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Executive Summary

The seafood industry in Alaska generates about one million ton of fish byproducts annually from processing two million tons of fish harvested in Alaska waters. Processing the byproducts into fish meal and fish oil are cost effective for large fish processing plants, but high initial investment, high energy consumption, and effective marketing networks prevent attempts from establishing such a process in middle and small fishing communities and fish processing plants. Because of high nutrient content in fish byproducts, an alternative low-cost approach is to compost the byproducts so that they can be used for local gardening and agricultural crop production. Ocean Earth Fish Compost, a company in Homer, Alaska, has composted fish byproducts since 2004 using sphagnum peat moss and fish byproducts transported from Deep Creek Custom Packing, Ninilchik, Alaska. Investigations were needed for the company for its composting method, compost quality, impact of compost application on crop growth, and possibility of using compost leachate as liquid fertilizers. Such evaluation can help other fishing communities in Alaska to use fish byproducts for local food production, and hence promote sustainable living for these fishing communities. The objectives of this project were 1) to assess the fish compost, and compost leachate quality; 2) to determine optimal compost/ top soil mixing ratio when used as a potting material; and 3) to determine impact of the compost on soil fertility and growth of timothy grass hay.

Three experiments were conducted in the Homer area in summer of 2008. A compost pile was set up in the early June and temperature change in the pile was monitored. Compost samples were taken from the pile during entire course of composting. Compost leachate samples were taken in a nearby drainage ditch for

analysis of nitrogen (N) and carbon (C) content. Containers with green onion (*Allium fistulosum*) and radish (*Raphanus sativus*) grown in five compost/top soil mix ratios (1/3 compost + 2/3 top soil; 1/2 compost + 1/2 top soil; 2/3 compost + 1/3 top soil; 100% top soil; and 100% compost) and 100% sphagnum peat moss were established. Samples of different mixtures were taken for analysis of their chemical properties, and plant samples were taken for biomass determination and analysis of tissue nutrient concentration. Treatments with and without compost application were implemented in a timothy grass (*Phleum pratenu*) hay field. Soil samples prior to treatment implementation and from both treatments in late August were sampled for nutrient determination. Timothy hay samples in August were taken from both treatments for determining biomass yield and nutrient concentration.

Compost and soil samples, and compost/top soil mixtures were analyzed for pH, electrical conductivity (EC), mineral N, total N, total C, and extractable phosphorus (P) and potassium (K). Total N and total C in compost leachate samples were determined. Plant samples were analyzed for total N, P, K, and array of micronutrients concentrations. All chemical analysis was conducted at the soil laboratories in the School of Natural Resources and Agricultural Sciences, University of Alaska Fairbanks.

Results showed that the compost pile, with weekly turning intervals, reached 115^{o}F (46^{o}C) three weeks after its start, and remained that temperature for three days. Nitrogen concentration in the leachate was too low for a liquid fertilizer. The matured compost had a C:N ratio of 16:1, which was within the range of C:N ratio for matured compost (5 to 20:1) in the market. The matured compost from the pile also contained 1.6% N, and an array of micronutrients that are essential to plant growth. The dissolved salt concentration measured as electric conductivity in the matured compost was less than 2 mS/cm. This is lower than most compost reported in the literature. Due to its low dissolved salt concentration, no biomass reduction was observed for radish and green onion grown in the 100% compost treatment. Nevertheless, a 50% or less compost in compost/soil mixture for potting materials is recommended with a consideration of variations in salt tolerance of domestic plants, variations of compost salt concentration of different piles, and incompletely mixing of matured compost. Compost application resulted in a 26% increase of timothy hay yield in the year of application, improved hay raw protein content (106% increase) and soil nutrient status. Due to slow release characteristics of nutrients in compost, it is expected that timothy hay yield and quality will continue to be improved in the second and third year after application. In conclusion, ratio of sphagnum peat moss and fish byproducts for composting used in Ocean Earth Fish Compost was appropriate. Decrease in turning frequency (i.e. once per 1.5 week instead of once per week) may help the compost pile to reach higher temperatures. Nutrient concentration in compost leachate was too low to be used as a liquid fertilizer. Fish compost from Ocean Earth Fish Compost had a low salt concentration, and reasonably good N content. It can be used as a soil amendment, and has a potential for use in the organic farming/gardening market, but rigorous certification must be completed before selling to this market. Given peat moss may not be available for some of the coastal fishing communities, more research is needed for composting fish byproducts with other carbon sources.

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Introduction

Fish harvested in Alaska waters contribute about 65% of total human fish consumption in the USA (Bechtel, 2003). The annual seafood harvested in Alaska is over two million metric tons and after processing, there are approximately one million metric ton of fish byproducts (Crapo and Bechtel, 2003; Bechtel and Johnson, 2004). Fish byproducts can be processed to make various marketable products, such as fish oil, protein, or fish meal. But high investment for facilities, marketing channels, and cost of transporting these processed products out of Alaska are hurdles for establishing such facilities, especially for remote communities.

Food and fresh vegetables consumed in Alaska are mostly imported from west coast states of USA. Increase in production and transportation costs have put the food prices unprecedently high, especially in some off road communities. Promotion of vegetable production and community gardening is bottle-necked by poor soils (acidic soils, low in organic matter content) and nutrient deficiency. Fish byproducts in Alaska, depending on the fish species and components, vary in nutrient concentration. For example, Alaska pollock contains 25% protein in skins, 15.2% in heads, in comparison, pink salmon heads contain 13.9% protein. Currently, most of the fish byproducts are dumped as waste materials. But they can be a source of plant nutrients for food production.

Directly applying fish waste in soil causes problems of odor and attracting wild/domestic animals. Composting fish waste with locally available carbon sources is a good option for communities and vegetable growers in Alaska. Because of the variation of locally available carbon sources (cardboard, hay, peat moss), their properties and optimal mix ratios with fish waste for composting need investigation.

