COMPOSTING FISH BY-PRODUCTS:

A FEASIBILITY STUDY

Time & Tide RC&D
Mid-Coast Compost Consortium
1988

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1 Introduction

In the summer of 1987, a fish composting demonstration project was developed in Maine by a consortium of private and public agencies[1]. These persons and organizations shared a grave concern about the fate and disposition of fishery by-products originating in fishing industries scattered along the central Maine coast.

Whereas formerly fishery by-products were easily and inexpensively disposed of, escalating costs and environmental pressures have rendered many of the traditional measures less attractive.

Landfilling and land-application, once routinely practiced, have met serious practical and environmental limits. Environmental permitting complexities requiring a process of public review and ultimately public opposition, have made efforts at land-application increasingly frustrating. Despite their long history of existence, industrial processing methods, in which materials are rendered into other products such as fish meal and mince are for economic and lingering environmental reasons still not highly attractive. In fact, with the closing of the last remaining New England fish rendering facilities, among them Rockland, Portland and Gloucester based firms, fishery plants which have formerly sent all wastes for rendering must seek other alternatives. Finally, ocean dumping by barging to sea, is not only presently uneconomic but is eliciting increasing complaints from other fishing industries about habitat disturbances associated with the target fish crop, particularly those using waters nearer to shore.

Sensitive to the emerging issue, the Mid-Coast Resource Utilization Consortium was formed by the Time & Tide Resource Conservation and Development Area in mid-coast, Maine[2]. A sequence of projects were developed in an attempt to research a new alternative to fish-waste disposition,– composting, a treatment method virtually unknown to the fishing industry prior to 1986[3].

Herein presented is a feasibility analysis for composting fish wastes. The project included a regional waste material inventory, a composting demonstration, and a market survey for compost products. This report integrates the several aspects. It has been our endeavor to present the information in such manner as other individuals and organizations may make informed decisions concerning composting of fish wastes. The report is not necessarily complete, never the less it is our hope that it may stimulate interest such that others may learn and gain from this effort, supported as it has been by many outstanding persons and organizations.

This report omits specific information concerning certain phases of the project. A full review of the by-product materials inventory was presented in a separate report [4]. Similarly, the technical data from the demonstration project and the market survey results are found in separate reports [5] [6].

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[1] a listing of the project participants is attached in the appendix table C

[2] A locally controlled resource oriented organization having staff provided by the USDA's Soil Conservation Service

[3] a review of accepted waste technologies up to 1986 is seen in **Fish Waste Handling Systems for New England** New England Fisheries Development Foundation, Boston, MA

[4] Compostable By-Products in the Mid-Coast Area of Maine. 1987 *by* M.D. Seekins & W. Walton, Time & Tide RC&D

[5] Compost Demonstration *by* Woods End Laboratory, Time & Tide RC&D

[6] Mid-Coast Compost Project Market Study *Report to National Coastal Resources Institute* 1988; Time & Tide RC&D, Waldoboro, ME

2 Project Overview

2.1 By-products Inventory

As a prelude to the composting demonstration project, an inventory was made of by-products currently disposed of in one form or another in the Mid-coastal region of Maine. It was our interest to compare the proportions of fishery by-products with other commonly encountered wastes including those from food, farm and municipal sectors. The data was collected partly to lend perspective to the issue of wastes as well as to provide estimates on the magnitude of compatible ingredients available for composting with fish materials.

A summary of the results of this data collection process are presented Table 1, in which materials are grouped by type. The separate report concerning the inventory process identifies all the significant, individual materials [7].

Table 1: COMPOSTABLE BY-PRODUCTS INVENTORY
1987–Mid-Coastal Region
Waldo-Knox–Lincoln–Sagadahoc Counties

By-Product Material	*est.* Total Production
Apple Pomace	71
Cardboard	1,700
Clam + Mussel Shells	640
Crab-Lobster-Shrimp	600
Fish Waste	10,500
Chicken Cage-Manure	9,000
Chicken Litter	10–20,000
Horse Manure	9,020
Poultry Processing	2-3,000
Seaweed	12,360
Vegetables	6,500
Whey	1,600
Wood Chips	7,425
Sawdusts	30,625
TOTAL TONNAGES	112,841
est. Nitrogenous Fraction	52,610
est. Carbonaceous Fraction	60,231

The inventory process suggests that a quantity of carbon comparable to all nitrogenous by-products exists whereby composting could be accomplished with a minimum of required material trucking. However, by the same token, it suggests that local shortages of carbon are likely to exist *if all the nitrogenous wastes were to be composted in this region.* Most likely, this would not be the case, and therefore if fish wastes are targeted for composting, there should be no

[7] Seekins & Walton *op. cit.*

limitations of carbonaceous material.

Of the needed carbon sources, competition exists for their use elsewhere than in composting. Wood chips are routinely purchased for burning in energy generating boilers, sawdust and shavings for animal bedding material and bark for horticultural purposes. Of these, sawdust poses the least competition since (i) the prices paid by farmers are not high and (ii) considerable reserves of aged, stockpiled sawdust exist having no market. Finally, there exists a considerable network of truckers throughout New England who routinely haul large amounts of sawdust and other wood products. Forming a relationship with such persons is indispensable to acquiring a constant supply of carbon for composting.

Another carbon is peat moss which is prized both for composting and horticultural uses elsewhere. We did not assess its reserve since it is not a by-product, but have included some discussion concerning it (see Section 3.1).

2.2 Demonstration Project

Previous- and very recent- attempts to compost fish wastes in Maine [8] [9] had dealt only with small scale applications of composting technology. Elsewhere other recent attempts likewise utilized small-scale layering techniques for composting [10] [11]. It was our concern to test fish composting on a significantly larger scale utilizing equipment specifically designed for modern operations.

Of particular interest was implementing mechanically aerated "windrow" methods which make use of power turning machines. In general, this kind of equipment has been designed for compost operations ranging from a minimum of 500 ton up to approximately 100,000 tons per year capacity.

For purposes of contrast, we also wished to test "static pile" compost methods which do not use mechanical turning equipment. Such methods are typically utilized by medium-sized municipal facilities composting sludges. As the name implies, it does not involve actually moving or turning materials and therefore no large equipment is required. However, because the method does not allow for homogenization during composting, initial power mixing becomes a necessity. For this reason, a large batch mixer was incorporated into the demonstration.

It should be noted that the comparison of these methods was weighted in favor of the mechanically aerated windrows. Of the approximate 800 cubic yards composted, only about 50 yards were used in the static pile. The primary reason for this is that- as mentioned- the windrow turning machine which was acquired for the project affords composting of fairly large volumes of material. Other aspects which would influence deciding on one method over the other are discussed more fully in the section on equipment operation.

Therefore, a demonstration project was organized in which materials where brought to a permitted site and composted from approximately August 1, 1987 through October of that

[8] Composting Fish Waste with Peat. *by* J.L. Brooks 1986 Univ. Maine Dept Civil Engineering, Orono ME

[9] Report to North Atlantic Products on Bench-Scale Composting of Fish-Gurry with Various Carbon Sources *by W. Brinton* 1984 Woods End Laboratory, Mt Vernon ME

[10] Composting Fishery Wastes—Washington Island Pilot Project. Interim Report *by* Lynn Frederick 1988 University of Wisconsin, Sea Grant Institute

[11] Feasibility of Preparing High Quality Composts from Fish Scrap and Peat with Seaweeds or Crab Scrap *report by S.P. Mathur et al.* 1986. Land Resource Research Institute, Ottawa, Ont.

year. The project ultimately produced about 500 tons of finished compost.

2.3 Market Study

A market study of composts and related products for Maine was undertaken by the Consortium[12] as part of the overall project. In this survey an attempt was made to identify the principal organic products in the market, their source and distribution system, prices and benefit segments.

Some of the most significant findings included the wide range of organic materials and prices now being paid for them. These variations apparently reflect a number of factors including differences in perceived effectiveness of material, relative likelihood of contaminants, availability of manufacturers rebates, and subsidization of production costs by public funds (*e.g.* sludge composts).

Volume estimates from the study indicated that between 90,000 and 100,000yd^3 of *compost-related* material are sold in packaged form in Maine annually and that over 130,000yd^3 are sold in bulk. The packaged material is about two-thirds baled peat or peat-based potting mixes. Sixty-percent of the remainder is sold as topsoil or potting soil and forty-percent is either composted or dehydrated cow manure.

Finally, an important finding of the market survey was that approximately 20% of the respondents to the survey said they would definitely buy fish based composts. It appears that there is a perception that compost containing fish would be very effective as a soil amendment and for fertilizer. There was some concern expressed for odor of product. Thus, with this limitation, it is clear that there exists considerable potential to develop a positive market-oriented strategy for fish-waste disposition.

[12] Mid-Coast Compost Project Market Study *op. cit.*

3 Material Technical Parameters

3.1 Composting Ingredients Used

Nitrogenous - The primary focus of the composting project was fishery by-products including: dogfish-gurry, whole herring, groundfish (flounder racks), as well as crab and lobster shells. Also considered but not included in the demonstration project were shellfish (mussel) by-products.

The carbon:nitrogen (C:N) ratios of fishery by-products are very low (*i.e.* 3-5) owing to the meaty, proteinaceous nature of the fish. Materials of this sort are highly decomposable by nature, but owing to protein decomposition products which include volatile amines, amides and ammonia the malodorous potential is very great. For these reasons, rotting fish presents a known attractant to flies, rodents and other small mammals (see discussion in Section 3.2.1).

In contrast, the carbonaceous ingredients, which ranged in C:N from 50 to 240 for horse litter and sawdust, respectively, are expected to balance the nitrogenous with a non-odorous, carbon or energy rich substratum, useful for composting. The success of composting will rest on the proper blending of such diverse materials. In Table 2 we show the principal fishery by-products and their analyses.

Table 2: COMPOSITION OF FISHERY BY-PRODUCTS

Fish Material	Solids %*wet basis*	Nitrogen %*dry basis*	Volatile Solids %*dry basis*	C:N	pH 1:1 H_2O	Sodium %*dry basis*
Crustacean Mix	39.0	7.9	63.0	4.0	7.8	0.6
Dogfish Gurry	22.0	11.0	90.0	5.0	8.1	0.8
Herring	27.0	13.4	89.0	3.3	6.7	0.9
Flounder Racks	24.0	14.2	89.0	3.0	6.7	0.5
Processing Sludge	6.0	6.8	68.0	5.2	9.1	2.3
Mussel Waste	37.0	3.6	17.0	2.2	6.3	0.7
Breading Crumbs	90.0	2.0	96.0	28.0	5.9	1.2

Solids content was moderately low in the range of 22–39%, with the exceptions of processing sludge and breading crumbs which fell to either extreme side. Coincidentally, our carbonaceous ingredients were also somewhat moist, or low in solids. Thus, mixing to achieve proper moisture— to avoid having piles too wet— would take precedence over carbon:nitrogen balancing *per se*. In Figure 1 and Figure 2 we show the relative carbon:nitrogen ratios and moisture contents for the materials used in the project.

Previous compost testing suggested that fish oil content would not pose a problem in decomposition of such a mix, and so the matter was not specifically pursued. However, there is a

Figure 1: CARBON : NITROGEN RATIOS OF SELECTED WASTES

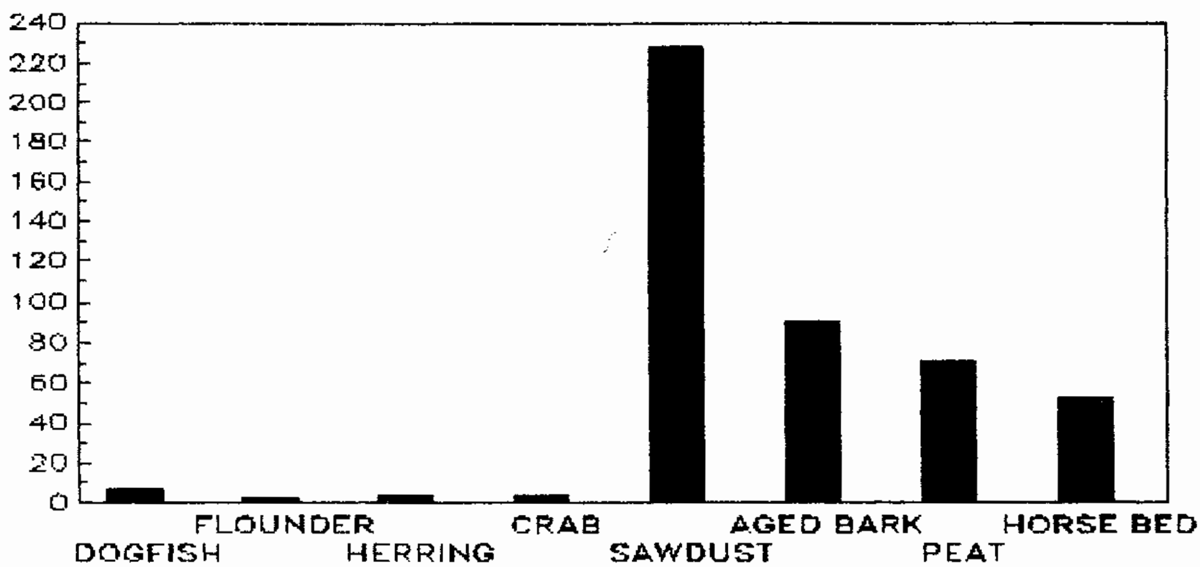
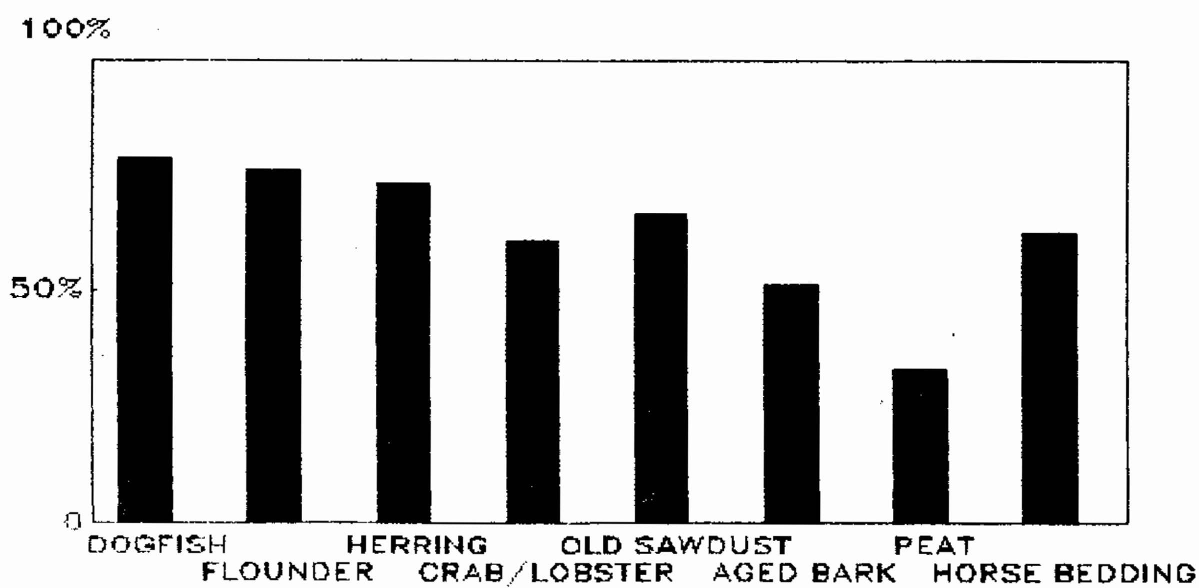


Figure 2: MOISTURE CONTENT OF SELECTED WASTES



definite connection of oil content to odor retention, since oil hydrocarbons are significantly more resistant to decomposition than other carbohydrates. Oils are partly volatile and tend to cling, thus the matter may deserve some attention for further composting efforts.

Carbonaceous - Several carbonaceous materials were identified in the resource inventory and laboratory tests were conducted on them. Of these tests, some selected C:N ratios are seen in Figure 1.

Previous research with fish-gurry composting in the Northeast has focused on peat mosses as the principal carbonaceous ingredient. Peat contains significant amounts of carbon and a high ratio of carbon to nitrogen, a desired attribute in composting. Furthermore, peat's highly porous physical nature, with moisture retention capacities approaching 1000%, mean that its absorptivity potential for any liquid waste will be high. Earlier trials have shown that peat is useful and possibly superior to other carbonaceous products in stabilizing ammonia and odor in fish by-products [13].

Peat is a resource in plentiful supply in some parts of the world, including Maine with reserves estimated to exceed 100-million dry tons[14]. It is therefore noteworthy that for all practical purposes peat is currently not available in Maine. Where it is produced, such as in Quebec and New Brunswick, it is utilized exclusively for a high-end market in the form of bagged horticultural products [15].

Sawdust has number of characteristics that make it a useful carbonaceous material for composting. The high C:N ratio allows it to balance a material such as fish that is high in nitrogen. The low pH tends to help prevent ammonia volatization. The moderately high absorbency means it can hold large quantities of wet material. We estimated that sawdust has a 100 to 1000-fold greater surface area than wood chips. Owing to this, sawdust should be more effective in providing carbon and in absorbing and desorbing moisture.

Not all sawdusts perform equally. Hardwood sawdusts are generally considered to be more effective in composting than softwoods. The difference probably relates to the concentration of resins or oils in the wood. Aged sawdusts also perform differently that fresh sawdust. Generally, older sawdusts are wetter and therefore will absorb less moisture and may heat up more slowly. However, older sawdust may be partially decomposed, and therefore may finish composting sooner.

All these variations must be considered when selecting a carbon source, and each source may require some preliminary experimentation to determine how best to use it in composting.

3.1.1 Recipe Development for the Compost

The basis for composting is the oxidative metabolism of carbohydrates by microorganisms in an environment containing adequate nutrients and moisture [16]. Traditionally, the emphasis is on mixing carbon or energy containing matter with nitrogen (nutrient containing) matter in such ratios as are dictated by microbial metabolic requirements. For example, for each

[13] Brinton, W.F. *op. cit.* & Mathur S.P. *op. cit.*

[14] Peat Resources of Maine. Maine Geologic Survey, Dept. of Conservation, 1984

[15] two principal suppliers, Premier Peat, Ltd. and Conrad Fafard, Inc. produce over 30 millions bales/year of peat products with a retail value exceeding US$100 million.

