishment stage)	%	0.243	0.349	0.293	0.014	0.029
Total leaf P (Early fruit set stage)	%	0.140	0.136	0.135	0.010	0.021
Total leaf P (fruit at harvest)	%	0.259	0.288	0.283	0.016	0.032
Final Olsen-P (0-30 cm)	mg/kg	6.6	50.8	10.8	3.45	7.0
Final Olsen-P (30-50 cm)	mg/kg	3.5	21.5	4.4	2.34	4.8

Mean Olsen P for the superphosphate treatment (T2) at the end of the trial was significantly higher than T1 and T3 at both depths (Table 4).

Conclusion

Processing tomato crops appear to benefit from the application of the fish based P fertilizer to the same extent as traditionally used superphosphate. However, further work would be required in order to validate the results before any general recommendations for fish based P fertilizer use could be made.

References

- Agnihotri, V P, (1970) Solubilisation of insoluble phosphates by some soil fungi isolated from nurseries seedbeds. Canada Department of Fisheries and Froetry, Ontario.
- Anon (2002). Waste Management: reduce, reuse, recycle. Centre for Excellence in cleaner production. 5pp.
- Chitralekha, R., Rajan, S.S.S. and Mclay, C. D. (2000). Influence of Superphosphate and Micgrobial phosphate fertilizers on adsorbed and solution P in Allophanic soil. Dept. Earth Science, University of Waikato, New Zealand.
- Crapo, C, Paust, B, and Babbitt, J. (1993). Recoveries and yields from Pacific fish and shellfish. Marine Advisory Bulletin 37 Rev, 37pp.
- During, C. (1984). Fertilizer and soils in New Zealand Farming. Ruakura Agriculture Research Centre, Ministry of Agriculture and Fisheries. P. D. Hasselberg, Government Printer, Wellington New Zealand.
- Jespersen, C., Christiansen, K., and Hummellose, B. (2000). Cleaner production assessment in fish processing. United Nations Environment Programme and Danish Environmental Protection Agency, 99pp.
- Knuckey, I.A. (2004). South East Fishery Industry Development Subprogram: Assessing the Commercial Viability of Utilising Fish Processing Wastes. Final report to Fisheries Research and Development Corporation. 23pp.
- Knuckey, I.A., Berrie, S.E. and Gason, A.S.H. (2001). South East Fishery Integrated Scientific Monitoring Program – 2000 Report to the South East Fishery Assessment Group. Australian Fisheries Management Authority, Canberra. 114pp.
- McKenzie H. C. (1995). Landcare Research New Zealand Ltd. (unpublish article)

McLaren, R. G., & Cameron, K. C. (1993). *Soil Science: an introduction to the properties and management of New Zealand soils*. Oxford University Press, Auckland New Zealand.

Acknowledgments

We acknowledge the Fisheries Research and Development Corporation (FRDC) and DPI through the Ecologically Sustainable Agricultural Initiative (ESAI) for their financial support. We also acknowledge Bruce Green and Victoria's Department of Innovation, Industry and Regional Development, NSW EPA's Profiting from Cleaner Production Industry Partnership Program, David Gregory from the National Food Industry Strategy. Special thanks to Gordon Pender for undertaking the plant feasibility project and Wayne Street of Street Ryan and Associates for all of the work and support he has provided for the initiation of ASCo. Thanks also to Ted Loveday and Jayne Gallagher from Seafood Services Australia, Terry Moran and Steve Buckless from SETFIA, John Roach and Michael Kitchener from Master Fish Merchants Association, Grahame Turk from the Sydney Fish Market, Malcolm McLaughlin from Consolfish, and Peter Dundas-Smith and John Wilson from the Fisheries Research and Development Corporation.