Three ingredients needed for facilitating a good composting are nitrogen (N) and carbon (C) sources, and a bulking agent for aeration. Fish byproducts are rich in proteins and can be used as a N source for composting. There are a variety of carbon sources for composting depending on their local availabilities. The decomposability for these carbon materials varies with their compositions. In general, the higher the lignin or recalcitrant carbon content, the lower the decomposability will be. The bulking agents can be wood chips, peat moss or shredded artificial materials such as used tires. Bulking agents (excluding peat moss) can be recovered for reuse. Ideally, the carbon and nitrogen ratio for composting starts at 30:1 and reaches 5 to 20 at maturity depending on feedstock (Epstein, 1996).

Composting is a biological decomposition process that has three phases: mesophilic, thermophilic and curing (Fig.1). In an ideal compost pile, the mesophilic phase often takes a few days, coupled with moderate temperature rise ($\leq 40^{o}$C); the thermophilic phase, in contrast, takes a few weeks with a sharp rise in temperature from 40^{o}C to 60 – 70^{o}C. This temperature is critical in killing most pathogens in feedstock. The curing phase can last a month or more. In this phase, compost will be stabilized and ready for package.

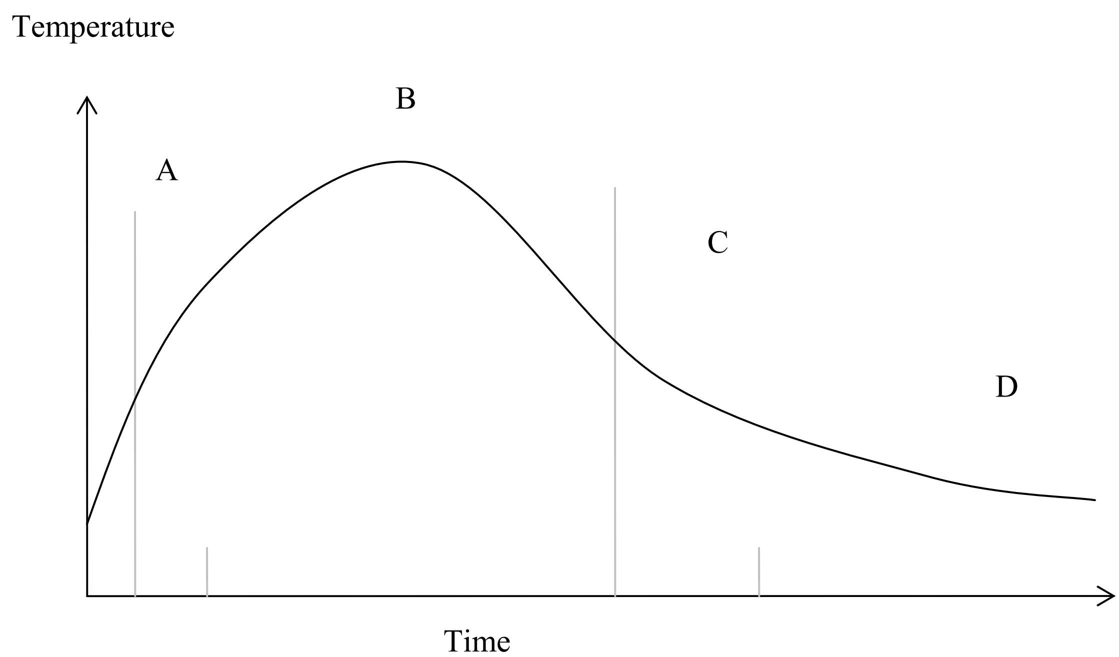

Fig.1. Illustration of phases in composting. A = mesophilic phase; B = thermophilic Phase; C = mesophilic phase; and D = curing phase.

There are several ways to treat fish waste. However, composting fish waste is regarded as a simple, economical and environmentally friendly approach to effectively treat fish waste (Martin, 2007). Many publications show how to compost organic waste materials, but most of them are developed based on materials such as sewage sludge, or animal manure. In these publications, especially for small scale home composting, animal meat waste in compost piles is not recommended for avoiding attraction of domestic or wild animals. Composting fish waste has been reported before. Frederick et al. (1989) recommended using three volumes of peat moss, one volume of fish waste, and one volume of covering material (compost or peat moss) to compost fish waste in a windrow in Wisconsin. Martin (1991, 2007) reported composting fish waste in

Newfoundland, Canada. In all these reports, peat moss and passive aeration are used. Peat moss both as a carbon source and as a bulking agent has been very successfully used in composting fish materials (Mueller, 1972; Martin, 1991; Frederick et al., 1989; Martin, 2007). For decomposability, peat moss with less degree of decomposition (brown color) is more suitable for use as a carbon and bulking agent for composting than the ones with a high degree of decomposition (black color). For outdoor composting facilities, weather (temperature and precipitation) also has a strong impact on the composting process.

Total quantity of fish waste in Alaska is substantial (1 million metric tons per year). Attempts have been made to develop low cost, locally used compost products from fish waste in Alaska. Baumann (2007) reported fish compost developed in Kenai using fish waste and spruce wood chips. A more systematic study was conducted in Sitka in 1998 by Sitka Tribal Enterprises and subcontracted to E&A Environmental Consultants, Inc. in Bothell of Wash. (E&A Environmental Consultants, Inc., 1998). The feedstock for the study is whole coho salmon (75%) fish from fish hatchery and black cod and red snapper heads and viscera (25%) and ground bark (60%) and sawdust (40%). Aerated compost piles were set up with wood material:fish waste ratios (4.1:1, 3.7:1, 2.9:1, volume base). The matured compost has a C:N ratio of 61:1, 52:1 and 40:1 respectively for these three feedstock ratios corresponding with 0.8%, 0.7% and 1.2% total N content. In 2005, Juneau Economic Development Council (JEDC) provided a feasibility study on how Alaska can achieve 100% utilization of fish waste with wood byproducts through passive aeration composting (JEDC, 2005). Using Kake Tribe as a model, the study concluded that making fish compost with wood byproducts is economically viable and can create local jobs. Ocean Earth Fish Compost, a company in Homer, Alaska, has composted fish byproducts since 2004 using sphagnum peat moss and fish byproducts transported from Deep Creek Custom Packing, Ninilchik, Alaska. The overall objectives of this project were to study quality of peat moss and fish waste cocompost from Ocean Earth Fish Compost and to determine its effectiveness when used as a soil amendment and as a potting material. To achieve this, this project focused on 1) monitoring compost temperature; 2) evaluating compost product quality; 3) evaluating compost leachate; 4) determining compost soil mix ratios for potting materials; and 5) determining impact of compost on hay crop growth.