[16] *see for example* Golueke. C.G. (1972) Composting: A Study of the Process and its Principles, Rodale Press

100 parts of cellulose consumed, microorganisms will need approximately 3 parts of nitrogen. Additionally, it is important for aerobic microorganisms that the compost mass be relatively porous, containing only enough water to effect a 60-70% saturation of the materials water-holding capacity. Understanding the nutritional requirements of microorganisms, therefore, forms a basis for composting recipe development.

Nitrogenous (meaning proteinaceous) materials, particularly those of fish origin, which can be as high as 12% N, require careful blending with other carbonaceous matter so as to effect transformation of potentially highly malodorous protein decomposition products into organic compositions. Where combinations that are too low in the ratio of carbon to nitrogen are employed, it is likely that they will be malodorous to the point of attracting flies and rodents, possibly leading to nuisance complaints. Therefore, the model of using large-particle wood matter as bulking agent alone, was considered to be unsuitable for the Waldoboro demonstration project. Rather, a mix of carbon of small particle sizes was selected.

Invariably, composting will require mixing two or more materials having markedly different qualities. For example, as we have shown, a fish gurry of high nitrogen content will probably be blended into a relatively large volume of carbonaceous matter. It is therefore important to be able to calculate the quantities or mix-ratios to reach the desired C:N before proceeding. This is where most of the errors in composting occur, since not enough attention to initial mixtures is given. The determination of mixing ratios is performed by a process called a mix-ratio analysis.

3.1.2 Calculating Compost Recipes

For every set of compostable materials, a theoretical ideal combination exists which optimizes carbon:nitrogen ratios, moisture and texture. This section will provide technical details on conducting an analysis to develop a recipe. The reader who is not interested in this mathematical process may wish to skip to the following section.

The calculation or "mix-ratio analysis" procedure to arrive at proper mixing proportions is based on the classical mathematic formula for simultaneously solving for two or more unknowns (in this case, the mix proportions). Although used principally to solve for carbon : nitrogen ratios, the method can be used for moisture and density analyis.

If we have two ingredients Fish (F) and Wood (W)—say sawdust— which we intend to mix, and where $_C$ and $_N$ are carbon and nitrogen contents, respectively, then in order to find the relative mixing proportions for the fish component (a) and for the wood component (b) where C and N are targeted Carbon and Nitrogen portions:

$$\begin{aligned} (i) Fish_C a + Wood_C b &= C \\ (ii) Fish_N a + Wood_N b &= N \end{aligned} \tag{1}$$

To fill in with actual values we found for fish gurry and sawdust (wet basis) gives:

$$\begin{aligned} (i) 14.5a + 20.1b &= 30 \\ (ii) 2.06a + 0.07b &= 1 \end{aligned} \tag{2}$$

Basically, the procedure is to solve first for (b) by dividing each equation by its coefficient for (a), eliminate (a) by subtracting (ii) from (i), solving for (b), and then by substitution to arrive at (a). Since our principal targeted products for the demonstration were fish gurry and hardwood sawdust, we will proceed from here to demonstrate some simple numerical transformations to show how the analysis works.

The most convenient form of expression which is easier to remember is a "determinant" which we construct for each of the two (F & W) ingredients to be mixed; again, (b) is the mix-portion of carbonaceous material:

$$b \doteq \frac{\begin{vmatrix} F_C & C \\ F_N & N \end{vmatrix}}{\begin{vmatrix} F_C & W_C \\ F_N & W_N \end{vmatrix}}$$

The value of such a 2×2 determinant is the product of the two numbers in the principal diagonal minus the product of the other two numbers; thus, let us assume that where F_C and F_N for fish gurry carbon and nitrogen content are, respectively 14.5% and 2.06% ($C : N = 7$) (wet basis– as originally described) and where W_C and W_N are carbon and nitrogen contents of 20 and 0.07%, respectively, for wood sawdust ($C : N = 285$), then the proportion (b) of sawdust in the mixture to get a C:N of 30:1 becomes:

$$b = \frac{\begin{vmatrix} 14.5 & 30 \\ 2.1 & 1 \end{vmatrix}}{\begin{vmatrix} 14.5 & 20 \\ 2.1 & 0.07 \end{vmatrix}}$$

thus the numerical solution for (b) is:

$$\frac{(14.5)(1) - (2.1)(30)}{(14.5)(0.07) - (20)(2.1)} = \frac{-48.5}{-41.2} = 1.18 \qquad (3)$$

substituting (b) in the original equations (1) and (2) we find that the fish proportion (a) must be 0.45; therefore the mix ratio is 1.18 : 0.45 or approximately 2.5 parts fresh hardwood sawdust to every part fish waste (weight basis). Thus, we ascertained that no more than 28% of a compost mix may be fish gurry, or about 750 pounds mixed into a ton of sawdust. This translated into about 150 gallons per ton of sawdust, and formed the basis for all variations on the mixtures.

Since more than two carbonaceous ingredients may be incorporated into a compost mixture, meaning we should be simultaneously solving for mix-proportions (a), (b) ... (d) *etc*, the arithmetic demands become more formidable. The use of modern computers with number crunching potential is obviously very useful[17].

It should be pointed out that mix-ratio analysis should be performed at least for the two most important (carbon–nitrogen) ingredients; in our case this meant analyzing for the wood versus fish gurry component. The other fish wastes had similar C:N ratios meaning any pound for pound substitution would have no appreciable effect on the end C:N ratio of the compost. Raceway manure which was also selected for the blend had a C:N close to 40, or in other words, very close to the targeted C:N for the compost. A material having a C:N close to the desired C:N will similarly not have any significant effect on the analysis provided the principal two ingredients (in our case hardwood sawdust and fish wastes) are mixed in the proper ratios as indicated in the mix-ratio analysis. Thus we were free to add any amount of horse litter we chose to. Had horse litter alone been used to achieve a final C:N of 30, it would have required about 3 times the amount as needed in sawdust, as determined in our mix-ratio method. Adding one-fifth of the compost weight as horse litter affected the C:N only very little.

Table 3: COMPOSITION OF WALDOBORO DEMONSTRATION COMPOSTS

Pile ID *at site*	**Mixture Ingredients** *Description*						% Fish w/w
# 1	Sawdust $100yd^3$	Horse Litter $20yd^3$	Fish Gurry 5000 gallons				24
# 2a	Sawdust $80yd^3$	Horse Litter $25yd^3$	Fish Gurry 2500 gallons	Wood Ash 8 tons			13
# 2b	Sawdust $40yd^3$	Horse Litter $12yd^3$	Fish Gurry 1500 gallons	N-Save 1 ton			17
# 3	Sawdust $120yd^3$	Horse Litter $40yd^3$	Fish Gurry 3000 gallons	Herring 5500 lbs	Crab-Lobster 3300 lbs	Groundfish 24,000 lbs	24
# 4	Sawdust $100yd^3$	Horse Litter $30yd^3$	Fish Gurry 3000 gallons				15
# 5	Sawdust $30yd^3$	Horse Litter $10yd^3$	Fish Gurry 750 gallons	Herring 1375 lbs	Crab-lobster 825 lbs	Groundfish 6000 lbs	24

3.1.3 Waldoboro Compost Recipes

The compost project in Waldoboro utilized 5 differing recipes in developing its compost piles (see Table 3). Some sawdust was found to have contained substantial levels of diesel fuel as an inadvertent contaminant and was therefore segregated as Pile #1 with addition of fish gurry. All other piles were variations of sawdust plus fish wastes, and one pile was split for a comparison of the behavior of "bio-ash" from the SD Warren Westbrook burn facility as versus "N-Save", a

[17] Woods End Laboratory utilizes a spreadsheet program to simultaneously analyze several ingredients for ideal mix ratios

Table 4: CHARACTERISTICS OF INITIAL COMPOSTS

Pile #	C:N	Volume yd^3	Moisture %	pH
Pile 1	42.8	148	60.1	5.5
Pile 2a	56.8	122	58.5	8.6
Pile 2b	40.2	61	64.4	8.2
Pile 3	34.9	234	68.1	6.9
Pile 4	36.3	185	62.2	7.8
Pile 5	41.6	38	60.5	8.0
MEAN	42.1	(Total) 788	62.2	7.5

compost pH modifier, from Zook & Ranck, Inc., of Gap, Pennsylvania. The composition of the mixtures (Table 3) as shown resulted in the traits such as moisture, density and C:N ratios as shown in the following table (Table 4).

The actual percentages of fish material in the compost varied somewhat from the targeted amount of 28%, with the weighted average fish content of the total mix being 20%. An explanation for the discrepancy (aside from routine difficulty of controlling mixtures when large, crude equipment is being used) is related to problems encountered when mixing gurry which had been unexpectedly stored over a weekend in a tanker truck. This storage period was sufficient to effect considerable solids decomposition, such that we were limited in addition rate by the increased water content. Thus, we never added as much gurry-nitrogen as originally projected; consequently the C:N ratios were higher than expected (see Table 4). A possible solution to the dilemma would have been to make additions of gurry at a later point after sufficient moisture had evaporated from the piles. This proved impractical in our demonstration, so we took our chances and let the composting develop without further modification. Additions of more fish nitrogen could have occurred as soon as the moisture fell to less than 50% of the water holding capacity.

3.1.4 Compost Pile Layout and Volumetric Model

A compost windrow is a polyhedric object of indefinite shape; hence estimating the initial volume and, subsequently, volume reduction during composting, is made very difficult. Composters often refer to *triangular* or *trapezoidal* shaped piles, but little apparent effort has been made to confirm the shape. We wished to know the volume and surface area utilized in the composting project.

To enable this measurement and determination of actual volume and surface area, we modelled the shape of the windrows from cross sections once they were built and transcribed the polygon to graph paper, as seen in Figure 3.

The shape of the windrows varied somewhat as can be seen in Figure 3, but closely approximated a smooth, parabolic curve above the soil surface. This shape was obviously influenced by the action of the compost turning machine, which tended to throw up moderately steep sides, as in Pile #1, which settled slowly into a pile such as in #3 (see Figure 3).

Once the cross sections were transposed to paper, we determined actual area by counting cross-hatched squares. Then, we compared the measured area to that calculated for various polygons, such as the triangle and parabola. We used this to ascertain which best matched the

Table 5: AREA/VOLUME MEASUREMENTS OF COMPOST PILES

Pile ID	W x H x C† (day 60)	Actual Volume $ft^3 \cdot ft^{-1}$	Triangular Volume $(\frac{bh}{2})$	Parabolic Volume $(\frac{4}{3}xy)$	Surface Area $ft^2 \cdot ft^{-1}$
#1	11.0 3.40 12.3	21.8	18.7	24.9	13.5
#2a	11.8 3.33 13.8	27.5	19.6	26.2	14.1
#2b	11.3 3.10 12.5	21.0	17.4	23.2	13.3
#3	11.6 2.83 13.1	22.5	16.4	21.9	13.3
#4	10.7 3.25 12.5	24.2	17.4	23.2	13.1
#5	9.8 2.80 11.7	20.9	13.7	18.3	11.7
MEAN $\overline{x}$	- - -	22.98	17.20	22.95	13.2

† C = circumference of pile surface

actual volumes. The result of this analysis is shown in Table 5. The parabolic function described the actual volume nearly perfectly while the triangle formula underestimated the volume by over 25%. For purposes of calculation, (b) is the base or width SQ in Figure 3, (y) is half the base or RQ, and (x) and (h) are heights PR.

The volume analysis reveals that the surface area of our piles averaged 57% of the volume, ranging from 51–63% (reported as square feet per lineal foot of pile divided into cubic feet per lineal foot). This is practically the maximum it could be under the circumstances. Increased surface area favorably affects evaporation and natural aeration, but pre-disposes piles to increased water absorption. However, heaping the piles into a more triangular shape will not decrease the surface area very substantially, but it will limit the quantity of rainfall striking the compost. Increasing slope is not likely to enable water to shed unless a moderately impermeable surface such as straw or leaves is employed, and in any event this could create an undesired runoff condition. Finally, solar warming of the piles is maximized by north–south alignment and a side slope perpendicular to the suns height in the sky– this obviously implies a fairly low profile for summer composting.

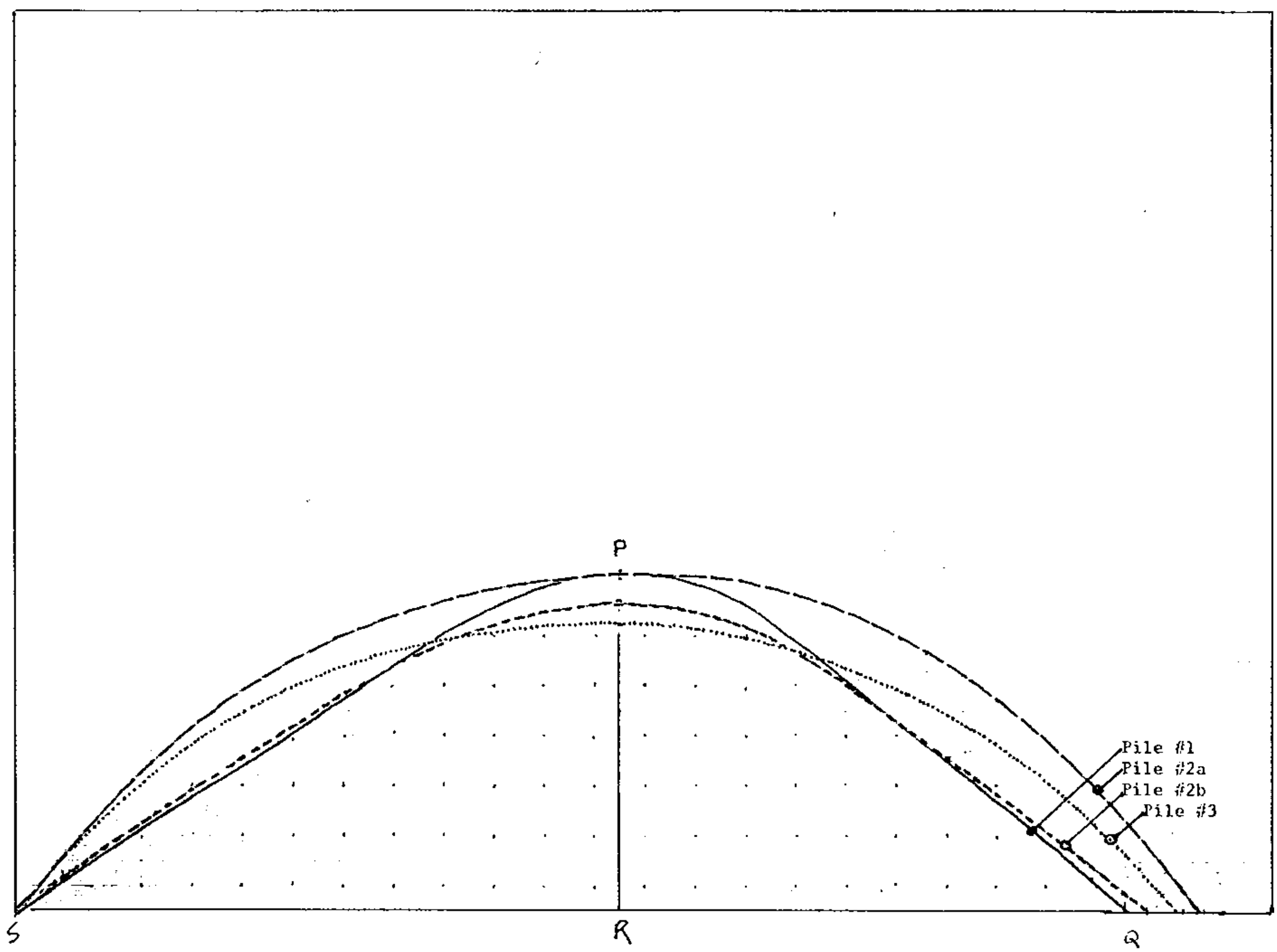
3.2 Composting as Process

A composting process consists of a series of related physical, chemical and biological events. Their nature and course is conditioned by the environmental circumstances surrounding composting.

In our composting we emphasized the use of carbonaceous materials of wood origin. Normally, in nature woody materials decompose slowly by specific steps originating in actions by soil macro-fauna. Only after suitable stages of physical comminution by *primary* and *secondary* decomposers,– including wasps, beetles, mites, collembola, nematodes and earthworms– does action by microoorganisms such as fungi and bacteria set in. This latter group is uniquely capable of producing the necessary enzymes, such as cellulases, to substantially attack molecular structure of the wood and advance decomposition at the micro-environment level. Following this, processes broadly defined as "humification" set in.

Composting essentially interrupts the stages associated with macro-fauna (which incidentally

Figure 3: COMPOST PILE CROSS-SECTIONALS



occur over 3–7 years under forest conditions) and place bacterial and fungal activity into center stage. Consequently, decomposition takes a rapid course, and the copious energy release results in evident elevation of temperatures, which reach such a point that bacterial populations themselves separate into two broad categories, *mesophyllic* and *thermophyllic* based on temperature survivability.

No easy methods exist to fully characterize the dynamic stages of composting but testing a compost periodically by certain methods is one means of revealing the nature and quality of the process.

The compost period we used was divided into four terms for testing to ascertain the changes occuring in the process. Thus, samples were taken at 2, 20, 37 and 60 days and exhaustively analyzed for general traits, as shown in Table 6.

Table 6: FISH COMPOST—PERIODIC ANALYSES

Pile ID#	Moisture%	pH as-is	Org-Matter	Total Nitrogen	Ammonia	Phosphorus	Potash	Calcium	Salts mmhos	ORP mV	C:N
			———percent dry basis———								
Day 2:											
MEAN:	62.2	7.49	80.12	1.146	0.272	0.262	0.547	0.768	2.8	92	42.1
σ (SD)	3.4	1.12	9.73	0.290	0.091	0.096	0.554	0.565	1.9	61	7.8
Day 20:											
MEAN:	45.1	7.88	76.21	1.193	0.187	0.240	0.609	0.944	1.9	164	37.6
σ	5.7	0.49	4.81	0.162	0.061	0.113	0.215	0.449	0.5	93	5.4
Day 37:											
MEAN:	53.1	7.67	73.36	1.166	0.104	0.373	1.013	1.035	2.2	207	37.0
σ	6.5	0.60	7.30	0.201	0.095	0.094	0.401	0.529	0.9	68	4.2
Day 60:											
MEAN:	50.5	7.05	71.38	1.288	0.046	0.370	0.495	1.302	2.6	207	32.7
σ	11.8	0.47	5.37	0.242	0.048	0.078	0.178	0.699	0.7	78	5.7

The general trend in data indicate several characteristic changes occurring during composting. The lowering of pH to a neutral point at the end of composting signifies degradation of carbonates and ammonia. Moisture declined rapidly during the initial high heat period, and retrenched somewhat with rainfall occuring at approximately 1 month into composting. This addition of water was in fact needed to maintain the composting process, which may become inhibited by dehydration if below approximately 40%.

Organic matter declined as a result of decomposition, while total-nitrogen held at about the same relative level all the way through. Consistent with this, phosphorus and calcium increased as a result of concentration factors, but potassium varied to the point that it was difficult to ascertain a trend. The measure of oxidation-reduction (ORP) potential showed an increasing slope during composting, a favorable sign indicative of aerobic or oxidative stabilization. Salts remained at about the same moderate level, and finally, C:N declined as expected.

3.2.1 Odor Generation

Discussions concerning fish waste disposal inevitably lead to the question of odor. In fact, odor generation at a fish compost site may well be the most significant quality control aspect. This is so despite the subjective nature of odor perception and the ambiguity implicit in attempts by authorities to regulate air–odor emmissions.

Sensory impressions of odor are extremely complex, since dozens of organic and inorganic compounds can condition an overall experience of smell. In fact, we do not know where to begin in characterizing odor specifically. The presence in fish of labile proteins implies susceptibility to malodor associated with semi-decomposition products— compounds formed from incomplete oxidation of organic material. Also, with fish products there is the oil itself, which at least to some persons has a rancid, off-odor.

In our project, several sensory observations were made by a variety of persons, followed by some testing to pinpoint material qualities which might condition odor development. These and other observations indicated that odor subsided rapidly following intitial set-up of the compost piles. In fact, almost immediately after initial blending into sawdusts and litter, the offensive odor of fresh fish waste disappeared. Initially, it was *masked* by the pungent smell of the wood, but eventually it vanished entirely from decomposition. Upon subsequent turning of the piles, only ammonia and oils could de detected with the nose. None of these were present in sufficient quantity to permit detction of the operation at any measurable distance from the site.

It should be noted that the level of alkalinity or pH in the compost will exert an important controlling function on any possible odors which may develop. Those odors classed in the *putrefactive* class— resulting from anaerobic rotting of proteins— tend to be odorous more at neutral to low pH values and are diminished by treatment to raise pH, whereby salt compounds are formed. In contrast, ammonia and amine related odors are more volatile at elevated pH and are lessened by lowering pH. All other factors being equal, it is probably best to lower rather than raise pH in aerobic composting (see the discussion in Section 3.2.4).

The fish oils present initially appeared to persist significantly longer than other odor compounds, but also eventually vanished, particularly as composting passed the 60–90 day mark. However, it was felt that some oils could still be detected olfactorily in aged compost, but they were not deemed to be offensive in any way.

3.2.2 Nutrient and Solids Recovery

Of importance in the composting of food and farming wastes is the amount of nutrient value retained during the degradation process. We know that the intensive biological events that take place in composts will reduce the solids or organic portion by a substantial amount. Theoretically, this will cause a concentration of the ash or mineral portion to occur such that all other factors being equal, nutrients should be conserved and increased in concentration, not decreased.

However, a few significant factors, among them moisture loading, high pH and oxygen stress, may contribute to losses of nutrient value. In particular, potassium may leach (it is known that potassium salts leach out of farm manure piles into the soil below) and nitrogen is volatized through two pathways, including ammonification and denitrification. Of the latter two, high pH favors ammonia escape, while intermittent oxygen deprivation favors denitrification, regardless of pH. Of pertinence here is the fact that these latter play an important rôle in perception of quality in composting, and ultimately, in overall technical success of a project.

By adding relatively large amounts of available carbon, we may expect that immobilization of nitrogen released from protein decay may be significant, hence both ammonia loss and denitrification should be minimized. In the rapid initial breakdown expected of fish (or related) proteins, however, copious amounts of ammonia may be released before microorganisms have a chance to utilize it (particularly if the pH is high).

In general, wood sawdusts are high in carbon and moderately low in pH, so our basic requirements are met. The hardwood sawdust with which we worked contained approximately 57% carbon with pH values at or below 5.0. We did not test the availability of the carbon which is affected by analytical method, but by adding an excess (C:N = 30–40) we expect ample carbon is available to meet average microbial needs of 10–15 parts carbon to each part nitrogen consumed.

In order to analyze actual recovery of nutrients and organic matter, we measure the change in ash content, which theoretically is proportional to the loss of organic matter, and from this calculate recovery of any single parameter (Table 7). Of course, if a pile could be weighed in and out, we should gain the same information, but this is rarely practical. In any event, it is important to be able to assess losses or gains from composting as this will affect choice of methods and possibly influence product end-uses.

Table 7: RECOVERY FACTORS FOR DEMONSTRATION FISH COMPOST

Parameter	Recovery % (ΔR)
Organic Matter[(a)]	61.8
Total Nitrogen	78.8
Phosphorus	98.1
Potassium	62.8
Calcium	117.0
Solids[(b)]	69.4
Moisture	43.1
Volume	85.0

The recoveries or change from initial status of the composts (ΔR) are based on average compost values (piles #1–5) and are calculated as follows, for (a):

$$\Delta R = \frac{P_x/P_i}{A_x/A_i} \tag{4}$$

where A is ash content, P is any parameter and where $_x$ and $_i$ are final and initial values, resp.

and for (b):

$$\Delta R = \frac{(OMi)(OM_{\Delta R}) + A_i}{100} \tag{5}$$

This analysis on the *average* composition of the Waldoboro composts indicates several important facts:

- 38.2% of the organic matter was decomposed, or 30.6% of the total solids;
- 57% of the initial moisture was lost, *plus* all the rain-fed moisture which fell into the material during the season;
- 21.2% of the total nitrogen is unaccounted for (lost);
- 37.2% of the potassium is unaccounted for (lost);
- essentially all the phosphorus is recovered, and calcium shows a net gain (most likely sampling error associated with dissolution of crustacean shells);
- water-holding capacity diminished by approximately 25%.

It is our view that with the exception of the anomolous fate of potassium, the recoveries are normal, and with regard particularly of nitrogen, very good. Decomposition products of highly labile wastes such as manures and fish are known to trigger large losses of nitrogen (upwards of 85%) under certain circumstances. Through the composting process we have captured the major portion of fish-nitrogen, immobilizing it into stable organic humus compounds.

As also seen from the data, the composting process has effectively decomposed 40% of the initial organic substances, and reduced the weight by 30%. The evaporative loss of moisture has been substantial at nearly 60%. In fact, had not rainfall occured, it may have become necessary to apply additional water to the piles.

3.2.3 Compost Temperature Monitoring

After piles were constructed, temperatures rose rapidly. As a rule, they attained 55°c (130F) within the first 3 to 4 days. In the following section, a summary table of the temperatures is shown, plus individual graphs of the actual temperature curves over approximately a 60-day period. The temperature graphs have been grouped by pile type and are shown in Figure 4, Figure 5 and Figure 6.

A tabular summary data of pertinent temperature data is seen in Table 8. This table shows average temperatures over the 60 day period, the number of accumulated days the piles met or exceeded 55°c, and the consecutive days by group in which period temperatures are over the specified limit.

The temperature data indicate that the active heating period ($> 35^oC$ or 95^oF) extended to 65 days for all piles; however, only short "bursts" of temperatures exceeding 55°c (130°F) were encountered, and reflect the different compositions of the variously constructed piles. The pile with the highest average daily temperature was Pile #3, which had all the fish mixtures in it, and consequently the lowest C:N ratio. Thus, the lower C:N yielded a more rapid energy exchange in decomposition.

Figure 4: COMPOST TEMPERATURE GRAPH— PILES 1-3-4

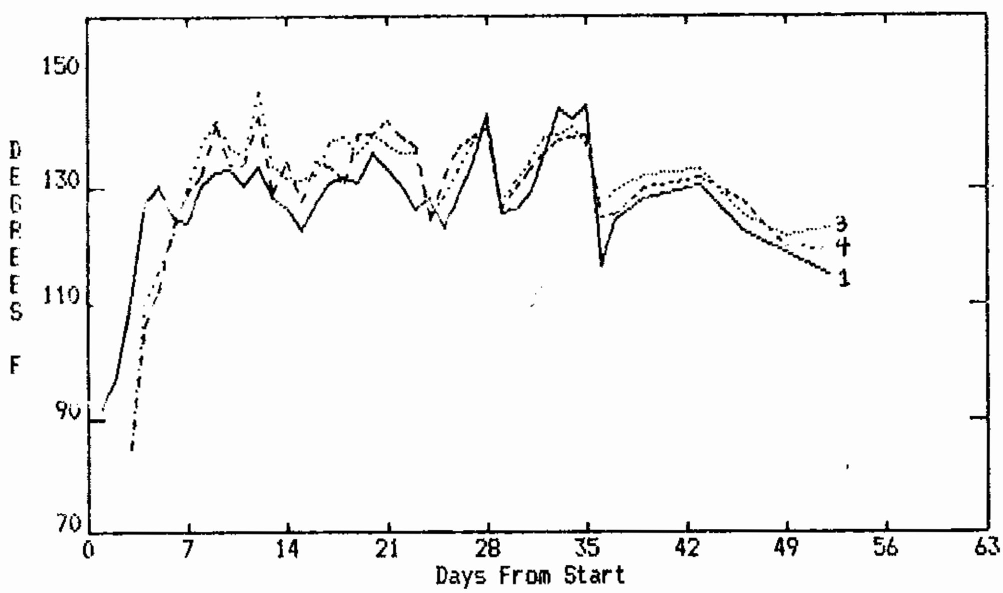


Figure 5: COMPOST TEMPERATURES— WITH *N-SAVE* and WOOD ASH

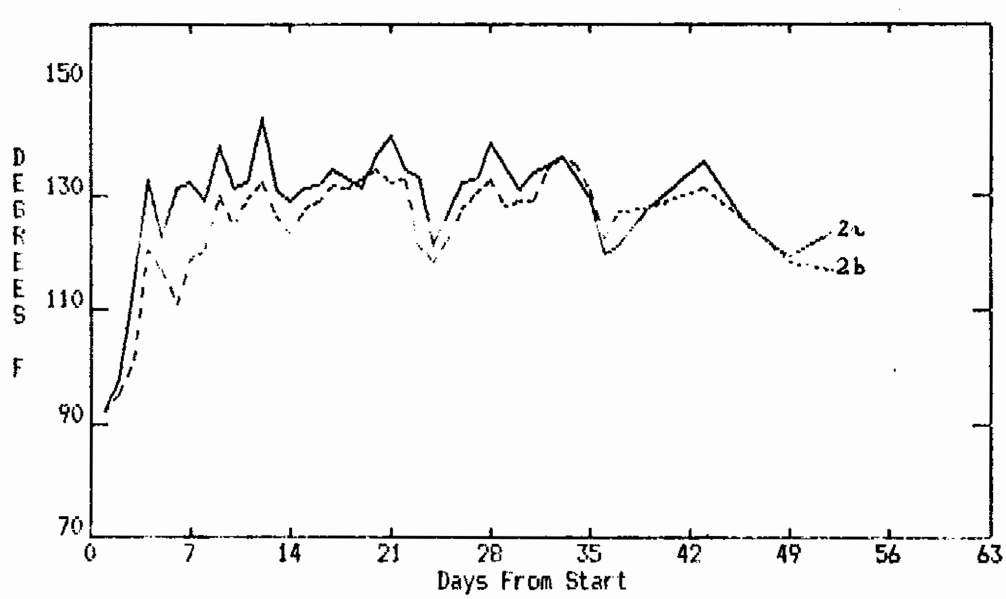
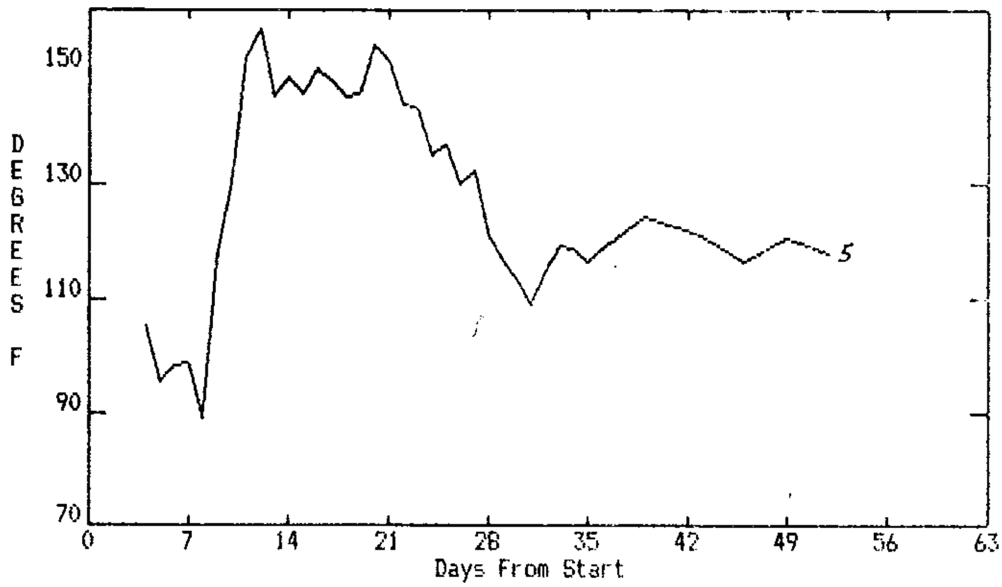


Figure 6: COMPOST TEMPERATURE GRAPH— STATIC AERATED PILE #5



3.2.4 *Wood Ash* and *N-Save* Treatment Comparison

There has been some speculation that additives such as ash or fertilizer may exert a controlling influence on odors. As mentioned previously (see Section 3.2.1) this all depends on the nature of the odor compounds. Early USDA work[18] encouraged the application of phosphatic fertilizers in manures since they tended to form slightly acidic, non-volatile salts in reaction with nitrogen related compounds. Modern odor control systems have applied the principal of non-acid salt formation[19] or direct acidification such as with dilute inorganic acids, used often in

[18] Soils & Men: USDA Handbook 1938
[19] Zook & Ranck Co's "N-Save" product is based on this principal

Table 8: SUMMARY TEMPERATURE DATA FOR FISH COMPOSTS

Item	Pile-1 w/Gurry	Pile-2a w/Ash	Pile-2b w/NSave	Pile-3 all fish	Pile-4a Plain	Pile-5 Static
Mean C°/day	52.4	53.7	51.4	55.1	54.7	53.0
$\sum$ Days $\geq 55°C$	19	26	14	28	26	17
$\approx$ consec. days $\geq 55°C$	5 – 6 – 4	5 – 9 – 8	6 – 2 – 4	17 – 3 – 6	5 – 8 – 6	16 – 0

gaseous odor scrubbing systems. Elsewhere in the fish-industry, other forms of processing wastes have routinely relied on acidification of by-products to achieve stability, such as in acid-enzyme hydrolysis, but this is an extreme example.

In our project we compared the use of wood ash from a energy recovery facility versus the use of a commercial compost pH modifier as an additive to composting. The wood ash had been used successfully elsewhere as a "bulking agent" in sludge composting[20]. The ash had a pH of $\geq$12.0 and the fertilizer based additive of approximately 5.0. Replicates of treatments were not performed, consequently no scientifically valid conclusions concerning overall performance could be made, however, some important observations were noted.

Within the first few hours following additions, the pH of the two composts differed markedly– the ash treated pile rose to 8.6 and the fertilizer treated pile fell to 5.5. Immediately subsequent to the ash addition copious amounts of ammonia related vapors could be detected olfactorily in the ash pile,– in fact, the intensity was great enough that the pile could not be approached closer than approximately twenty feet during active machine turning.

In contrast the piles treated with *N-Save* had no sensible ammonia smell. The pH which fell rapidly at the outset rose slightly to neutral before the second sampling period, and remained at neutral throughout the composting process. Thus, it exerted a significant effect in controlling pH and ammonia volatization. In the *Ash* treated pile, the pH fell very gradually over 60 days till it reached 7.7 on the 60*th* day. The ammonia odors vanished very early in the process, however.

There were significant odor differences between the two treatments which persisted throughout the composting period. The *N-Save* fertilizer product appeared to have masked odors associated with pH, consequently, oil related odors could be more easily detected. In contrast, in the ash treated pile oils odors could not be detected but more prominent were ammonia and amine type smells. It should be noted that neither of the so treated materials were deemed malodorous in any way.

Both Ash and *N-Save* products add other valuable nutrients such as phosphorus, calcium and sulphur, so that their use as compost additives needs further investigation.

Ash products, however, can vary tremendously in nutrient content, particularly with regard to potassium and lime. If used at all, it is suggested that ash additives be applied only later in the composting process to avoid ammonia generation. We would caution that, contrary to some speculation, none of the elemental carbon present as a residue in ash products can be utilized by microorganisms as a carbon source.

Another observation afforded by the additions of these materials was the depression of temperature (and therewith increase in variance of measurements) by the fertilizer *N-Save*. Although ash piles showed slightly elevated temperatures, the heating was apparently not significantly different that the untreated piles (see Table 8). There has been some speculation that ash alkalies tend to be exothermic (***heat producing***) in reaction, but measurements carried out in the laboratiory did not bear this out. There is neither enough water in compost to effect dissolution nor presumably sufficient pure oxides in ash (as versus competing carbonates and endothermic salts such as chlorides and sulfates) to enable such heating influence to measurably take place. Rather, where increased heating has been reported elsewhere[21], it is most likely a relative effect

[20] Hart, J (1986) Using Fly Ash as Bulking Agent. *Biocycle* Vol27:#1-pp28-30
[21] personal communications from DEP staff-persons realted to sludge treatment, 1987

Table 9: VARIABILITY OF TEMPERATURE MEASUREMENTS
season average for 5 replicate measures per pile per day

Pile ID	Coefficient of Variation %
Pile 1 (Sawdust + Gurry)	2.8
Pile 2a (w/Wood Ash)	3.7
Pile 2b (w/NSave)	4.7
Pile 3 (all fish)	3.1
Pile 4 (Sawdust + Gurry)	3.6
Pile 4b (as 4, SSI mix)	3.5
Pile 5 (Static)	12.3

stemming from increases in material density in relation to volume combustion potential.