Materials and methods

Site Description

Ocean Earth Fish Compost is located in East End Road about 20 miles from Homer's town center. The company started composting fish waste in 2004 using fish waste from Deep Creek Custom Packing, Ninilchik, Alaska, and locally available sphagnum peat moss. The compost site is located in a leveled peat moss field about one mile north of the East End Road. The peat moss used has a low degree of decomposition (brown color). The site is fenced with a solar powered electric iron wire fence to prevent intrusion of wild animals. The facility can compost three or four compost piles each year and timing of starting a compost pile is totally dependent on availability of fish byproducts. Two of the compost piles (June and early July piles) can reach maturity within a year of their start, while the others initiated in August will reach maturity in the next year. In each pile, there are approximately 12 totes of fish waste (800 to 1000 lbs/tote or 363 to 454 kg/tote) and 50 cubic yards (38.5 m^3) of peat moss. The compost pile is turned weekly by a front end loader. The finished compost is sold as soil amendment for home gardeners in the Homer area, and the company is planning to sell the compost to golf courses and school athletic fields.

Plate 1. Compost pile set up in early June in the compost site of Ocean and Earth. The wires were temperature sensors, and below the bucket was the HOBO data log.

Compost pile set up for study

A compost pile was established for this project in early June 2008. The pile consisted of 12 totes of fish waste (rock fish head, halibut head, some salmon fish head, and some fish bones) and 50 cubic yards (38.5 m^3) of sphagnum peat moss. The fish waste was mixed with peat moss and then buried by the same peat moss about 12 inches (0.3 m) deep. The pile was 14 feet (4.3 m) long, 12 feet (3.7 m) wide and about 8 feet (2.4 m) in height. The pile was turned weekly since its start. Three HOBO temperature sensors were set up in 5 (1.5 m), 3 (0.91 m), and 2 (0.61 m) feet above the ground in June 17, 2008 to monitor pile temperature during composting. In addition, temperature of a compost pile started in August was also measured over the entire winter of 2008/2009. Composite samples (4 sub samples) were taken from each side of the pile and at different heights on June 17, and July 9, 2008. On August 20, 2008, three replicated samples were taken from the pile. HOBO data were downloaded each time when the compost samples were taken. Compost leachate samples were taken in a nearby drainage ditch each time when compost samples were taken. Raw salmon fish head samples were taken at the beginning of composting.

Experiment for determining compost:top soil mixing ratio

Following were treatments used to determine optimal compost:soil mixing ratio: 1) 1/3 top soil + 2/3 compost; 2) 1/2 top soil + 1/2 compost; 3) 2/3 top soil + 1/3 compost; 4) top soil; 5) compost; and 6) peat moss. Top soil used in the experiment was from a virgin soil near a home garden; compost was from matured fish compost of 2007, and peat moss was collected from the compost site. Each of these treatments was placed in a container (3 feet (0.91 m) × 4 feet (1.22 m) × 0.75 feet (0.23 m) depth). The container was made of wood board and excessive water from watering was allowed to be drained. The containers were placed in an unheated semi greenhouse in which four sides were built with wood and only the roof was permeable to light. Two crops (radish

(*Raphanus sativus*) and green onion (*Allium fistulosum*)) were grown in the container, as test plants for biomass production and nutrient uptake. The seeds were planted in mid-June, and three replicated plant samples were taken from each treatment and for each vegetable in late August. Plant samples were oven dried (65^{o}C), weighed for biomass, and ground for nutrient concentration analysis. Because of quantity limitation of the dried plant tissue samples, the three replicates were combined, and ground (<2 mm) for chemical analysis for their nutrient concentrations. Samples of different compost/soil mixtures were taken on June 17, 2008 for determining their chemical properties. The samples were air-dried and sieved (< 2 mm) for nutrient analysis.

Experiment for determining compost nutrient values in timothy hay field

A timothy field that didn't receive any fertilizer application in the last five years was selected. The field was divided into two portions with about a half acre each. One section received fish compost application (100 t/ha or 40.5 t/ac) on June 20, and the other didn't. Replicated benchmark soil samples at two soil depths (0-15 cm and 15-30 cm) prior to the experiment were taken. The soil is Kachemak (NRCS Web Soil Survey) silt loam developed from loess with a pH 5.4, 0.5% total N and 6.7% total C. The soil was low in available phosphorus (<1 mg P/kg soil). Six replicated plant samples taken from 1 m^2 and three replicated soil samples (0-15 cm and 15-30 cm depth) were taken on August 20, 2008. Plant samples were oven dried (65^{o}C), weighed for biomass, and ground (< 2 mm) for chemical analysis for nutrient concentration. Soil samples were air dried, and sieved (< 2mm) for laboratory analysis.

Sample analysis

Samples (soil, compost and compost/soil mixture) were analyzed for total N, total C, mineral N (NH_4-N and NO_3-N), Mehlich 3 extractable P, and K, cation exchange capacity (CEC), pH and EC. Ammonium and nitrate in soil samples were extracted by 2 *M* KCl followed by determination in a Technicon II Autoanalyzer (Technicon AutoAnalyzer, 1973a, 1973b). Soil pH was determined in deionized water with a soil:water ratio of 1:1 (McLean, 1982). Total N and C in soil samples and manure samples were determined in a LECO CHN 1000 analyzer (St. Joseph, MI). Cation exchange capacity was determined by the ammonium acetate autoextraction method at pH 7.0 (Soil Conservation Service, USDA, 1982). Extractable P and K in soil samples were by Mehlich 3 (1.5 *M* NH_4F + 0.1 *M* EDTA) (Mehlich, 1984) followed by determination using inductive coupled plasma atomic emission spectroscopy (ICP-AES, PerkinElmer Optima 300XL).

Plant samples, after ground into < 2 mm, were analyzed for total nutrient concentration in plant tissues including total N, P, K, Ca, Mg, Cu, Zn, and Fe. In addition, Na and Mn were analyzed. The total N concentration was determined using the LECO CHN 100 analyzer. The remaining elements were determined by digesting samples in concentrated nitric perchloric acid (Jones and Case, 1990) followed by analysis using ICP-AES.

Compost samples were analyzed for total N and C concentration using the LECO 1000 CHN analyzer. In addition, ammonium, nitrate, pH, CEC, electric conductivity (EC), and Mehlich 3 extractable P, and K were determined. The methods for the analysis were the same as the ones used for soil and soil/compost mixture as discussed before.

Compost leachate samples were analyzed for total C and total N concentration using a Shimadzu TOC-V Combustion Analyzer (Shimadzu Scientific Instrument Inc., Columbia, MD, USA).

Data analysis

Biomass and soil/compost mixture data from containers were analyzed for variance (ANOVA) using a complete randomized design. Mean comparison was made at Least Significant Difference at ≤ 5% level. Bromegrass biomass yield and soil data from compost and non compost treatments were compared using a pair t test ($t \leq 0.05$). Statistix 8.0 software (Analytical Software Tallahassee FL, USA) was used for all data analysis.

Results and Discussion

Compost feedstock and compost pile temperature profile

Raw fish salmon head (composite of three heads) had a moisture content of 53.7%. It contained nutrients that are essential for plant growth (Table 1). The fish head had 5% N and 45% C in contrast with 1.1% N and 24% C of peat moss. Based on these C and N, the calculated C:N ratio for the compost piles was about 17 to 21:1, which is slightly lower than the recommended C:N ratio (25-30:1) in literature (Home and Garden Mimeo HG#35, 2005; Backyard Composting). However, the estimated C:N ratio could fall within the 25 to 30:1 if the bones and their proportion (which was hard to measure) in the fish waste were included in the analysis. The results of feedstock analysis also showed that there were high amounts of mineral N in the peat moss used for composting. This high mineral N was probably from the compost leadate of previous compost piles.

In addition, concentrations for P and K were high in fish head, showing that fish waste materials can supply the most important three essential plant nutrients: N, P, and K. Electric conductivity (EC) is a measurement of the amount of dissolved salts in solution. The relatively high EC (1.2 mS/cm) for the peat moss used in the composting indicated that the peat moss might intercept leachate from previous compost piles. In general EC for sphagnum peat moss is 0.09 to 0.13 for horticultural uses (Premier Horticulture, www.premierhort.com/eProMix/Horticulture/TechnicalData/pdf/TD2-PRO-MOSS-Hort-STU.pdf). But some sphagnum peat moss has a high EC (1.3 to 1.7) (FAO Biogas Process for Sustainable Development, www.fao.org/docrep/t0541e/T0541E0d.htm). The peat moss used in the compost pile had an acidic pH and high CEC, these characteristics can help to capture NH_4-N released during composting processes.

The results from analyzing compost samples taken from early June (compost starting time) to August (maturing stage) demonstrated an increase of nutrient concentrations (Table 2). The higher concentration in the July samples was caused by the heterogeneity of samples. Large semi-decomposed materials that existed in large chunk made it hard to take a representative sample consisting of both fish and peat moss (Plate 2). Nevertheless, when compared with the June sample, the trend of nutrient concentration increase can be seen in the samples taken in August (Table 2). The high NH_4^+ concentration in the August samples indicated substantial amount of mineral N released from decomposition of fish waste. All of these tested parameters indicated the undergoing decomposition process in fish waste composting. Compost pH changed very little, but cation exchange capacity increased slightly.

Table 1. Characteristics of compost feedstock for the compost pile set up in mid-June 2008 in Ocean and Earth, Homer, Alaska.

Analytical item[1]	Fish head	Peat moss
Moisture content (%)	53.7	6.5
Total C (%)	45.2	24.0
Total N (%)	5.0	1.1
C:N ratio	9.0	22
Total P (mg/kg dry matter)	19136	169
Total K (mg/kg dry matter)	3565	207
Ca (mg/kg dry matter)	465	NA
Mg (mg/kg dry matter)	638	NA
Na (mg/kg dry matter)	4569	NA
Cu (mg/kg dry matter)	4.4	NA
NO_3-N (mg/kg)	NA[2]	620
NH_4-N (mg/kg)	NA	63
Total Mineral N	NA	683
CEC (mmol (-)/kg	NA	49
pH (1:1)	NA	3.6
EC (mS/cm)	NA	1.2

[1]Composite samples of three were used for analysis.
[2]NA = Not analyzed.

Table 2. Chemical properties of compost samples taken at different time of composting for the pile set up in early June of 2008.

Analytical item	Sampling time		
	June	July	August
Moisture content (%)	1.5 ± 0.2[1]	3.4 ± 2.6	4.4 ± 1.3
Total C (%)	28.8 ± 0.2	26.8 ± 0.5	25.8 ± 1.1
Total N (%)	1.20 ± 0.01	2.06 ± 0.35	1.61 ± 0.11
C:N ratio	24	13	16
Total P (mg/kg dry matter)	22 ± 4	670 ± 284	168 ± 45
Total K (mg/kg dry matter)	143 ± 13	1122 ± 443	604 ± 78
NO_3-N (mg/kg)	226 ± 26	5 ± 1	157 ± 106
NH_4-N (mg/kg)	105 ± 74	9695 ± 3416	6057 ± 1387
Total Mineral N	331 ± 100	9700 ± 3415	6214 ± 1345
CEC (mmol (-)/kg	51.0 ± 11.3	54.5 ± 9.2	55.8 ± 4.0
pH (1:1)	3.7 ± 0.1	3.7 ± 0.2	3.7 ± 0.1
EC (mS/cm)	1.17 ± 0.04	1.06 ± 0.08	1.09 ± 0.04

[1]Standard deviation

Plate 2. Semi decomposed fish waste mixed with sphagnum peat moss. Representative sampling in this compost stage was difficult.