The depression of temperature by the fertilizer product is considered to stem from salt effects which tend to suppress microbial activities. Consequently, addition rates must be monitored carefully. We estimate we inadvertantly over-applied N-Save by about 50%.

Finally, the disposal of ash in composting may require separate environmental permitting not otherwise required for normal agricultural composting. Thus, it should be considered only for those types of composting which already require permitting [22]. The ash material appeared to have increased the metals content of the composts by at least a factor of two. Despite this, the final analyses indicate levels well beneath any environmentally imposed limits (see Table 11).

3.2.5 Sampling and Testing Techniques

Temperature Compost temperatures were taken daily during the entire project using 2' stem thermometers pushed into the 200 foot-long piles at five random locations. The probes were inserted over the length of the pile and allowed to stabilize in a period of 2-4 minutes each, which was about the time it took to walk the length of the pile. Thus the technician would return to the head of the pile immediately and record the temperature on a clipboard while walking back down the pile, removing the probes as he or she went.

We analyzed the variability of repeat temperature measurements for data on individual piles. This analysis indicates that reproducibility of random measurements was fairly good, but varied somewhat depending on pile treatment. The coefficient of variation (CV%) of temperature measurements, defined as the standard sample deviation divided by the mean ($\frac{\sigma n-1}{\bar{X}}$) is shown in Table 9.

The data indicate that the variability was well under 5% with the marked exception of the Static Pile which showed a CV of 12.3%, or more than three times that of the other piles. Thus temperature measurements at five points for most of the piles appeared to be adequate to obtain representative values, but for the static pile the readings were considerably less representative, pointing in this case to inhomogenous composting.

[22] for current information on the status of ash regulations and Permit-By-Rule procedure, contact the Maine Dept. of Environmental Protection, Augusta, ME or other appropriate environmental authority.

U.S. EPA and State DEP temperature regulations established for composts permit short (≥ 3 days) periods of temperatures $> 55°c$ to satisfy PFRP (***Process to Further Reduce Pathogens***) requirements for ***static pile*** composts, and 15 days for conventional mechanically-aerated windrows. The reason for the difference in permissable heating duration has never been fully explained, but may have to do with assumptions that turning a pile introduces variable cooling or that recolonization with pathogens may occur if the surface stays cool[23]. In our experiment, the static piles showed very uneven heating in contrast to the aerated windrows (see Table 9). Very detailed temperature measurements would have to be made to assess the actual effects of physical turning on internal heat homogeneity.

Oxygen Active decomposition of organic materials requires oxygen if aerobic microorganisms are to develop. Measurements of oxygen (O_2) levels within a compost pile is therefore necessary to gauge the effectiveness of aeration or turning systems.

Atmospheric O_2 levels are 20.9% but will fall rapidly within any decomposing material to levels considerably less than ambient. Turning a pile, or alternatively blowing air into it, has the effect of temporarily restoring the O_2 levels to normal.

Since the diffusivity of oxygen is moderately high in semi-solids such as compost, a natural oxygenation effect is present which over time will approach a steady-state dictated by the rate of conversion to CO_2 versus rate of diffusion from outside the pile. Generation of heat and evaporative expansion of water act to create a natural "chimney" whereby air will be drawn into the pile towards the base and move to the top center for exit. For obvious reasons, a pile which is too compact or moist will severely limit this natural action of aeration, thus placing greater requirements on any aeration system.

We experimented with oxygen monitoring techniques in the course of the project. At first, we attempted to use a semi-permeable probe directly in the pile, but this proved impractical and unreliable. The relatively high heat and moisture, plus the effect of disturbance of material, introduced operational problems that could not be resolved. Consequently, we developed a probe from 5' x 2"diameter PVC pipe which had perforated holes in the bottom. At the top, a vacuum port was attached. An oxygen probe was inserted into the pipe through a pressure seal at top and air was drawn up through the tube from a vacuum source connected via a nylon hose outside the pile. At first, a hand-held vacuum pump was used, but it could not draw sufficient volume at once to produce stable readings. We finally used a power vacuum source, requiring AC current, which drew a sufficiently large volume of air into the pipe from the pile interior, and produced stable readings.

Measurements made at the beginning of composting indicated that O_2 levels fell close to 5% in the first several days of active composting, so turning sequences of twice-daily were recommended. In the static pile which had an electric ventilation system through pipes, O_2 levels were initially 17% or more, indicating that oxygenation was more than ample, and the aeration timing was subsequently altered, particularly as it correlated with excessive cooling of that pile. After the first week, O_2 climbed in most piles and was never seen below 5% as long as one-per-day turnings were observed.

We were not fully satisfied with the reliability of oxygen readings, despite use of a very

[23]This requirement is not applicable to agricultural materials not regulated under state solid waste laws. Static piles must be stored 21 days after PFRP. For documentation of federal regulations affecting composting see:
US EPA (1985) Composting of Municipal Wastewater Sludges. EPA625/4-85-014 *also*
US EPA (1981) Composting Processes to Stabilize and Disinfect Municipal Sludges. EPA430/9-81-011

expensive oxygen probe-metering system. This is not surprising— many composters have experimented with oxygen systems owing to vagaries involved. Since there is no precise O_2 level at which aeration is adequate, this limitation appears to be insignificant.

3.2.6 Final Compost Quality

During composting most nutrients are conserved, as discussed, and biological stability will be increased. Consequently, the material is capable of being stored for indefinite periods without undue harm or leaching. In Table 6 we saw the progression to 60 days. At that time we measured microbial respiration to ascertain stability, and then re-tested the whole material at the end of the winter after outdoor storage (7 months later).

Table 10 gives data on carbon-dioxide respiration of the different piles on the 60th day, based on laboratory measurements from incubation at 32°c. The data show that respiration continues at a low rate and that there are some differences between the variously treated piles, the static pile appearing most active (least stable) followed by the ash-treated sample, with the lowest respiration seen in the N-Save treated pile. The respiration data serves to illustrate the point

Table 10: RELATIVE RESPIRATION RATE OF AGED (60 Day) COMPOSTS

Pile ID \#	Respiration Rate $gCO_2 - C \cdot gC \cdot day^{-1}$
Pile 1 (Sawdust + Gurry)	0.62
Pile 2a (w/Wood Ash)	0.83
Pile 2b (w/NSave)	0.47
Pile 3 (all fish)	0.55
Pile 4 (Sawdust + Gurry)	0.59
Pile 5 (Static)	0.97
(*example*: Fresh Compost)	2.53

that no compost is ever completely stable in the sense of being biologically inert. In fact, with the use of wood products as a carbon source, the active life may be prolonged owing to slow decomposition of lignaceous wood components. In a sense, therefore, the fish component was composted in the first several days, and after that, the wood fraction underwent composting. In any event, the respiration rates are low enough to be considered safe for normal storage.

In Table 11 we show the final metals test values for a composite compost compared with ash treated material. The latter has increased metals as compared to regular compost, but the numbers are still less than published environmental standards. All ash material should be tested in advance for metals since published data indicate metals may vary by 1–2 orders of magnitude over a relatively short period of time.

We mentioned previously (section 3) the inadvertent contamination by diesel fuel of some of the samples of sawdust. The material was analyzed at the outset of composting and again on the 60th day, with the result that all hydrocarbons appeared to have been decomposed to less than detection limit ($\leq$ 10ppb)- see Table 12. Also, no PCB's or salmonella *sp.* could be detected in the composite product (fish oils often contain appreciable PCB's).

Table 11: TRACE SUBSTANCE COMPOST ANALYSIS, mg/kg

Variable	Fish Compost	Compost with Ash	DEP-Limit
Cadmium	0.58	0.7	10.0
Chromium	11.0	22.0	1000
Copper	17.0	56.0	1000
Nickel	8.7	16.0	200
Lead	9.6	9.0	700
Zinc	65.0	115.0	2000

Table 12: DIESEL FUEL ANALYSIS FOR COMPOSTS

Sample Material	Initial *ppb*	After Composting, *ppb*
Pile #1	50,911	≤10
Pile #2–5	653	≤10.

Analyses of finished compost and the same material after 7 months storage are seen in Table 13. The data on our compost storage suggest that the principal change was an increase of moisture as a result of long-term outdoor storage. Other changes during winter storage were decreases of ammonia, pH, potassium and salts. The fact that salts and potassium declined may indicate immobilization of some sort, or possibly some leaching (there was never any observable leachate from the piles). It was noted that the stored product had a distinct, woody and earthy odor, with apparent colonization of fungi typical of drier, woody products.

In addition we compared the analyses of our finished compost with that from two other related fish scrap compost projects conducted earlier. The data show similarities particularly with regard to moisture, pH and organic content with our compost showing the lowest final moisture. There were significant differences, too, especially as regards nitrogen. Our compost had a much lower total-nitrogen content, and consequently a higher C:N ratio. We explained that this need not have been the case, as the initial mixing presented some limitations to us with regard to addition of fish. The other traits are similar enough not to require comment, and present an average picture of moderate nutrient contents and high organic value for these fish composts.

The compost was exhaustively analyzed for attributes related to plant potting mix development. Tests looked specifically at water holding capacity (WHC), and saturated salt extracts for macro and micro minerals. In general, WHC was impresive at 200–250%, and density was moderately low at $0.2g \cdot cc^{-1}$. These and other findings suggested suitability for use as a growing medium. The results of this testing and research process will be reported in a separate report (see discussion in Section B.1).

In so far as field application is concerned, we estimated that application rates to provide 100 pounds nitrogen per acre to soil assuming nitrogen release is equal to half the total-N would be of the order of 25–30 tons for our fish compost and 12–15 tons in the case of the other composts seen in Table 13. These aspects were developed into a separate corn field research trial (see discussion in Section B.2) to be reported elsewhere.

Table 13: FISH COMPOST FINAL ANALYSES

Moist-ture%	pH as-is	% Org-Matter	% Total Nitrogen	% Amm-onia	% Phos-phorus	% Po-tassium	% Cal-cium	Salts *mmhos*	C:N
				Waldoboro-Fish Composts:					
				Compost at Day 60:					
50.5	7.05	71.4	1.29	0.046	0.37	0.50	1.30	2.6	32.7
				Compost after 200 days:					
69.2	6.15	68.7	1.35	0.009	0.69	0.27	0.80	0.8	29.9
				Other Peat-Fish Composts					
				Mathur Peat Fish-Compost†:					
67.7	6.50	76.0	3.00	0.800	1.90	0.57	3.20	-	12.4
				Brooks Peat Fish-Compost‡:					
69.8	6.51	79.5	4.62	n.t.	0.57	0.41	0.72	-	17.2

†(see Mathur *op. cit.*)
‡(see Brooks *op. cit.*—dogfish-peat compost)

3.3 Summary

Composting is a biological process characterized by elevation of temperature and subsequent decomposition of organic materials. The fish by-products used in this project have been successfully degraded over a short period of time into a biologically stable, humus-like material. In the course of decomposing, temperatures have held at or above 130°F for approximately a two-week period, and have remained over 100°F for more than 8 weeks. This heating assures favorable decomposition and destruction of any pathogens or weed seeds which may have been inadvertently present in the waste materials.

Aerated static-piles of fish compost performed more poorly than expected, showing uneven heating and excessive drying. The mechanically aerated windrow method was efficient in producing a highly satisfactory compost. In all the composts, fish parts disappeared rapidly and completely. The piles lost a great deal of moisture as a result of evaporation. There was some increase of minerals such as phosphorus and calcium, and decrease of others, e.g. nitrogen and potassium.

The wood base for the composting appears to have been suitable for stabilizing the wastes, but more attention to initial C:N ratios should be given, whereby a C:N at or slightly below 30 is targeted for the initial mix. Moisture content at the outset may be the main determinant of mix ratios.

4 Equipment Technical Parameters

4.1 Equipment Demonstrated in the Compost Project

This section evaluates the equipment actually used in the Mid-Coast Compost Project. Some basic information about other equipment that may also be appropriate for a large scale compost operation is found in the Appendix. This information will be useful in developing alternative composting scenarios in the economic feasibility discussion later.

Equipment was necessary to perform many of the functions in the composting process. These functions included loading and handling the raw materials and the final product, reducing the size of various inputs, mixing the ingredients, building the piles, aerating the piles and monitoring them. The equipment used will be described and evaluated based on speed and ease of use, quality of performance, problems encountered and applicability to different scales and materials. (See Table 14.)

This evaluation must, of course, be limited to those pieces of equipment made available to us for this project. It should not be seen as an endorsement of these particular kinds or types of equipment.

4.1.1 Materials Handling--Loading

Loaders Two different loaders were used to handle material in the project. One was a small (approximately 30-40 hp) farm tractor with a half-yard bucket. The other was a John Deere payloader with a two cubic-yard bucket. Owing to the light weight nature of the compost ($< 1200 lbs/yd^3$) and its constituents, both vehicles could probably have handled much larger buckets if they had been devoted strictly to compost handling. In compost operations it is not unusual to see 2-yard buckets replaced with 4-yard buckets.

The farm tractor was used in pile construction and moving materials around on the site. Although it worked adequately for the purpose, the very small bucket size ($< 1 yd^3$) required that many trips were needed to accomplish each task. This slowed the process down significantly at times. Because of this, the use of a Department of Transportation payloader was requested when it came time to load trucks at the end of the project. The small (half-yard) bucket would have created a significant bottleneck in the operation and would have been costly from both a labor and machine operation point of view.

For a small operation, a small tractor with a $\frac{1}{2}$ yard bucket would probably be acceptable. For a larger commercial scale operation, a payloader with a 4-5 yard bucket would be essential.

4.1.2 Materials Reduction

Size Reduction Equipment - Originally, the project members intended to test either a tub grinder or a high torque shredder for shredding paper or cardboard as a part of the project. When it became evident that it would not be practical to obtain the paper or cardboard and that no electricity would be available at the site, this aspect of the project was dropped. We did, however, have the opportunity to observe some size reduction equipment as a result of the project and so will share our observations here.

Table 14: DEMONSTRATED EQUIPMENT FOR THE COMPOST PROJECT

Major Equipment Type	**Size–Capacity**	**Approx. Cost**
John Deere Tractor w/Loader	40 hp	$20,000
John Deere Payloader	2 yd^3 bucket	$50-70,000
International Farm Tractor	120 HP	$25,000 (used) $50,000 (new)
Wildcat Compost Turner	C-700 (500 ton/hr)	$17,500
SSI Mobile Batch Mixer	12 yd^3	$70,000
Kemp Brush Chipper	up to 1" branches	$1,000
Shred-Pax High Torque Shredder	7 hp – 100 hp	$2,000/hp
Minor Equipment Type		
Dayton Blower	335 cfm	$130
Weston/Taylor Analog Thermometers	2 ft stem 0-200°F	$75
Extech Digital Thermometer	hand-held -20–100°c	$90
YSI-Oxygen Meter	0–100% O_2	$1,200

We had a videotape made for us by the Shred Pax Company of Quebec in which they demonstrated the use of their AZ-7 high torque shredder. The video clearly demonstrated that the shredder could reduce almost anything that would fit into the hopper to pieces that were roughly $\frac{5}{8}$"$x\frac{1}{2}$" in size. It easily shredded wood, paper, cardboard, plastics, and even metal.

In a mini-experiment at the compost site we tried shredding hay with a home gardener type brush shredder (fixed-flail type) driven by a 5 hp Briggs and Stratton Engine. Without its discharge screen the shredder reduced full length, baled hay to pieces no more than six inches long. With the discharge screen in place, however, the shredder quickly plugged and stalled out. The small hay pieces mixed easily in a compost mixer while full length hay did not. (See discussion of mixing equipment.)

For a small scale operation, a shredder of this type should be adequate for hay shredding as well as for brush chipping/shredding. It appeared to be excellent also for reducing lobster shells. Further experimentation is needed to determine its effectiveness for other materials.

For large scale operations, the backyard brush chipper would definitely not be efficient due to its small hopper size and low capacity. To shred hay, for instance, requires hand labor to separate bales into chunks of about 5–8 lbs. each, then to individually feed them into the hopper. Larger commercial chippers could be very good for chopping certain materials, particularly hay and crustacean shells.

Finally, we observed that the Wildcat Compost Turner itself acted very effectively to reduce the size of materials placed in the windrows. The repeated turning with the high speed flails (250–500rpm) on a drum quickly broke materials like hay, crustacean bodies and whole-fish carcasses into small pieces enhancing their disintegration in the pile. We observed that even many of the pieces of oak wood that were in parts of the sawdust piles were broken into smaller chunks by the end of the composting process.

4.1.3 Compost Pile Construction

Pile Building Three pieces of equipment were used in pile building. The liquid dogfish-gurry was placed in the windrows using a Badger 2,500 gallon liquid manure spreader. Solid materials like fish carcasses and shellfish bodies were added to piles using the farm tractor with a front-end loader. In both cases, the Wildcat Compost Turner was used to mix and shape the piles (see Figure 12).

The Badger Manure Spreader worked well for the liquid waste because it had a vacuum/ pressure pump that allowed full control over the amount and placement of the gurry. The process, however, proved to be very slow because the hose had to be moved along by hand. If a system can be devised to mechanically suspend the hose or preferably to attach it to the Wildcat so that the gurry could be injected and mixed in one pass, this bottleneck could be significantly diminished.

For solid materials, the front-end loader worked fine but may require a concrete loading pad with a retaining wall or some other facility to allow materials to be dumped and easily picked up by the bucket. A larger bucket size would also help speed up the process.

The Wildcat Turner quickly mixed and shaped the windrows once the various fish materials had been added.

4.1.4 Compost Mixing

Two pieces of equipment were used in mixing different materials together. The primary mixing device used was the Wildcat C-700 Compost Turner. A truck mounted SSI (Sludge Systems Incorporated) Batch Mixer (loaned by the City of Gardiner, Maine) was also tried.