When other organic materials (i.e. manure or sewage sludge) are composted, pH rises toward the end of the composting process. The rise of pH can result in loss of N as NH_3 through volatilization. However, in this compost pile, the results showed that loss of N as NH_3 apparently was not possible with the pH of 3.7. The co-composting of fish waste with sphagnum peat moss didn't show an increase in pH because the sphagnum peat moss started with a very acidic pH, and even though cations from fish waste were released during decomposition, their concentrations were not high enough to cause a rise in pH. The matured compost had a C:N ratio of 16:1 (Table 2), much lower than 40 to 60:1 fish compost reported by Sitka Tribal Enterprises in 1998, in which the whole fish and fish waste were composted with saw dust and wood chips.

Temperature increased rapidly during the composting process (Fig. 2). A week after compost started, temperature of the compost pile rose to 30.6^{o}C (87^{o}F) and then dropped to 16.7^{o}C (62^{o}F) after turning, and rose again to 46.1^{o}C (115^{o}F) and stayed there for about three days (Fig. 2). Unfortunately, data for temperatures after the third week was not valid due to disturbance by birds. There were a good number of ravens in the compost site. The sensors were picked out by ravens and buckets used to cover the HOBO were removed, leaving HOBO data logs exposed to rains and became inaccessible by computer. Even so, this limited temperature record proved that the pile indeed was composting. The photograph taken on July 9 also showed high temperature status in the compost pile (Plate 3). In static pile composting, US EPA requires the pile to reach 55^{o}C (131^{o}F) for three days to kill human pathogens (US EPA 40 CFR Part 503 Regulation). The 115^{o}F in the compost pile appeared lower than EPA required, but reducing turning frequency may help piles reach the 131^{o}F. For turning frequency in an eight-week compost period (typical duration for composting), five turnings are recommended (Sandeen and Gamroth, 2003). Therefore, changing from current weekly turning to 1.5 or two-week turning intervals may be necessary and it may help to raise the temperature to the required level. Additional small trials may be needed to verify this. Temperature sensors in the compost pile started in August indicated that there were some composting activities in late August and September, but no composting activities at all from October to May 30 (Fig. 3).

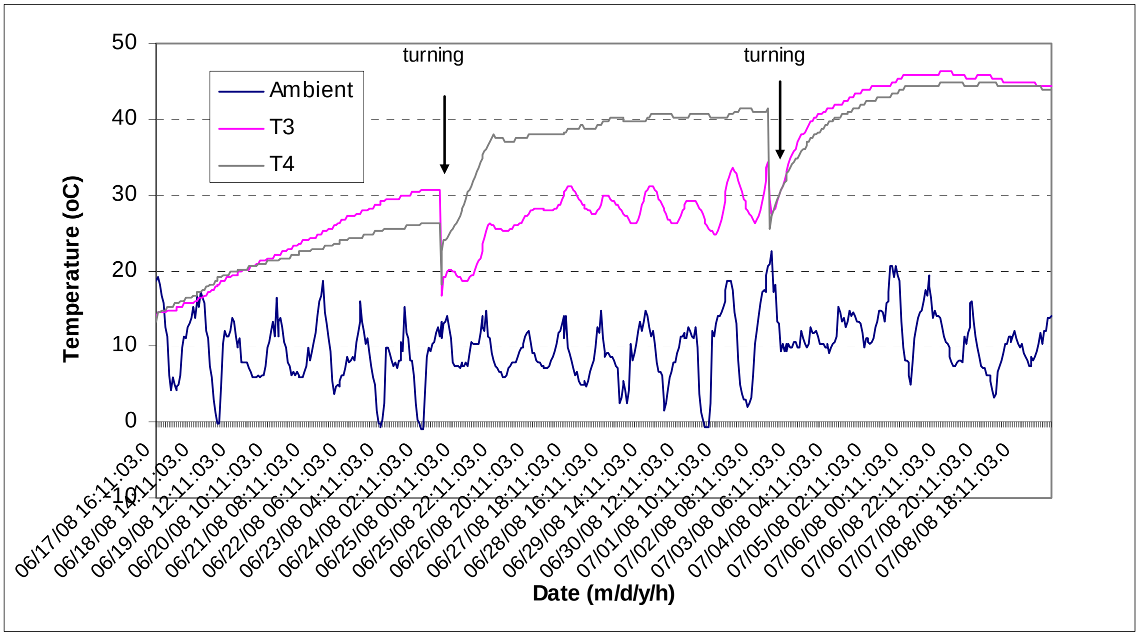

Fig. 2. Temperature profile of the compost pile started June 15, 2008. T3, and T4 were the temperature sensors at middle and bottom of the compost pile, respectively.