The Wildcat Turner performed its mixing functions extremely well. Generally, only one pass up each side of a windrow was needed to thoroughly mix the fish materials into the saw-dust/bedding mixture. A 100 ton windrow could be mixed in about 10-12 minutes once the fish had been placed in a depression along the top.

The only difficulties encountered had to do with the tractor that provided the power source for the turner. The tractor we used (a 120 hp International) did not have hydrostatic drive or a creeper gear. Because of this there was a tendency for it to go a little too fast (unless the operator rode the clutch!). This partly caused some of the liquid fish to flow down over the side of the pile before it could be mixed in. But more importantly, as a result of the higher than usual speed, the forward motion of the tractor exceeded the turners capacity to displace material backwards, causing a "drag effect" which resulted in the tractor being pulled sideways into the compost pile. Aside from having to ride the clutch, the operator is forced to use the left-hand brake almost continuously in an attempt to both slow and re-direct the motion.

Failure to properly control the speed and motion of the tractor–turner can result in becoming mired sideways in the pile. Since it is impossible to back up with a turner attached all efforts to free the machine must be made in a forward direction. Generally, the machine could be freed by raising the hydraulic arm that controls the turners depth as high as possible and turning the wheels sharply to the left.

All other factors being equal, the problem of drag appears to result principally from attempting to turn fresh materials which have been piled either too high or too wide. Also, wet soil conditions contributed to slipping, which had a similar effect. Since the piles were constructed with bucket loaders, it was difficult to gauge the correct size until considerable experience had been gained. Eventually, the operators in the Waldoboro project were able to perform all functions nearly perfectly, with no encountered difficulties. Nevertheless, it is important to recognize the great desirablility of hydrostatic drive which enables infinite speed adjustment without affecting pto torque. For a comparison of the performance of several windrow turning machines see section A.1.2.

SSI Mixing - The SSI Mixer also appeared to blend the various fish by-products and the sawdust mixture very well. Once the mixer was loaded, it only took about 5–10 minutes to thoroughly mix about 10-12yd^3 of material. Following the mixing the truck pulled along side a windrow and very quickly (less than 5 minutes) unloaded the entire batch.

The bottleneck in using the SSI was the long idle time between batches due to the small size of the tractor bucket used to load it. A larger loader would have made it a much more efficient process.

We found that the SSI worked better for some materials than others. It did a very good job at blending the liquid fish gurry into the sawdust/bedding mix but was completely stalled out by long hay, probably due to the drag this placed on the hydraulically turned arms. In two batches that included hay, the hay strands tended to wrap around the augers eventually causing the mixer to stall. The operator was not pleased at the prospect of unloading by hand. We also found that lobster and crab bodies tended to roll to the outside of the pile during unloading. Thus, the piles would have to be turned with a Wildcat or similar device almost immediately in order to re-incorporate the shellfish, which in a fresh condition attracted flies to the piles.

For a windrow operation, a turning machine like the Wildcat should be adequate for all mixing. For static pile operations using liquid wastes or uniformly sized materials (not hay) the SSI or similar mixer would do a very good job.

4.1.5 Compost Windrow Aeration

Aeration of the Piles Two approaches were used to aerate compost piles in the project. The primary approach was to completely turn the windrows using a Wildcat C-700 compost turner driven by an International (120 hp) Tractor (see Figure 11. The second approach was to use a 335 CFM electric blower to force air through 4" perforated pipes under the static compost pile.

The turner accomplished the aeration by lifting the material up and over the spinning drum and then depositing it in a shaped windrow behind itself as it moved along. Not only did this action add air to the pile but would loosen the material preventing it from compressing the air space out by its own settling action.

The frequency of turning had to be determined by testing the oxygen levels in the rows. The goal was to maintain oxygen levels above 5% if possible. In the first 2 to 3 weeks of the project this required turnings twice a day due to the rapid decomposition of the dogfish. The piles were turned once a day over the next 2 to 3 weeks and every third day thereafter as the material began to stabilize.

The blower system has worked adequately for sludge compost operations in Maine and elsewhere but in this project, the results from using the blower were not as good as those obtained using the turning machine. There were several reasons for this.

The first was the trial and error method needed to obtain the right amount of aeration in the pile. The amount of aeration depended on the number of minutes the blower operated each day. Initially the blower was operated for a half-hour out of each hour for eight hours a day. This proved to be too much air and it cooled the pile excessively. The time of operation was reduced to 15 minutes out of each hour and the pile temperature went up. From that point on, pile temperatures were generally higher than those of the other piles. However, the pile was dryer at this point, and this may have contributed to higher heat, since moisture evaporation is a principal cooling mechanism in composts. To attempt to control heating and moisture loss, we reversed the direction of the air flow (negative–i.e. drawing through the piles). This tends to prevent excessive drying near the core of the piles.

Another problem with the forced aeration system was that because the pile was static the materials did not get as well mixed as in the turned piles. This resulted in some parts of the pile that remained cold probably because there were pockets of unmixed sawdust. In other sludge composting situations, it has been noted that pockets of raw, unstabilized material are found within the overall ripened compost.

A third problem was that there was excessive drying in this pile. The high temperatures and rapid air flow through the pile tended to dry it out more than the others and so probably inhibited the composting process somewhat. This was compounded by the fact that rain (or other moisture sources) cannot be mixed into the pile to add moisture as needed. This was done with the turned piles so that moisture levels remained near optimum throughout the project.

There was also the problem of the compression of the air space out of the pile as it settled over time. At the end of the project, the pile had compacted into dry, firm layers. Each layer had a different color and moisture content depending on the distance from the outside of the pile and the aeration pipes and had apparently reached a different stage of maturity before becoming too dry. The lack of air space in the completed material probably contributed to the restrictions of air flow and the non-uniform nature of the final product.

One last difficulty was encountered with the blowers used in this project. The first blower operated fine for 3–4 weeks and then failed to function. A second blower was obtained and it too operated for 2 to 3 weeks and then stopped. It was hypothesized that the blowers may have gotten wet and short-circuited. The cause of failure was never conclusively determined. For obvious reasons, failure of this nature is far more serious for a static pile than for a standard windrow compost, which could be turned in a number of ways if the windrow machine was temporarily out of service.

In summary, in this project the results obtained in terms of uniform quality product and in ease of control of the operation were much better with the turning machine than with blowers and aeration pipes. For operations large enough to warrant a turning machine and where product quality is important, the turning machine is seen as the superior alternative. For smaller operations, the lower cost blower system (probably $500 or less to set up) can be a good alternative. In order to be successful, however, the operator must work to find the right aeration routine to provide sufficient air without excessive drying. The materials must also be very thoroughly blended before pile construction to prevent "dead" spots in the pile and ideally the pile should be rebuilt at least once during the composting period to prevent compression and to allow the addition of moisture if necessary. This would also mix materials that may be at different stages of maturity thus giving a more uniform product at the end.

Laboratory Sampling No special apparatus or equipment is needed to take compost samples from a pile. A shovel and bucket are all that is needed. Materials were mixed and bagged immediately after sampling, and transported to a laboratory. It is important that samples are contained or bagged loosely to prevent moisture escape, but they should not be stored in sealed bags for more than a few hours.

4.2 Summary

This project demonstrated the use of several pieces of equipment for performing different composting tasks. The primary piece of equipment used was a Wildcat Compost Turner. For larger scale windrow type operations this kind of equipment can help in building piles, mixing ingredients, aerating the piles, adding moisture as needed, preventing compaction of the material and even reducing the size of some materials. Modification of the turner to allow injection of liquid materials while mixing would enhance its performance in that task. For larger scale static pile systems, an SSI type mixer can provide thorough mixing and aid in pile building. A blower system can provide adequate aeration if properly controlled.

In all operation types, a front-end loader with the largest practical sized bucket is an essential piece of equipment since handling, moving, and loading materials and finished compost tend to be the most time consuming elements of the process.

5 Economic Feasibility Evaluation

This section is intended to give the reader a sense of the costs associated with a moderate scale compost operation using the type of systems employed in the Mid-Coast Compost Project.

In the process of collecting the background material for this section it was found that many factors can have a significant impact on the cost of an operation and on the return per ton of product. An almost limitless number of possible scenarios could be proposed in which these various factors are adjusted. Some of these scenarios would yield attractive profits while others would result in significant losses and still others would roughly break even. In order to determine if any particular operation would be viable, it would be necessary to analyze the specific information about equipment purchases and operating costs, sources of raw product, transportation costs, tipping fees, proposed markets, land requirements, etc.

To deal with the multitude of variables involved in analyzing a compost operation data was sought on equipment, materials, labor, financing terms, etc. The data collected is discussed in the next subsections of this report.

Later subsections analyze a few scenarios that we hope will be representative of some likely compost operations, and will discuss the conclusions drawn from each.

5.1 Economic Variables

Two of the most important variables are the number of tons of fish waste (or other nitrogenous materials) that will be composted in a year and the mix ratio to be used. These determine the total volumes of materials that will be handled, processed and sold. Some other important factors are product prices, wage rates, interest rates, acres of land to be bought, land price, and information on bulking agents that will be used.

Other factors to consider include structures to be built, equipment to be purchased, equipment to be operated and the proportion of the product that will be sold in different markets.

5.2 Material Costs

One of the most significant costs of operation of a compost business can be the purchase and transportation of bulking agents (carbonaceous materials). Data was collected from a number of sources on the cost of commercially available bulking agents. The costs at the time this report was compiled are reported in Table 15. Most of these costs include the trucking from the source to an operation in the Mid-Coast area. These costs range from $15 to $150 per ton depending on material and sources.

Some bulking materials may be obtained at little or no cost or for the cost of trucking only. Several such materials were identified in an inventory of the Mid-Coast of Maine (see the report *Compostable By-Products in the Mid-Coast Area of Maine*). Table 1 summarized the findings from that inventory. It appears that about 60,000 tons of bulky carbonaceous materials are available in the Mid-Coast area alone. Comparable or higher volumes especially of wood by-products, are probably found in other parts of the State.

Even when materials can be obtained free, the cost of trucking can be substantial. In general,

Table 15: SELECTED SOURCES OF CARBONACEOUS MATERIALS IN CENTRAL COASTAL MAINE†

Material	Source	Description	Approx. Cost
Sawdust	Wes Kinney Knox	Kiln-dry sawdust hardwood + hemlock & spruce	\$5–7yd^3
Sawdust	Various Mills	mixed softwood sawdust	\$2–4yd^3 F.O.B
Sawdust	A.W. Chafee Oakland	Soft & hardwood sawdust from various mills	\$4–5/yd^3
Sawdust	Flo Jo Inc. Belgrade	Dry softwood sawdust	\$5–6/yd^3
Bark Compost	Flo Jo Inc. Belgrade	aged residue	\$10-12/yd^3
Horse Litter	Fairgrounds & Raceways	sawdust/shavings litter with some straw	n/a
Mulch Hay	Locally available	wet or spoiled Hay unsuitable for livestock	\$1/bale or \$50/ton
Whole Chips	L.E. Thompson S. China	Chips inc. twigs, bark, leaves and wood	\$5-6/yd^3
Wood Chips	Flo Jo Inc. Belgrade	chipped stumps	\$4-6/yd^3
Shavings, Woodchips	Bob Parkway Old Town	Wood chips mixed w/soil plain shavings	\$4–6yd^3
Peat	W.H. Shurtleff S. Portland	Agricultural grade peat	\$.075/lb (\$150/ton)

† incomplete data; costs do not necessarily include trucking

the compost operator should plan on trucking costs of about $.10-.20 per ton mile. The scenario calculations used a figure of $.15 per ton mile when specific information was not available.

In many (perhaps most) situations, some mixture of free and purchased bulking agents will be used. Many of the free materials, for example, are quite wet due to being stacked outside. These would have to be supplemented with drier material to achieve an acceptable moisture content in the initial mixture.

5.3 Other Costs

A number of other important costs must also be factored into the compost analysis. One of these, the cost of purchasing equipment of various types is given in Table 14 and Table 22 in the equipment evaluation sections 4.1 and A. Other important cost factors are given in Table 16. These include the cost of operating key pieces of equipment like trucks and payloaders and the cost of hiring or renting their services. They also include some labor, building and packaging cost figures as well as typical financing costs and terms. These values were obtained primarily through phone conversations with various sources and probably do not apply to many situations. In order to determine the economic viability of any particular operation it would be necessary to use the appropriate values for each of these items for that operation. In the absence of specific information, the values given in Table 16 should give reasonable, if not exact, results.

5.4 Composting Enterprise Scenarios

5.4.1 Scenario Introduction

In order to give the reader a sense of the range of the types of possible compost operations and the impact of various factors on their economic feasibility, four different compost scenarios were devised and analyzed. The four different scenarios can be briefly described as:

1. A small scale, processor owned facility with disposal as primary goal;
2. A medium scale farm based operation using existing equipment where possible;
3. A large, fully capitalized commercial operation;
4. A medium scale operation owned by a primary fish (or other) processor.

The following sections describe each of these scenarios in more detail, including equipment and land used, source(s) of carbonaceous materials, market assumptions made, and avoided costs or fees. The net profit or loss for each scenario is given and the major production cost elements are identified. For some the sensitivity of the results to changes in certain factors was tested by changes to one or more important factors. Special attention has been given to the impact of including avoided costs explicitly in the analysis, where this is a factor.

5.4.2 Scenario#1: A Small Disposal Operation

In this scenario a compost operation would be run by a small seafood processor as a way of disposing of its waste fish parts. It is assumed that the processor will use an aerated static pile

Table 16: SELECTED COSTS ASSOCIATED WITH A COMPOST OPERATION

ITEM	COST
Consumer Packaging	
88 lb. bag (plastic)	$.30 each
40 lb. bag (plastic)	$.25 each
3-ply paper bag	$.35 each
Fertilizer Bagging (contract)	$15/ton
Trucking Services	
Dogfish	$7/ton
Fertilizer	$8/ton
General	$.10-.20/ton mile
D.O.T. 12 yd. Truck Operation	
Truck Costs with Depreciation	$20.70/hour
Operator Costs	$9.58/hour
Payloader Operation (Minus Depreciation)	$10/hour
Depreciation on Payloader ($70,000)	$6-7/hour
Payloader Useful Life	12,500 hours
D.O.T. Loader Short-term Rentals†	
1-1/4 yd. Gravel Capacity	$16.70/hour
with operator	$23.91/hour
2 yd. Gravel Capacity	$23.60/hour
with operator	$31.18/hour
3 yd. Gravel Capacity	$30.60/hour
with operator	$38.18/hour
Payloader Purchase Price	
Caterpiller Model 916	$85,000‡
Caterpiller Model 910	$69,000‡
Buildings	
Open Pole Structure	$8.00/sq. ft.
Enclosed Building	$20.00/sq. ft.
Labor Costs	
General Labor Wage	$7.00/hour
Project Manager (large operation)	$25,000/year
Finance Costs	
Interest on Land and Buildings	12.0%
Interest on Equipment	10.8%
Term on Land and Buildings	84 months
Term on Equipment	60 months

†Long-term rentals are usually less. ‡Discounts available for State or municipal operations.

system and will not bag or screen the final product. The final product will be sold to local citizens for $20 per ton at the plant. Current disposal cost is assumed to be $15 per ton, but is being threatened with closure.

The bulking agent used will be 70% sawdust which will cost $17/ton, 10% horse litter and 20% other locally available materials such as yard wastes.

Due to its small size, no land will need to be purchased but approximately one acre will be leveled and gravelled and a 40 x 100 ft. concrete pad will be installed for materials reception.

It is assumed that a frontend loader is already available so that the only equipment purchases would be two blowers with control systems and testing equipment for monitoring the piles.

All land and equipment purchases are assumed to require a 20% cash down payment with the remaining 80% borrowed. Capital costs would be about $10,420, most of which is the cost of grading and paving the site.

With a total annual production of only 200 tons of fish waste, daily production averages only one or two tons, which can be easily handled by existing plant workers.

Findings: Total production would be about 385 tons of compost per year. When 95% is sold at $20 per ton this would result in revenues of $7,315. The cost of production given this scenario would be approximately $9,898.20. This translates into $49.49 per ton of fish or $25.71 per ton of compost (see Table 17 and Figure 7).

The net return for the operation would be minus $2,583.20 or $12.92 per ton of fish. Although this operation does not "make" money for the firm, it is still feasible if the $12.92/ton of fish is less than the next best disposal option. It is also a relatively low cost means of maintaining good public relations with the neighbors who may be thrilled with the compost for their gardens.

Note that over 50% of the cost of this operation is the cost of the sawdust. If a dependable, lowcost source of sawdust or other carbonaceous material could be found that could replace the sawdust, material costs could be cut by half. Such an arrangement would allow the compost operation to breakeven. The only other significant cost is the site preparation and concrete pad. The amount that will need to be spent on these items will vary but probably cannot be eliminated entirely.

5.4.3 Scenario#2: A Farm-Based Operation

In this scenario, a compost operation is part of an existing farm that already has the land and most of the equipment needed to set up a compost business.

It is assumed that the farm has an arrangement with a fish processor to accept 2,000 tons of fish by-products annually and will receive $10 per ton from the processor. It is also assumed that half of the product will be sold locally in bulk at a price of $20 per ton. Forty-five percent of the product will be bagged and sold in garden centers, nurseries, etc. in the state. The wholesale price is expected to be $2/40 lb. bag due to the high nutrient value and "all natural" character of the material. In order to maintain a high quality product for bagging and spreading on farmland, all compost product will be screened.

In order to compost the fish, 5,000 tons of bulking agents will be needed. The bulking agents to be used will be 30% sawdust, purchased at a price of $15/ton; 10% stable bedding at a cost

Table 17: ENTERPRISE BUDGET—SMALL COMPOST UNIT

VARIABLE	Cost/Year	/ton fish	$/ton comp	%of cost
Transportation	$520.00	$2.60	$1.35	5.3
Materials	5,250.00	26.25	13.64	53.0
Equipment Purchase †	353.21	1.77	0.92	3.6
Land ‡	1,465.75	7.33	3.81	14.8
Buildings ‡	0.00	0.00	0.00	0.0
Equipment Operation	514.50	2.57	1.34	5.2
Labor	490.00	2.45	1.27	5.0
Miscellaneous	1,304.74	6.52	3.39	13.2
TOTAL	9,898.20	49.49	25.71	100.0
TOTAL REVENUE	$7,315.00	$36.58		
		Labor Wage	$7.00	
NET PROFIT/LOSS	($2,583.20)	‡Int. Rate A	12.0%	
Per ton of fish	($12.92)	†Int. Rate B	10.8%	
Per ton of product	($6.71)	Disposal fee	$0.00	
		Vol. Fish	200	
RATE OF RETURN on Invested Capital	-125%	Tax Rate	0.015	
INVESTED CAPITAL	$340.00			
Interest Paid (annual avg)	$558.48			
Total Capital Cost	$10,349.22			

of about $4 per ton (for transportation); 20% wood chips at a cost of $17/ton; 20% recycled woodchips and 20% other locally available carbonaceous material.

The operation will require about 3.5 acres, of which about two acres must be graded and graveled at a cost of $2,500/acre. A paved area 40x100 ft. will be constructed as well as a 7,300 sq. ft. open pole building. Existing buildings can be used to store bagged product until it is sold. Equipment purchases will include a compost turning machine to go on a tractor, a hopper and conveyor setup, a compost screening device and bagging equipment. Testing equipment like thermometers will also be needed. Total capital costs would be $131,000.

Findings– This operation should produce approximately 3,850 tons of final product, of which it is assumed that 95% or 3,660 tons will be sold. If 45% is sold in bagged form at $100 per ton and 50% is sold in bulk at $20 per ton the annual revenue from sales will be $211,750. Total cost would be about $151,800 annually. This would result in a net profit of $59,930. Adding the $20,000 received as disposal fees from the fish processor would bring this total up to about $79,930 or about $21/ton of compost (See Table 18 and Figure 8.)

It should be kept in mind, however, that this net profit is based on the assumption that existing equipment will be used in the operation. The additional hours put on this equipment means that it will need to be replaced sooner than if used only for the farm operation. An additional $20,000 per year would have to be earmarked for the replacement of the tractor needed to operate the turner and a payloader. So, even though a farm operation would have a cost advantage initially over a business starting from scratch, eventually the compost operation would have to be able to cover the additional cost of the equipment needed.

The major cost items for this operation would be the cost of the bulking materials (about 26%) and the cost of transporting bulking materials (about 20%). Another major cost area is the bagging operation which accounts for about 22% of the total. Of this, the cost of the bags needed to handle 1,730 tons would be about $22,000 at 25 cents each or about 15% of total costs.

Significant changes in production costs could be made by identifying lower cost sources of carbonaceous materials. A three dollar per ton reduction in the price of sawdust for example would save the operation $4,500 per year. A free local source would save about $20,000 per year if it were suitable.

Elimination of the bagging operation would reduce costs by over $40,000 per year but would reduce revenues by $138,600. This would require an increase in the disposal fee charged to the fish processor to about $16.50 per ton to breakeven (see Table 19). It appears that a farm operation of this size would need to sell at least 15-20% in bagged form each year at $2/bag in order to cover all operating costs and be able to replace equipment as needed.

A cautionary note should be added here. This analysis is based on the assumption that the compost operation will be able to sell 1,730 tons of compost in bagged form in Maine. Although the market study indicates that this is certainly possible, it will not happen without some effort and expense. Some firms estimate that promotion costs run about 5-10 cents per bag sold. For our example, this would be about $5,000-$10,000, but considering this would be a new enterprise, it may require considerably higher expenditures in the first year or two to get into the market. (Alternatively, it might mean lower revenues due to the need to give away large quantities of product to develop a demand for it).

5.4.4 Scenario#3: A Large Scale Commercial Operation

The compost operation being analyzed in this scenario is a compost business that is independent of any particular waste generator and who may accept compostable wastes from several sources. This operation is accepting about 5,000 tons of fish by-products annually for which it charges a disposal fee of $15 per ton.

From these materials, 9,625 tons of finished compost would be produced. Thirty-five percent (or about 3,400 tons) of the product would be sold in bagged form at $2 per 40 lb. bag. (This is the volume indicated by the market study that could reasonably be expected to be sold in Maine.) Sixty percent (or almost 5,800 tons) would be sold in bulk at a price of $20 per ton.

At a mix ratio of 2.5 to 1 the operation would use 12,500 tons of carbonaceous bulking material. Sixty percent of this would be sawdust purchased at a cost of $15 per ton. Ten percent would consist of woodchips purchased at $17 per ton. Another ten percent would be animal bedding that would be free but cost about $4 per ton for transportation. The final twenty percent would be old sawdust and other free materials that would cost roughly $7.50 per ton to transport.

An operation of this size would require about 7.5 acres of land for composting activities

Table 18: ENTERPRISE BUDGET–FARM OPERATION

VARIABLE	Cost/Year	/ton fish	$/ton comp	% of cost
Transportation	$ 30,223.75	15.11	7.85	19.9%
Materials	39,500.00	19.75	10.26	26.0
Equipment Purchase †	15,063.40	7.53	3.91	9.9
Land ‡	1,895.64	0.95	0.49	1.2
Buildings ‡	9,896.83	4.95	2.57	6.5
Equipment Operation	11,852.92	5.93	3.08	8.7
Labor	15,502.08	7.75	4.03	10.2
Miscellaneous	26,589.21	13.29	6.91	17.5
TOTAL	$151,823.20	$75.91	$39.43	100.0%
TOTAL REVENUE	$231,750.00	$115.88	Labor Wage	$ 7.00
			Equip. Cost	$10.00
NET PROFIT/LOSS	$79,926.80		‡Int. Rate A	12.0%
Per ton of fish	39.96		†Int. Rate B	10.8%
Per ton of product	20.76		Disposal Fee	$10.00
			Vol. Fish	2,000
			Vol. Prod.	3,850
RATE OF RETURN on Invested Capital	281%		Tax Rate	0.017
INVESTED CAPITAL	$26,180.00			
Interest Paid (annual)	$7,303.17			
Total Capital Cost	$131,000			

OPERATION	Annual Cost	Percent
Bagging	$34,041.05	22.4%
Screening	6,734.28	4.4
Turning	14,610.39	9.6
TOTAL	55,385.71	36.5

plus another 5 acres of buffer land. A larger ($67{,}000 ft^2$) open building plus a small ($1{,}000 ft^2$) enclosed building would also be needed. The total cost of the land and buildings is estimated to be about $633,000 of which 35 percent is paid in cash and the rest is borrowed at 12 percent for 20 years.

Equipment purchases for this operation would include a payloader, a turning machine (self-propelled type), a tractor with a badger spreader, a small frontend loader and a bagging system including a conveyor and hopper. Testing equipment will also be required. The total cost of equipment is projected to be approximately $224,500. This would be bought by paying 35 percent down and borrowing the rest at 10.8% for seven years. In addition, a screening device would be rented for about a month each year at a cost of about $4,800.

Findings:

This operation would annually generate $336,875 from bagged compost sales, $115,500 from bulk compost and $75,000 from disposal fees for a total revenue of $527,375.00. The total annual cost of this operation would be about $434,000, so that the net profit would be about $93,000

Table 19: ENTERPRISE BUDGET–FARM *Bulk Compost* OPERATION

VARIABLE	Cost/Year	/ton fish	$/ton comp	% of cost
Transportation	$18,529.38	$9.26	$4.8	17.5%
Materials	39,500.00	19.75	10.26	37.2
Equipment Purchase †	10,907.98	5.45	2.83	10.3
Land ‡	1,895.64	0.95	0.49	1.8
Buildings ‡	9,896.83	4.95	2.57	9.3
Equipment Operation	10,986.67	5.49	2.85	10.4
Labor	9,438.33	4.72	2.45	8.9
Miscellaneous	4,932.96	2.47	1.28	4.6
TOTAL	$106,087.78	53.04	$27.56	100.0%
TOTAL REVENUE	$106,150.00	$53.08	Labor Wage	$7.00
			Equip. Cost	$10.00
NET PROFIT/LOSS	$62.22		‡Int. Rate A	12.0%
Per ton of fish	$0.03		†Int. Rate B	10.8%
Per ton of Product	$0.02		Disposal Fee	$16.50
			Vol Fish	2,000
RATE OF RETURN	0%		Tax Rate	0.017
on invested Capital			Vol. Rate	3,850
INVESTED CAPITAL	$22,180.00			
Interest Paid (annual)	$5,230.52			
Total Capital Cost	$110,900			

OPERATION	Annual Cost	Percent
Bagging	$0.00	0.0%
Screening	$6,734.28	6.3%
Turning	$14,610.39	13.8%
TOTAL	$21,344.67	20.1%

(see Table 20).

As with most compost operations analyzed, the major expense for this compost business would be the transportation and purchase of bulking materials. Together these two items make up almost 47% of the total annual cost. Miscellaneous costs (of which two- thirds is the cost of bags) is the next biggest item, followed by labor and building costs.

Clearly, the profitability of the business is going to be sensitive to availability and price of bulking agents. If, for example, half of the sawdust can be replaced by suitable material for which a disposal fee would be paid, the net profit would increase dramatically. For the sake of illustration, assume the generator of the carbonaceous waste material will pay $10 per ton and deliver it to the compost site. This would change the net profit from $93,500 to about $187,000!

Again caution is needed in interpreting these results, since they are also very sensitive to the price and volume associated with sales of bagged product. We have assumed that nearly 3,400 tons of compost can be sold at $2 per bag. But promotion costs at 5- 10 cents per bag would be $8,500 to $17,000 for this volume of material. In addition, in order to sell this volume, the price might have to be dropped to $1.50 or even $1.25 per bag. The net effect of promotion costs of five cents per bag and a $.50 per bag price drop would be a drop in net profit from $93,500 to about $800.00, or barely breaking even. A sharper drop in price would result in net losses.

The other significant assumption is the volume of compost that could be sold in bagged form. If 45 percent of the product could be sold in bags at 2 dollars each instead of 35 percent, net profit would jump up to $148,000. Conversely, if only 20 percent could be sold in bags, annual profits would fall to about $12,000 (of which most may be absorbed by promotion costs.)

Table 20: ENTERPRISE BUDGET–LARGE COMMERCIAL OPERATION

Variable	Cost/Year	/ton fish	$/ton comp	% of cost
Transportation	$69,661.25	$13.93	$7.24	16.1%
Materials	133,750.00	26.75	13.90	30.8
Equipment Purchase †	37,898.73	7.58	3.94	8.7
Land ‡	6,464.70	1.29	0.67	1.5
Buildings ‡	47,897.56	9.58	4.98	11.0
Equipment Operation	21,635.94	4.33	2.25	5.0
Labor	51,598.54	10.32	5.36	11.9
Miscellaneous	64,941.54	12.99	6.75	15.0
TOTAL	$433,848.26	86.77	45.08	100.0%
TOTAL REVENUE	$527,375.00	$105.48	Labor Wage	$7.00
			Equip. Cost	$10.00
NET PROFIT/LOSS	$93,526.74		‡Int. Rate A	12.0%
Per ton of fish	18.71		†Int. Rate B	10.8%
Per ton of product	9.72		Disposal Fee	$15.00
			Vol. Fish	5,000
RATE OF RETURN	31%		Tax Rate	0.026
Invested Capital	$273,768		Vol. Compost	9,625
Interest Paid (annual) §	$42,504		§Term	20yrs
Total Capital Cost	$782,196			
OPERATION	Annual Cost	Percent		
Bagging	$61,487.22	14.2%		
Screening	$5,935.42	1.4%		
Turning	$16,922.91	3.9%		
TOTAL	$84,345.54	19.4%		

5.4.5 Scenario #4: A Processor Owned Mid-Sized Operation

In this scenario, a compost facility that is owned and operated by a moderately sized fish processing firm is analyzed. This firm processes about 3,000 to 4,000 tons of fish annually, of which about 2,000 tons is waste available for composting. Because it will be processing only its own fish by-products, the firm will not be charging a tipping or disposal fee.

At a mix ratio of 2.5:1, the company will need to obtain about 5,000 tons of carbonaceous bulking material. When finally composted this should result in about 3,850 tons of product. It is assumed that the firm can sell 40 percent of this total in bags at $2.00 per 40 lb. bag and that 55 percent can be sold in bulk at $20 per ton.

The bulking materials to be used will include 2,500 tons of old sawdust which will be free but requires transportation at $7.50 per ton. Another 1,500 tons will be new dry sawdust at $15.00 per ton. About 500 tons of bedding or litter costing $4 per ton to transport and 500 tons of woodchips costing $17 per ton will also be used.

Land requirements for this operation will be about 8.5 acres, of which two acres must be cleared and two must be graded. About a half acre will be paved. Total land expenses are estimated to be about $42,000. Building costs for a 26,560 sq. ft. open building plus a 1,000 sq. ft. enclosed building are estimated at about $232,500. Eighty percent of these costs will be borrowed at 12 percent interest for a 20-year period.

Equipment purchased for this operation will include a payloader, a tractor mounted turner, a tractor, a small frontend loader, a liquid manure spreader (to handle the fish gurry), a bagging setup with a hopper and conveyor, and testing equipment. The cost of this equipment is projected to be about $183,500. The firm would borrow 80 percent of this amount at 10.8% interest for five years. A screening device would also be rented each year for about 65 hours of screening at a cost of about $2,000.

Findings:

Sales from bagged compost would yield $154,000 while bulk sales would add another $42,350 for a total of $196,350. Annual production costs would total about $209,050. This would result in a net loss of about $12,700 per year (See Table 21 and Figure 10). On a per ton of raw fish basis, the loss would be about $6.35 plus whatever promotional costs may be incurred. If this cost is less than the cost of the next best disposal option for the firm, it may justify the firm undertaking the compost operation. If another option is cheaper or is simpler and only marginally higher in cost it may not make sense to undertake the effort of setting up a compost operation.

Material costs are again extremely important to the success of this operation. If the firm must buy 60% of its bulking agent in the form of sawdust at a price of $15.00 per ton instead of only buying 30% at this price, net profits would fall from a minus $12,700 to a minus $24,500 (ignoring promotion costs). This translates into a cost of about $12.25 per ton of raw fish waste composted.

One of the major per unit costs for this operation (in addition to materials and transportation) is the cost of purchasing equipment. This is because, at this scale, nearly as much equipment is required as would be needed for a much larger operation. If the same operation processed a additional 1,000 tons of fish wastes each year using the same equipment, the equipment cost would drop from 18.2% to 13.7%. More importantly, net profits would change from a minus $12,700 to a plus $15,500. This emphasizes the notion of "economies of scale", where increased volume results in lower per unit costs. This does not consider the added cost of trying to sell the additional product.

Another approach to improving the financial outlook would be to increase the proportion sold in bagged form. An increase from 40% to 50% would yield a net profit of about $8,000 or about $4.00 per ton of fish. Here again there would probably be increased promotion costs to consider when trying to expand this market.

It appears that at this scale of compost operation one of the best strategies for success would be for two or more fish processors to co-operate on a single compost operation so that sufficient volumes could be processed to take advantage of the economies of scale available.