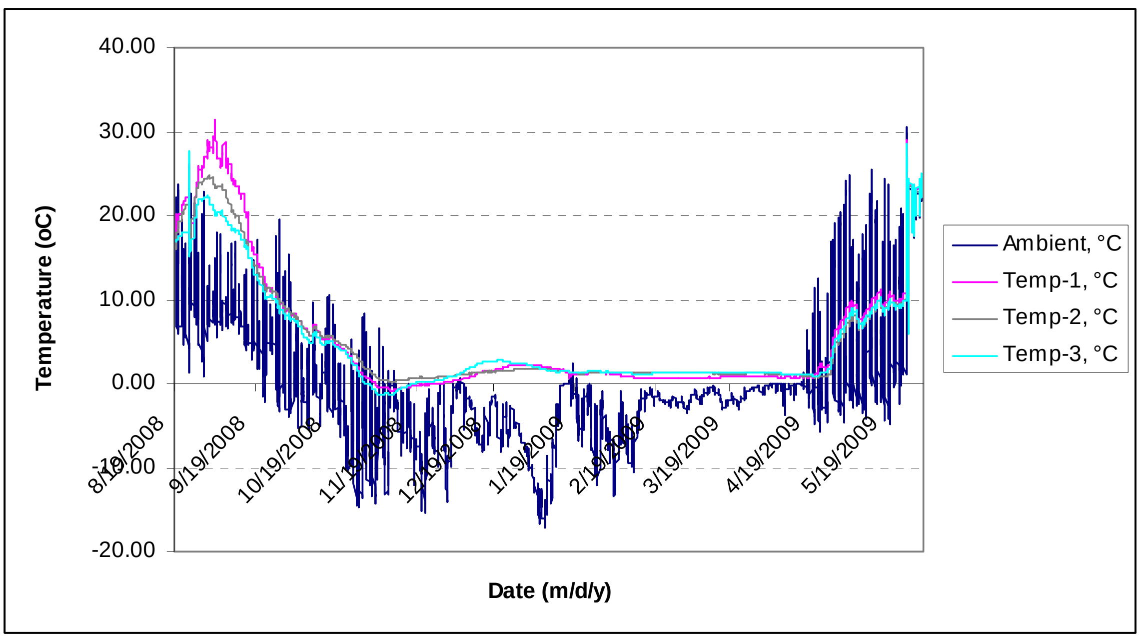

Fig. 3. Temperature profile from August 19, 2008 to May 31, 2009 for the compost pile started in mid-August 2008. Temp-1, Temp-2 and Temp-3 were sensors at the bottom, middle, and upper locations of the pile, respectively.

Plate 3. Steam coming from the compost pile set up in early June. The photograph was taken July 9, 2008.

Compost leachate sampled from nearby drainage ditch

The drainage ditch is close to the compost pile. There were substantial amounts of water from snow melting in over-wintered compost piles and rain water during composting season (May to September) running into the ditch (Plates 4 and 5). Water samples from the drainage ditch were taken at different times to determine if there was significant amount of N in water. The results indicated that both the total C and total N in the samples increased over sampling time (Fig. 4). The May sample had the lowest total N (2.3 mg/L) and total C (21.6 mg/L), indicating that water from snow melting didn’t bring much nutrients from the nearby over-wintered compost piles. This was partly reflected by the temperature data since no compost activities ever occurred during the winter. The total N and total C in August samples increased to 9.6 mg N/L and 44.0 mg C/L, showing rain water carrying nutrients into the drainage ditch. However, the amount of N in the samples is still too low to be marketed as liquid fertilizers. The soluble N concentration should be at least 50 to 100 mg N/L based on some commercial gardening fertilizers in the market (Scotts Horticulture http://www.scottspro.com/products/fertilizers/wsf_faq.cfm).

Plate 4. Drainage ditch near the compost site in which compost leachate samples were taken in May, July, and August, 2008.

Plate 5. Compost site after rain, two piles were in the far side of the photograph.

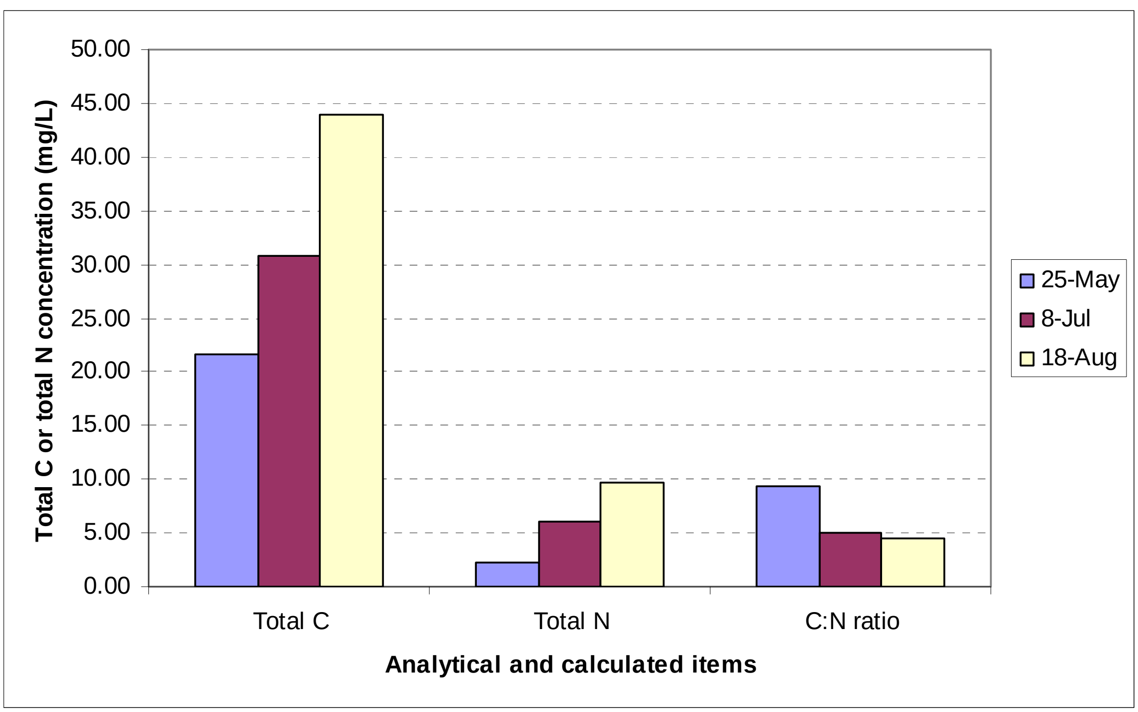

Fig. 4. Total N and total C in water samples taken in the nearby drainage ditch at different times in 2008. C:N ratio was calculated.

Container Experiment

Nutrient concentrations decreased as proportion of compost in the mix decreased (Table 4). Accompanying this trend was the EC (with exception of 1/2 soil and 1/2 compost). One factor preventing compost being directly used as potting materials is its high salt concentration (reflected by EC). Most compost has an EC value 4 mS/cm or higher. With this value, the majority of domestic plants won't grow, especially vegetables. Some compost even has an EC value of 13 mS/cm (Sancheez-Monedero et al., 2004). The fish compost in this study had an EC value of 1.2 mS/cm, which in general should not harm the growth of most vegetables (Blaylock, 1994; Swift, 2009). However, fish compost piles may vary in salt concentrations, therefore it is not recommended that 100% finished fish compost should be directly used as potting materials.

The soil used for mixture also had a high mineral N, and high available P (M3-P) content (Table 3). The soil was taken from virgin soil near a home garden. Its high nutrient concentrations might dilute the impact of compost on plant biomass production when used as a mixing material in the experiment. The sphagnum peat moss used in the experiment was also high in nutrients and salt concentration (Table 3), caused probably by the salt and nutrient leached out from previous compost piles.

Green onion is sensitive to salt. Even with minor salt concentration (EC = 1.4 to 2.7 mS/cm), a 25% yield reduction should be observed (Blaylock, 1994), and there will be no yield reduction when EC is less than 1.3 mS/cm. Radish, on the other hand, is moderately sensitive to salt. A 25% yield reduction can only be seen when EC is within the range of 2.7 to 6.3 mS/cm. No yield reduction can be found when EC is ≤ 3.0 mS/cm

(Blaylock, 1994; Swift, 2009). Observation on July 9 after seeding for three weeks showed no visual yield reduction (Plates 6, 7 and 8). However, the color of the leaves, especially radish leaves grown in 100% compost or 50% compost + 50% top soil appeared greener than the ones in 100% top soil. This trend continued to August 20, 2008 when plant biomass samples were taken. The plant biomass for both radish and green onion showed no statistical differences among treatments (Table 4). However, the probability of F value for green onions was 78%, much greater than that 27% of radish, indicating large variations among the individual green onion plants sampled. It might be possible that high salt concentrations existed in some spots which caused variations among individual plants. The apparent yield of radish was reduced when proportion of compost reached 2/3 in the mixture. No trend was found in biomass of green onion (Table 4). The plant tissue N concentration in radish was high in 100% compost treatment indicating plant uptake of N from the fish compost. But it was not so (e.g. K) for other elements except Na (Table 4). Sodium concentration in plant tissues was directly related to proportion of compost in the growth medium for both radish and green onion (Table 4). Unlike similar experiments reported in literature in which compost used has much higher EC values (> 4 mS/cm) and symptoms of salt damage in plants and biomass reduction can be easily observed (Sancheez-Monedero et al., 2004), the compost used in this experiment had a low EC value that resulted in no statistically significant biomass reduction, even in 100% compost treatment. Nevertheless, recommendation for proportion of compost in a potting mix should not exceed 50%. This recommendation was based on the observations of plant growth in containers, on variation of salt concentration for different fish compost piles, and on possible incomplete compost mixing.

Plate 6. Radish and green onion grown in the medium of 100% soil

Plate 7. Radish and green onion grown in 100% compost.

Plate 8. Radish and green onion grown in the medium with 50% compost and 50% top soil.

Table 3. Chemical characteristics of compost-soil mixture.

Treatment	Mineral N			M3-P	M3-K	Total N	Total C	CEC	pH	EC
	NH_4-N	NO_3-N	Total					mmol/kg soil		mS/cm
	mg/kg					%				
1/3 soil+2/3 compost	1212*a*[1]	75*b*	1287*ab*	203*b*	368*b*	1.02*b*	18.34*c*	41.3*bc*	3.6*cd*	0.9
1/2 soil+1/2 compost	993*a*	38*bc*	1031*b*	118*c*	352*b*	0.81*c*	14.17*d*	36.8*cd*	3.7*c*	1.9
2/3 soil + 1/3 compost	586*b*	22*c*	608*c*	59*de*	363*b*	0.72*d*	12.45*d*	35.5*cd*	4.0*b*	0.7
All soil	132*c*	14*c*	146*d*	21*e*	278*c*	0.56*e*	9.48*e*	30.8*d*	4.6*a*	0.6
All compost	1283*a*	121*a*	1404*a*	304*a*	440*a*	1.21*a*	22.81*b*	50.8*a*	3.5*d*	1.2
All peat	383*bc*	24*c*	406*cd*	77*cd*	124*d*	1.09*b*	25.28*a*	47.1*ab*	3.6*cd*	1.1
Probability (*F*)	0.002	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0007	<0.0001	NA[2]

[1]Values with different letters indicate Least Significant Difference ≤ 5%.
[2]Composite samples were used for the EC measurement, therefore, no statistical analysis was conducted.

Table 4. Plant biomass, N,P, K and metal concentration in above plant tissues grown in different compost-soil mixture.

Treat.[1]	Species	Biomass[2]	N[3]	P	K	Ca	Mg	Na	Cu	Zn	Mn	Fe
		g/plant	g/100 g					mg/kg				
1	Radish	1.9	3.63	0.45	2.17	0.90	0.15	2671	5.3	59	105	2597
2		2.1	4.57	0.46	3.40	1.02	0.20	3234	4.1	73	221	2146
3		1.8	4.21	0.37	4.05	1.02	0.21	2271	4.7	71	271	2639
4		2.1	3.30	0.24	4.29	0.96	0.24	1017	4.0	66	106	1601
5		1.9	5.08	0.45	2.96	0.92	0.15	3935	4.6	67	107	649
6		1.7	2.75	0.33	2.20	0.61	0.15	1615	5.1	38	83	1713
Prob.(*F*)		0.28	NA[4]	NA	NA	NA	NA	NA	NA	NA	NA	NA
1	Green onion	1.5	6.68	0.49	6.51	1.79	0.31	9206	3.2	74	143	314
2		1.3	6.41	0.38	5.73	2.26	0.36	8327	2.7	99	341	179
3		1.4	6.55	0.43	7.81	2.12	0.36	5331	3.6	69	141	437
4		1.2	6.13	0.33	6.44	2.53	0.42	2022	2.8	63	71	186
5		1.5	6.08	0.40	4.31	1.68	0.29	13900	1.5	70	83	194
6		1.3	6.48	0.44	5.15	2.22	0.38	7946	3.8	61	109	194
Prob.(*F*)		0.76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

[1]Treatment labels: 1= 1/3 soil +2/3 compost; 2 = 1/2 soil + 1/2 compost; 3 = 2/3 soil + 2/3 compost; 4 = all soil; 5 = all compost; 6 = all peat.
[2]Values with different letters indicate Least Significant Difference ≤ 5%.
[3]Composite samples were used for tissue nutrient concentration analysis, therefore, statistical analysis was not conducted.
[4]NA = not applicable.