Figure 7: COSTS OF SMALL DISPOSAL OPERATION

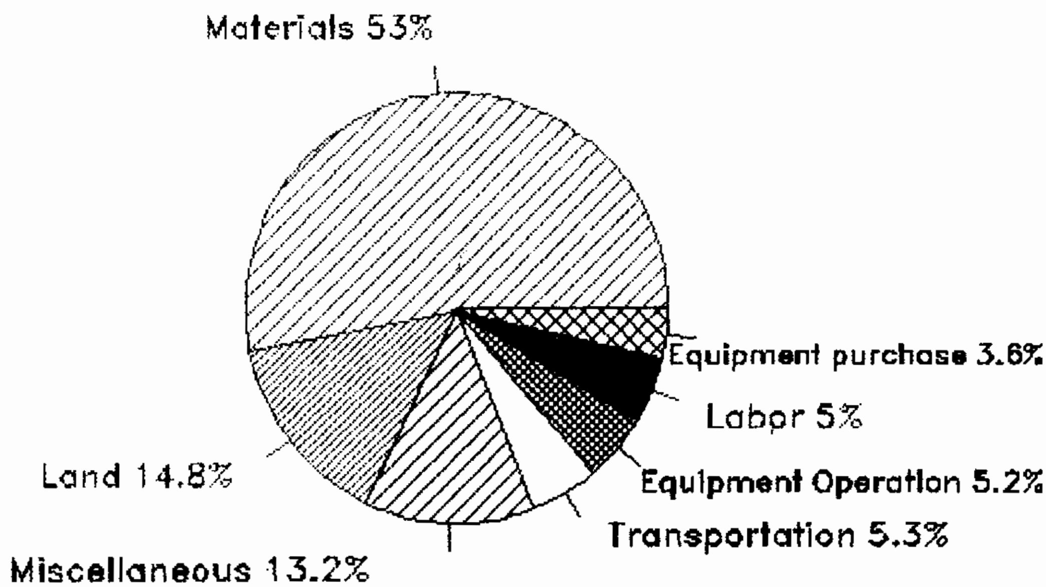


Figure 8: COSTS OF FARM COMPOST OPERATION

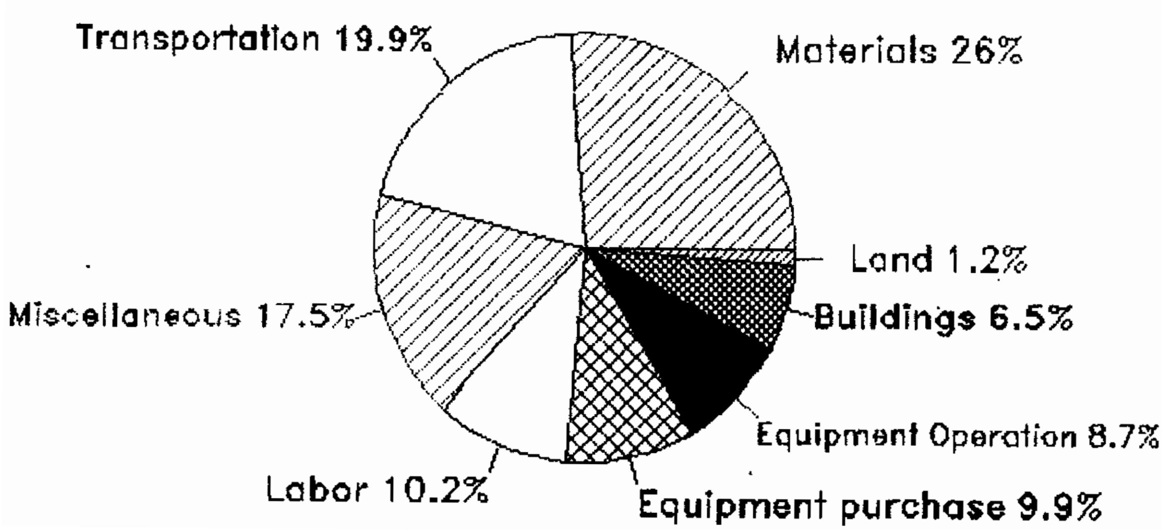


Figure 9: COSTS OF LARGE COMMERCIAL COMPOST OPERATION

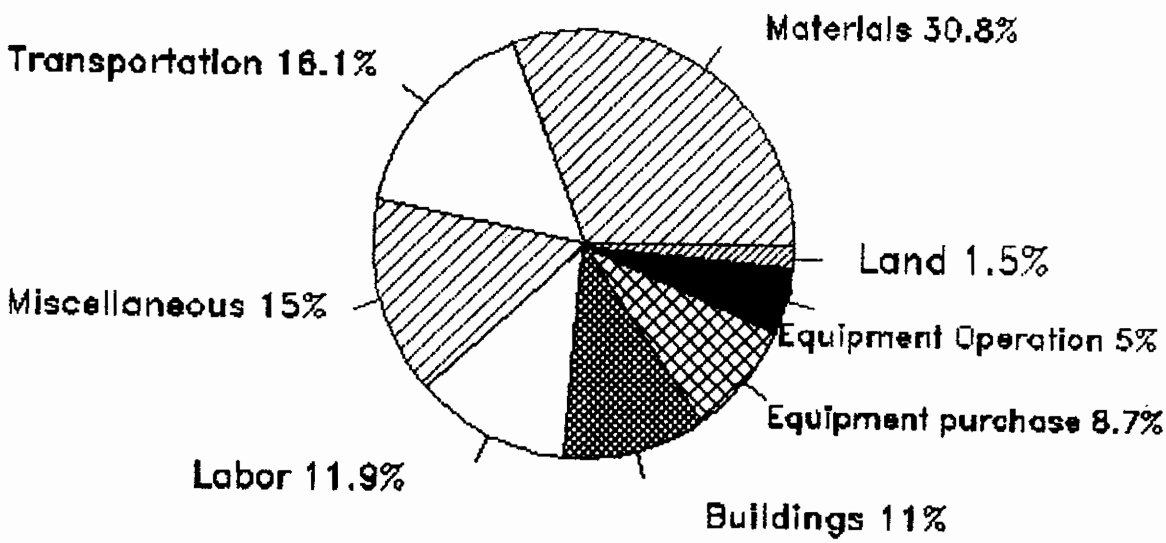


Figure 10: COSTS OF PROCESSOR OWNED COMPOST OPERATION

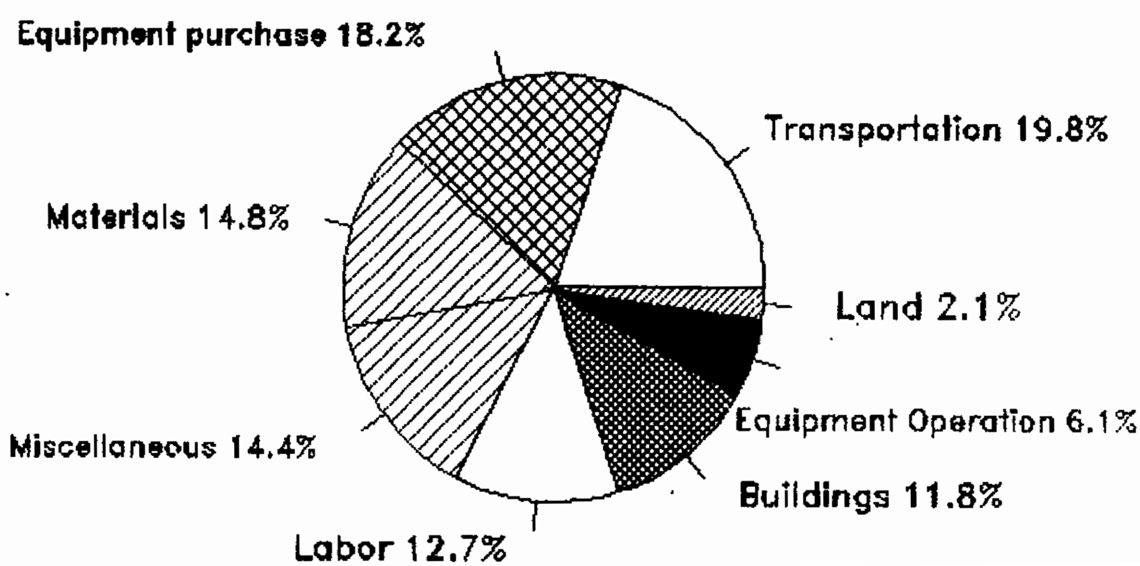


Table 21: ENTERPRISE BUDGET–PROCESSOR OWNED OPERATION

Variable	Cost/Year	/ton fish	$/ton comp	% of cost
Transportation	$41,410.00	$20.71	$10.76	19.8%
Materials	31,000.00	15.50	8.05	14.8
Equipment Purchase†	38,125.98	19.06	9.90	18.2
Land‡	4,460.25	2.23	1.16	2.1
Buildings‡	24,572.10	12.29	6.38	11.8
Equipment Operation	12,795.00	6.40	3.32	6.1
Labor	26,543.17	13.27	6.89	12.7
Miscellaneous	30,141.07	15.07	7.83	14.4
TOTAL COST	$209,047.57	$104.52	$54.30	100.0%
TOTAL REVENUE	$196,350.00	$98.18	Labor Wage	7.00
			Equip. Cost	$10.00
NET PROFIT/LOSS	(12,697.57)		‡Int. Rate A	12.0%
Per ton of fish	(6.35)		†Int. Rate B	10.8%
Per ton of product	(3.30)		Disposal Fee	0.00
			Vol. Fish	2,000
RATE OF RETURN	-14%		Tax Rate	0.026
on Invested Capital			Vol. Compost	3,850
INVESTED CAPITAL	$83,192.16			
Interest Paid (annual)	$26,812.08			
Total Capital Cost	$458,000			

OPERATION	Annual Cost	Percent
Bagging	30,720.42	14.7%
Screening	2,374.17	1.1
Turning	14,506.50	6.9
TOTAL	$47,605.09	22.8

5.5 Summary

It can be concluded from the economic scenarios investigated, that compot operations of almost any size can be economically faeasible depending on their purpose and particular circumstances. Each of these different operations can also be a financial failure.

For all four scenarios, material costs are the most significant operating expense. Equipment costs are important for all but the small disposal oriented operation while land acquisition and preparation costs are the most substantial hurdle to establishing a processor owned or a large commercial operation.

Of the scenarios evaluated, the farm based and the large commercial operations appeared to be the most likely to be financially successful. The farm operation due to the availability of land and equipment and the large commercial due to the economies of scale available. Marketing looms as a more significant factor for the larger operations, however, due to the finite size of the Maine market for bagged product.

Processor owned facilities may be justified on the basis of avoiding other diposal costs. The chances for financial success for a processor owned facility would be enhanced by cooperation with another processor to achieve economies of scale in production or by a relationship with a farm that would reduce initial capital costs. Most operations would need to sell some proportion of their product in bagged form if the opertion is to be a profit maker. At small or moderate scales, disposal fees will probably be necessary to attain profitability.

A Other Composting Equipment

The data for this section was researched in order to provide input data for the economic feasibility analysis. It was felt that the data itself may be of interest to those who are considering setting up a compost operation.

Mention of a type or brand of equipment should not be seen as an endorsement of that product nor should the omission of a particular piece of equipment be seen as a negative comment. Rather, the following represent what data was provided to us by dealers or manufacturers in response to requests for information.

Information was collected on the following types of equipment:

- Compost Turners
- Screening Devices
- Shredders and Grinders
- Mixing Equipment

For most of these, the information available was only that provided by manufacturers. For screens and mixing equipment there was additional information available from articles appearing in the magazine *Biocycle*[24]. In a few cases, information was also obtained from individuals who have operated the equipment in question.

A.1 Compost Turners

A.1.1 General Desciption

Table 22 contains information on equipment manufactured by five different companies. Of these, there seem to be three basic types of units.

1. attachments to go on farm tractors
2. self contained units that straddle windrows
3. self contained units that push windrows to the side

The Wildcat units are all designed to be used on a tractor, bulldozer or payloader. These units all use a rotating drum with flails that lift the compost and repile it as the machine is pulled through the pile. Although the capacity of these units is lower than the self contained units, the initial investment is smaller.

Recovery Systems of Nebraska, Scarab Manufacturing, and Eagle Crusher Corporation all make large self contained units that straddle the windrow and lift and aerate the material in a way similar to the Wildcat machines. These large self contained units have higher capacity but cost significantly more to purchase.

[24] Biocycle Magazine, published by J.G. Press, Inc., Box 351, Emmaus, PA 18049

Table 22: COMPOST TURNING EQUIPMENT

COMPANY NAME	EQUIPMENT TYPE	SIZE CAPACITY	COST	COMMENT
Wildcat Manufacturing	FX400	3'H x 8-10'W (windrow size)	$10,000	Needs 40-60 HP tractor
	FX700	4'H x 14'W 300 tons/hr.	$11,500	Needs 60-120 hp tractor
	C700	4'H x 12'W 400 tons/hr.	$17,500	Needs 90-140 hp tractor
	CX700	5'H x 14'W 500 tons/hr.	$23,500	Needs 100-225 hp tractor
	CX700ME	5'H x 14'W 800 tons/hr.	$51,000	self-powered 117hp diesel
	M700E	1400 tons/hr.	$68,000-78,000	self-powered 250hp diesel
	M700E special	2000 tons/hr.	$91,000-100,000	self-powered 325hp diesel
Eagle Crusher Corp.	Cobey Composter	1,600 tons/day		Drum with teeth lifts compost
	Auger Dryer Composter	10 ft.w windrows		Auger moves compost to side
	Terex Composter	4-4½' high x 10' wide		Paddles push it up and to side
Brown-Bear Corporation	Brown Bear I Auger Composter	225-290 hp windrows 5'H x 11-12'W 4,000 cu yd./hour		Auger moves compost to the side
	Brown Bear Grizzly Brown Bearcub Auger Composters	175 hp x 3,000yd^3/hr. 95 hp 1,500yd^3/hr.		Auger moves compost to the side
	Brown Bear Paddle Type Aerator	attachments for all size machines		Lifts and aerates material
Resource Recovery Systems of Nebraska	KW (King of the Windrow) Composter	up to 3,000 tons/hr. 6'H x 14'W	$105,000	Machine straddles windrow and drum lifts and turns material
Scarab Manufacturing and Leasing Co.	Scarab Windrow Composting	up to 3,000 tons/hr. 5'H x 14'-18'W	$90,000-$160,000	Machine straddles windrow and drum lifts and turns material

Crusher Corporation and the Brown-Bear Corporation both manufacture machines equipped with augers or paddles that are pushed into a pile and move it sideways. These machines were designed primarily for drying sludge and similar materials but have been used to aerate compost windrows as well.

Large commercial compost operations tend to favor the large self contained units that straddle the windrows while smaller farm scale operations would probably find the units that attach to a tractor to be the most practical. Most of the operations using the auger type units are drying and composting sludge.

A.1.2 Equipment Comparisons

In another compost operation visited during the Waldoboro project, we had the occasion to observe and handle the self-propelled Scarab-type turner. This is a 220hp belt (or hydraulic) driven machine which straddles the entire pile. Despite the enormous torque available to turn the materials, similar operational difficulties were observed, particularly having to do with drag. The Scarab can dig itself into the ground if the operator is not aware that forward motion is too fast, or if he fails to notice that the pile is too high or wide to afford easy passage. Should the machine sink into the soil (or gravel) there is considerable danger that the flails on the drum will be damaged or broken by encountering rocks. As with the Wildcat, if the Scarab machine became stuck it had to be dug out of a windrow with a loader.

Some interesting comparisons were afforded in comparing these two turning machines with respect to handling rocks. With the Wildcat turner, rocks as large or larger than a football made a great deal of noise, bent some flails, but never caused any jamming or breakage. But as alluded to, rocks appeared to pose greater risk to the Scarab-turner, possibly causing breakage of flails or the brackets they mount upon. This underscores the significance of maintaining a clean site if one expects to use larger equipment such as the windrow staddling turners.

One final observation regarding the problem of becoming mired was made in comparing the regular Wildcat C700 series turners with Wildcat's larger payloader-mount version, which we witnessed in a demonstration made elsewhere during the Waldoboro project. This model is equipped with its own 200hp engine, is considerably larger, and attaches to a quik-attach type bucket loader (enabling an operator to change from a bucket to the turner in a 5–10 minute period of time). For several reasons, it appears to be impossible to get the machine stuck in any way. Firstly, the turner is mounted on the payloader's hydraulic arms and consequently can be raised– although awkwardly– to any height, even clear out of a 6 foot high pile, in event of blockage. Furthermore, since payloaders are 4-wheel drive *and* utilize hydrostatic control, the event of getting physically stuck is rare indeed. Would-be large scale composters who contemplate a rough, outdoor site, should consider these points carefully.

A.2 Screening Devices

Many different types of screening devices are used to separate compost, woodchips, gravel and other soil-like materials. In the limited search undertaken for this project, eight different types of screening devices were identified. They were:

Rectangular Shaker Screens - These devices are incorporated into a single unit consisting of a feed hopper, conveyor and shaker screen. The screens are often "piano wire" screens and are used to separate gravel. Others have wire mesh or perforated panels as screens. The City of Gardiner has a screen of this type for sludge compost separation.

Circular Oscillating Screens - This type of screen is used to separate fine materials, both wet and dry, through rapid vibration caused by a motor with an off-center weight. These machines are used in industrial processes but some models have been adapted specifically for compost use. The cities of Bangor and Old Town both have this type of screen for their sludge compost operations.

Trommel Screens - Trommel screens are similar to the rectangular shaker sceens above in that they often include a large hopper and feed conveyor. The screening device itself, however, is a rotating drum with holes. Some large municipal compost operations in the Northeast (such as the city of Philadelphia) use trommel screens.

Rotary Screens (Spinning Disk) - Rotary (spinning) screens have plates or discs with holes of selected size onto which a material fed. Its spinning action throws oversize material to the outside. This type of screen is often used in sawmills to separate sawdust from larger materials.

Flexing Belt Screen - One of the more unusual concepts for a screening device is the flexing belt system. This device has a slotted belt of a durable material., Sections of this belt are alternately flexed then snapped taut throwing the material up and clearing the slots. These large machines are used by large sludge composting facilities such as the Blue Plains Facility in Washington, D.C.

Moving Belt Screen - This system uses a rapidly moving abrasive belt that shreds, separates, and mixes materials. It includes a built-in feed hopper and conveyor. The primary use for this device appears to be for loam type products.

Stationary Screens - The stationary screens identified in this survey consisted of a perforated trough containing an auger that moves the materials from one end to the other. The fine material drops through the holes and coarse materials pass on to the end. Multiple auger/screens can be combined to achieve multiple separation of sizes. This type of equipment is designed to remove soil and fine materials from woodchips.

Scalping Disks - This device uses vertically placed banks of overlapping scallop-edged rotating disks to move coarse items from one end of the screen to the other. Smaller pieces fall between the disks as they rotate. Scalping disks are designed to remove large items like trim ends from usable woodchips or sawdust.

Several specific screening devices were tested and reviewed in the May-June 1981 issue of *Biocycle* Magazine by Higgins, *et.al.*. They rated the devices on the basis of effectiveness and cost per ton. In the article three shaker type screens, one flexing belt and one trommel were analyzed. Table 24 lists per unit costs and effectiveness ratings for those specific units reviewed. The reader should refer to the complete article for more detail on their evaluation.

In general, it appeared that the small shaker screen (Van Dale) and the flexing belt screen both resulted in very clean woodchips but allowed various amounts of the chips in the finished compost. The two larger shaker screens (Power Screen and Royer-Mogenson Sizer) did much better job at keeping chips out of the final product but resulted in significant amounts of compost going into the chip pile. The trommel (Royer) resulted in over 95% separation of both chips and compost but at higher moisture levels the compost tended to form into balls due to the rolling action.

Although no formal evaluation was available for the other types of screens listed, some personal observations were made about the circular oscillating units and the spinning disk type of unit. One manufacturing representative did not feel the spinning disk type screen sold by his company would be effective for compost due to their low capacity and potential for "blinding" due to wet materials. ("Blinding" means the holes in the screen become plugged with material.)

Comments were received from both a municipal sludge composter and a commercial compost operator regarding circular oscillating screens. Both observed that these units were effective at producing clean compost. The municipal composter also noted that due to a self cleaning kit, the screen could be used with compost up to 68% moisture without serious blinding problems.

Each unit, then had its strong and weak points from the point of view of effectiveness. In order to choose which is best for a particular application, the compost operator should try to view units in action to determine how they would work for the specific material being composted.