Timothy hay yield and soil properties impacted by fish compost application

Timothy hay after receiving compost application (~ 100 t/ha) showed a lush green color as compared to the hay not receiving compost application (Plate 9), showing nutritional values of fish compost in promoting agricultural crop growth in the field. Compost application increased soil N (both available N and total N), extractable K, total C, but no difference from compost application was found for soil CEC at 0-15 cm depth. Except K, no impact from compost application was found in 15-30 cm depth (Table 5).

Biomass of Timothy hay with compost application was higher ($p = 0.006$) than the ones without compost application (Table 6). Compost application also improved Timothy hay quality indicated by high N concentration. Along with N, higher P and K concentrations in the Timothy tissues sampled from the field that received compost application were also found.

Unlike inorganic N fertilizer in which 100% of N is water soluble and ready for plants to absorb after application, most N in the compost is in organic forms. The release of the organic N depends on breakdown of organic matter in compost facilitated by soil microorganisms. The total amount of N applied (~1600 kg N/ha) in this study is expected to be released over many years. It would be interesting to learn how much N will be used in the second or third year after application under Homer's climatic conditions. In literature, on average, plants use about 20% of N in the first year, 5% in the second year, and 3% in the following two years (Deluca and Deluca, 1997) after composted manure application. Zhang et al. (2006) reported 8%, 2%, and 1% of N recovery in three years after solid cattle manure application in Palmer, Alaska. In this study, the calculated Timothy N recovery from fish compost was about 3%, lower than

Zhang's report on cattle manure in a similar climatic condition. This might be attributed to different N forms between cattle manure and the fish compost. Future study should be focused on forms of N in fish compost, rate of fish compost N release over time, and total availability of N in fish compost to plants.

Plate 9. Timothy hay after receiving 100 t/ha compost application (far) in contrast with the ones not receiving (near). Photo was taken in August 20, 2008.

Table 5. Chemical characteristics of soil samples taken on August 20 after receiving compost application in late June of 2008.

Depth	Treatment	Mineral N			M3-P	M3-K	Total N	Total C	CEC	pH
cm		NH_4-N	NO_3-N	Total						
		mg/kg					%			
0-15	Compost	10	19*a*	29	1.3	84	1.00*a*	8.00*a*	23.7	5.1*b*
	No compost	9	3*b*	12	<1	69	0.68*b*	6.67*b*	23.8	5.4*a*
	Sd	1	1	2	NA[3]	2	0.02	0.11	0.42	0.04
	Prob (t)	0.56	0.001	0.07	NA	0.07	0.01	0.01	0.98	0.04
15-30	Compost	4	2	7	<1	20	0.39	5.7	19.9	5.2
	No compost	4	1	5	<1	15	0.37	5.3	22.3	5.4
	Sd	<1	1	1	NA	2	0.24	0.90	2.23	0.9
	Prob (t)	0.93	0.08	0.22	NA	0.03	0.53	0.51	0.52	0.10

[1]Values with different letters indicate t test at ≤ 5%.
[2]Sd = Standard error.
[3]NA = not applicable since the P level was below the detection limit of 1 mg P/L.

Table 6. Biomass of hay, and N,P, K and metal concentration in above ground Timothy hay tissues.

Treat.[1]	Biomass	N	P	K	Ca	Mg	Na	Cu	Zn	Mn	Fe
	kg/ha	%					mg/kg				
1	3362 *a*[2]	2.53	0.26	1.35 *a*	0.71	0.28	396	5 *a*	57	108	86 *a*
2	2640 *b*	1.23	0.11	0.67 *b*	0.74	0.27	143	3 *b*	46	96	62 *b*
Sd[3]	209	0.23	0.01	0.11	0.04	0.02	95	0.03	6	8	7
Prob. (t)	0.006	0.0002	<0.0001	0.0001	0.49	0.59	0.02	<0.0001	0.08	0.10	0.004

[1]Treatment description: 1 = with compost application; 2 = without compost application.
[2]Values with different letters indicate t test at ≤ 5%.
[3]Sd = Standard error.

Conclusions

The recipe for fish waste compost (12 totes of fish waste and 50 cubic yards of peat moss) can facilitate the composting process with a rise of temperature to 115^{o}F. It is recommended that turning frequency may need to be reduced to once per 1.5 week from current once per week to increase temperature to 131^{o}F as required by US EPA. The matured compost had a C:N ratio of 16:1, which was in the range of most matured compost reported. In addition to N, the matured compost contained other plant essential nutrients as well.

Total N in the compost leachate collected from the drainage ditch varied in sampling times. The highest N concentration found in the leachate was 9 mg N/L sampled in August, and this amount of N was not high enough for using as a source of liquid N fertilizer.

Even though soluble salt concentration in the fish compost was low (EC < 2 mS/cm), it was recommended that the proportion of compost used as a potting material should not exceed 50%. It is also recommended that lumps in a finished fish compost should be crushed and well mixed before use.

Fish compost can be used as a soil amendment to improve soil nutrient status and to increase hay production. This research used a 100 t/ha application rate to demonstrate the nutritional values of fish compost and its residual effect. In practice, the application rate can be lower. The recommended rate for fish compost application in a hay field is 25 to 30 t/ha (11.4 to 13.6 t/ac).

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September 22, 2009

Ocean Earth Compost
48750 East End Rd.
Homer, Alaska 99603

Greetings Messrs Dr. Zhang, Palowski, Browning, Van Veldhuizen and Berger:

I'd like to take this opportunity to thank Dr. Mingchu Zhang along with Bob Veldhuizen and the staff at the University of Alaska Fairbanks, for providing the scientific and technical expertise, in what I deem as a successful research project in converting fish waste into a viable and important soils amendment for various uses in Alaska. Additionally, I'd like to recognize Dr. Zhang for his scholarly reporting and producing the final report "Composting Fish Byproducts with Sphagnum Peat Moss: An experience from Ocean Earth in Homer".

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Sincerely,

James Van Oss (Grantee)
Ocean Earth Producer