Table 23: COMPOST/LOAM SCREENING DEVICES

COMPANY NAME	EQUIPMENT DESCRIPTION	CAPACITIES	COST	COMMENTS
Morbark Equipment	Mortran Screen. Double auger separates coarse, med., fines	75 ton/hr.	$32,500	
	Disc Scalping Screen	?	$13,500	Removes coarse wood pieces
	Rotary Screen 5'x5' (used in sawmills)	?	$7,165	Sales doesn't think these would do the job
	Spinning Disk 6'x6'	?	$ 7,720	
Power Screen	Double deck vibrating screen 16ft^2 deck -piano wire lower deck	30 cu yd/hr. municipal compost	$49,700 (1980)	Includes hopper and conveyor
	Double deck vibrating screen 4'x6' deck Model Mark II	50 cu yd/hr.	$110,000 or $6,500/mo lease	Includes hopper & conveyor; heavy duty, built for sand and gravel
Resource Recovery Systems, Inc.	Rotary Screen/Shredder (trommel or rotating drum)	50-125 cu yd/hr.	$85,000-$110,000	Includes hopper and conveyor
	Double Deck Vibrating Screen 4'x8' Deck Screen (piano wire screens)	75-125 cu yd/hr.	?	Similar to Power Screen above)
	30'24"W Stacking Conveyor		$9,200	
SWECO, Inc.	P.O.D. Separator Oscillating screen - carbonsteel - stainless steel 72" deck	$\leq 50 yd/hr$ 75-80yd/hr	 $20,500 $23,500 ?	Dust tight shell
	Compost Separator (oscillating screen) 72" deck	60 yd/hr	$25,000 (approx.)	Used by Bangor Compost Operation at up to 65% moisture
Royer Foundary and Machine Co.	Mogensen Sizer Vibrating Multidecc Screen	27 cuM/hr.	$68,000 (1980)	
	Trommel Screen (Rotating Drum)	40-45 cuM/hr.	$119,600 (1980)	
	Royer Shredder Mixers moving belt screen	30 to 200 cu yd/hr.	NA	Includes hopper and conveyor– shreds and separates particles
Krebs Engineering	Liwell Screen Model#8S-1.5 5'x17' deck	60-70 cuM/hr.	$167,400 (1980)	Flexible slotted panels alternated sag then snap taut throwing particles up and clearing screen
	Liwell Screen Model 6SF-1.5	up to 30 tons/hr	$55,000	
Plains State Engineeering MFG. Company	Series 600000 Double Deck Vibrating Screen Model 648082ET (48" x 8' deck)	150-200 tons/hr	$30,000	Includes feed hopper and 40' conveyor

Table 24: COMPOST/LOAM SCREENING DEVICE COST-EFFECTIVENESS

Unit Name	Cost/ cu yd of capacity	**Separation Effectiveness** EA x EB EA†EB‡	**Type**	**Capacity** (cu yd/hr.)
Van Dale	$5,900	68.6% 71.0% 96.3%	Shaker	6
Power Screen	$1,660	73.9% 80.7% 54.4%	Shaker	30
R.M. Sizer	$2,520	69.2% 96.4% 71.8%	Shaker	27
Trommel	$2,931	92.5% 96.7% 95.6%	trommel	40.8
Liwell	$2,661	29.5% 28.1% 97.9%	Flexing Belt	62.9

NOTE: These figures were taken directly or developed from information in:
Higgins et al., (1981) Evaluation of Screens for Sludge Composting Biocycle May-June. pp 22-26.
†EA = Amount of oversize in overflow (indicates cleanliness of compost) *Amount of oversize entering*
‡EB = Amount of undersize in underflow (indicates cleanliness of chips) *Amount of undersize entering*

A.3 Compost Mixing Equipment

Compost operations have used a variety of types of equipment to mix together their carbonaceous and nitrogenous materials. These include front-end loaders, industrial type tractors with augers on the front, pug mills, batch mixers, and drum mixers (see Table 25).

A 1981 Biocycle Magazine article reported on a study of different mixing devices conducted by Higgins *et al.* In that study the effectiveness and cost of two batch mixers, one pug mill, a drum mixer and a front-end loader were evaluated.

The drum mixer was found to be ineffective in mixing sludge, and woodchips since the rolling action tended to form the sludge into balls thus preventing it from composting properly.

The front-end loader was able to produce an acceptable mix but if care were not taken sludge ball formation could occur. The quality of the mix achieved was clearly dependent on the skill and care of the operator.

The pug mill appeared to mix ingredients more thoroughly than the batch mixers but all three were found to achieve acceptably good results when mixing sludge and wood chips. The choice between the continuous feed pug mill and the batch mixers then would have to be made on the basis of other factors such as speed, need for mobility, cost per ton, etc. The pug mill was found to be faster than the batch mixers. If the capacity to move a larger volume of material in a short time was critical, the pug mill would be the best choice. Due to its continuous feed action, the pug mill required that all materials be continuously delivered to the mixer in the correct proportions. This probably requires the synchronization of at least two conveyors. Such a set-up would be much more practical for a stationary application than for a mobile one. Two different types of batch mixers were tested. One type (the Van Dale or SSI Mixer) used four horizontal augers in a bin to do the mixing. This unit also features built-in scales for measuring the weight of the ingredients or the total weight of a batch. The second type (the Arts-Way Silamix Unit) used slats on a continuous chain to mix the materials (a more detailed discussion of the SSI Mixer appears in the section on equipment used in the Mid-Coast Project). A third type (not tested in the study) is made by McLanahan who also manufactures one of the commonly used pug mill systems. The McLanahan batch mixer uses paddles on two rotating horizontal shafts to mix the materials.

The batch mixers were less expensive and more mobile than the pug mill unit. For smaller operations and those where all operations would not be fixed in one location, a batch mixer would be the logical choice.

The final mixing device mentioned in the Higgins article was the Cobey Composter. This machine has an auger on the front of a vehicle that resembles a front-end loader. The Brown Bear Corporation also makes a similar machine. They mix materials by pushing the auger through piles of materials dumped on the ground. Their effectiveness for this purpose was not evaluated. Both the Brown Bear and the Cobey Composter are found in Table 22 and in the discussions of compost turning equipment (section A.1).

A.4 Grinding and Shredding Equipment

As with some of the other types of equipment discussed, there seems to be a variety of grinding, crushing and shredding equipment being offered by different manufacturers. Among these there are three major categories of industrial type shredding or grinding equipment being promoted for compost systems. These are the high torque shear shredders, hammermills of various types and tub grinders.

Hammermills accomplish size reduction through the use of a spinning shaft on which a number of free swinging metal hammers are mounted. Material dropped into the hammermill is continually smashed by the whirling hammers until the size is small enough to escape through the discharge opening(s). No cost information was given for these industrial type machines.

The shear shredders have two turning shafts on which hooked cutter disks are mounted. These overlapping rows of cutters draw material down into the shredder while slicing it into ribbons ranging from 1/2" to 1-1/2" in width, depending on cutter size. Manufacturers' promotional materials show these devices shredding everything from newspaper to styrofoam to automobile tires to 55 gallon steel drums.

Because these units turn slower than hammermills and slice instead of break, they are quieter and less prone to dust problems. Rates of throughput, however, would be slower. Costs appear to be about $2,000/hp for smaller units and about $700/hp for larger units.

Table 25: COMPOST MIXING EQUIPMENT

Manufacturer	Unit Name	Size/Capacity	Cost†	COMMENTS
Sludge Systems International‡	SSI Sludge Mixer			Batch Mixing 4 augers. Truck mounted. Built-in Scales
	Model 285	8 cu yd.	$31,000 (1980)	
	Model 335	10 cu yd.	n/a	
	Model 435	12 cu yd.	$60,000–$70,000	
	Model 500	14 cu yd.	$60,000 (1980)	
Arts-Way Silamix	Model 850	11 cu yd.	$35,000 (1980) (includes 60hp tractor)	Batch Mixer using chains with slats Mounted on single axle wagon. PTO driven
McLanahan	Blendmaster Pug Mill			Continuous Mixers Stationary, paddles mix and push material through, powered by two electric motors
		18 TPH, 7-1/2 hp	$15–20,000	
		42 TPH, 15 hp	$20–22,000	
		75 TPH, 20 hp	$24–26,000	
		117 TPH, 25 hp	$29–31,000	
		220 TPH, 30 hp	43–45,000	
	Batch Mixer	15 cu yd.	n/a	Shafts with paddles do mixing. Drag chain conveyor to discharge. Trailer mount or stationary. Self contained diesel engine.
Fiat-Allis	Frontend Loader Model 645-B		$97,500 (1980)	

† Cost Information taken from: Higgins et al. 1981. Mixing Systems for Sludge Composting *Biocycle* Sept.-Oct. pp18-22.
‡ Formerly Van Dale Company

Table 26: GRINDING AND SHREDDING EQUIPMENT

Manufacturer	Unit Name/Type	Size/Capacity	Cost	Comments
Shred-PAX LTD.	Shear Shredders Model AZ/7 Model AZ-15 Model AZ-40 (also # A-80 & 160)	7 hp 1,200 lb/hr 15 hp 4,000 lb/hr 2-20 hp 13,000 lb/hr	$14,000 $30,000 $75,000	High torque shredders Will shred almost anything that will fit into the hopper
Carthage Machine Company	Mitts and Merrill Shredders Model MS-1714 Model MS-2817 Model MS-2833 Model MS-4220 Model MS-4526 Model MS-6028 Model MS-5040	 10 hp 20 hp 30 hp 50 hp 75 hp 7 125-150 hp 200 hp		High torque shear shredders. Handle paper, steel and aluminum turnings, tires, wood, plastic, glass, trash
MAC Corporation	Saturn Shredders Model 52-32 Model 62-40 Model 96-50 HT Model 72-50 HT Model 72-46 HT	 150 hp 120 pallets/hr 200 hp 150 pallets/hr 400 hp 400 hp 350 hp	 ? ? $292,000 $260,000 $195,000	High torque shear shredders similar to above
Eidal International Sales Corporation	Shear-type Shredders - electric drive - hydraulic drive	 5 hp - 200 hp up to 52" x 100" ID		High torque shear shredders
Hi-Torque Shredder Co	Model 1500 Series 2000 Series 2600 Series 3200 Series	7-1/2–20 hp 25-50 hp 25-75 hp 75-100 hp	starts at $13,000 up to $100,000	High torque shear shredders. Will custom make feed hoppers
Shredding Systems, Inc.	Electric shredders Single drive Dual drive	 10-100 hp 60-300 hp		High torque shear
	Hydraulic Single drive Dual drive	 25-250 hp 60-300 hp		Special models available
Farmhand, Inc.	6650 Tub Grinder	Single Axle-PTO driven unit for tractors up to 200 hp (9' tub diameter)	$19,995	Large tub with hammermill. Designed for hay, bark, wood waste
Jones Manufacturing, Inc.	Mighty Giant Tub Grinder	PTO unit for tractors up to 200 hp (11' 10" tub diameter)		Hammermill type tub grinder comes in stationary, truck mounted, PTO driven, and self-powered Wood, hay, bark
Cont ./.				

Table 26 GRINDING AND SHREDDING EQUIPMENT, cont.

Manufacturer	Unit Name/Type	Size/Capacity	Cost	Comments
Fuel Harvesters Equipment, Inc.	Waste Wood Tub Grinder	Diesel engine up to 475 hp/10-25 tons per hour (10' tub diameter)	$110,000 -$115,000	Large tub with hammermill
Gruendler Crusher	Hammermills	Wide range of types and sizes		These are all heavy industrial use pieces of equipment
	lump breakers	up to 60" wide roll		
	roll crushers	from 10" x 6" to 60" x 144" opening		
	refuse shredders	36" x 46" to 60" x 104" opening 50 tons/hr.		
	wood and bark hogs	up to 60" diameter hammermill		
	leaf shredder (leaf- eater)	25-250 cu yd/hour		
American Pulverizer Company	Crushers	2-1/2 - 600 TPH		Heavy duty equipment- wide variety of machine types and sizes
	Wood hogs (hammermills)	3/4 - 40 TPH		
	Waste shredders (hammermills)	10-100 TPH 31" x 49" to 84" x 122" opening		

Tub grinders are actually a variation of the hammermill on which the input hopper has been replaced with a large rotating tub. These devices are designed for the reduction of bark, wood wastes, and hay. The small hammers tend to grind material in the tub into small irregular pieces.

Tub grinders are usually either truck mounted or trailer mounted so as to be portable. Some manufacturers even offer models that can be run off the P.T.O. Drive on a tractor. Prices range from around $20,000 for a P.T.O. driven unit up to $115,000 for large self-powered units. Tub grinders appear to be the logical choice for operations needing a mobile grinding device and where the materials to be ground are similar to those for which the machine was designed. The shear shredders and industrial hammermills are better suited to stationary operations where heavy duty performance is required or when reducing materials different from those for which the tub grinders were designed. Choice between the various shear shredders and hammermills probably will depend on the shredding speed needed, the size and shape of output material and the level of concern about noise and dust.

B Agronomic Research Trials

B.1 Potting Mix Study

As part of a follow-up to the compost demonstration project, a research trial was developed and funded under a Maine Department of Agriculture Technology Transfer grant. The fish compost was used to produce a potting mix by blending 40:60 v/v with sphagnum peat moss plus lime. It was compared to commercial peat potting mixes and one commercial compost based mix. The commercial mixes included Premier Peat ProMix^{TM}, Fafard growing Medium #2, and Zook & Ranck's Organic potting mix.

This potting mix demonstration was implemented with a replicated split-split-plot design. The trial incorporated vegetable seedlings — tomatoes, broccoli, and lettuce– and was overlaid with fertilizer treatments.

The full results of the trial will be released as part of a separate report. The general finding was that the fish compost was a suitable substrate for seedling growing media if blended with peat and supplemented with soluble nitrogen if the available N levels are low. The nitrogen requirement for the Waldoboro fish compost stemmed from the use of large amounts of wood in the compost. The compost was also tested for suitability with soil-block equipment which compresses fibrous material into self-supporting cubes.

B.2 Field Trials

Another follow-up to the compost demonstration project was use of the fish compost in a replicated, randomized corn field trial utilizing manure and commercial fertilizer comparisons. In addition, the compost was applied to vegetable soil plots and monitored for nutrient and quality effects. The fish compost spread very easily with a manure spreader at rates up to 100 ton/acre.

Initial corn yield response to fish compost was positive although somewhat less than response to raw manure or chemical N-P-K. The effects in decreasing order were N-P-K = Manure > compost > control. Soil tilth effects on the heavy silt-loam from applying the compost appeared to be very favorable. This project was funded separately under a SCS *Challenge Grant*.

In the garden trials[25], nutrient tests in the spring following fall compost application indicated a generally improved condition with regard to pH, calcium, phosphorus, potash and available N. The results of these trials will be presented as part of a separate report.

[25] information on garden trials is part of a Maine Organic Farmer & Gardener Assoc. trial, Augusta, ME

C Mid-Coast Compost Consortium Participants

Contributors/ Funding Sources

Maine Science and Technology Board
New England Fisheries Development Foundation
Foundation for Permanent Agriculture
Maine Technology Transfer Program
National Coastal Resources Institute
North Atlantic Products, Inc.

Organizations— Administration Oversight

Time and Tide Resource Conservation & Development Area

Private Companies—Project Technical Consultants

Woods End Laboratory

Private Companies— Site Management/Equipment

William Branigan
Waldoboro Water Company

Private Companies—Fish By-Products

F.J. O'Hara & Sons
North Atlantic Products, Inc.
Port Clyde Foods Inc.
R&R Seafoods

Private Companies—Research

Commonwealth Marketing and Development, Inc.
Soilizer Corporation
DeCoster Egg Farms

Organizations—General Support, Promotion

Maine Organic Farmers and Gardeners Association
Maine Sardine Council
Town of Fort Fairfield

Government Agencies–General Support, Promotion, Research

Knox-Lincoln Soil & Water Conservation District
ME Cooperative Extension
ME Department of Agriculture, Food and Rural Resources
ME Department Environmental Protection
ME Department of Marine Resources
ME Department of Transportation
U.S. Soil Conservation Service
University of Maine
Waltham Suburban Ag. Experiment Station

Other private companies— equipment, supplies, promotion

Great Eastern Mussel Farms, Inc.
John Fancy, Inc.
Resource Conservation Services, Inc.
Stinson Canning, Inc.
Wildcat Manufacturing Co.
Zook & Ranck, Inc.

D Interpretation Of Compost Tests

MOISTURE: There is no absolute moisture level which is ideal for composts. Rather, ideal moisture is relative to the sample's water holding capacity. Optimal micro-biological activity occurs at 60-80% saturation of the moisture capacity. The impression of moisture one receives by handling a sample reflects accurately this relative relationship of water to the sample's holding capacity, rather than any absolute moisture content. Thus, a material which can hold its own weight in water (i.e. 100% WHC), will feel sufficiently wet at only about 40% moisture while a sample which holds twice its weight in water requires 60% before being ideally moistened.

Water holding capacity diminishes during composting, due to loss of organic content, and thus the ideal level of moisture will likewise diminish. Moisture is customarily reported as percent of fresh weight. Also reported is the estimated maximal ideal moisture content in so far as biological activity is concerned.

pH: The significance of pH for effective composting and storage of natural materials is frequently underestimated. pH has special significance for composting. Ideally, the pH should be neutral to slightly acid (7.5-6.0) and efforts should be made to control it if it exceeds 8.0 for more than a few weeks, as it is likely that at this pH the manure or compost will lack self-regulating ability. Not only will lowering a high pH limit ammonia volatization, but it will most likely favor a more balanced microbial population, indispensable for proper composting. In other materials, such a potting soils, pH adjustment is important for reasons of plant growth.

ORGANIC MATTER/VOLATILE SOLIDS: Organic matter and volatile solids are generally considered to be the difference between to total weight minus the ash of a compost sample, with allowance for volatile minerals. The organic or volatile portion of a compost is synonomous with energy content, each 1% organic content roughly containing 150,000BTU or the equivalent of one gallon #2 fuel oil[26]. There is no absolute level of organic matter which is ideal, but levels must be sufficient in fresh composts in order to develop aequate heating. It is useful to contrast the initial and final organic content to ascertain composting effectiveness.

NITROGEN- total, ammonium, nitrate: The quantity and form of nitrogen present in composts or wastes is important in shaping the material's quality. In general, it is desirable that a majority of the nitrogen be organic, and that the ammonia fraction be small.

The percent of nitrogen found to be immediately soluble is useful where fertilization is concerned. Also important is the amount of nitrogen which is volatile as ammonia vapor, i.e. which is subject to loss if the material is surface spread. Volatility of ammonia is increased by higher pH. Total N is an important factor for assessing C:N ratios.

CARBON:NITROGEN RATIO: An important aspect of initial compost mixing, the ratio of carbon to nitrogen in the wholle mixture will affect the quality of compsoting. It is customary to use C:N figures to assess the decomposibility of compost mixtures. If we know that a material has undergone composting, C:N ratios may accurately reflect when ripeness has been reached. However, caution is necessary before taking any actions based on the C:N figures alone. One

[26] *for a discusion of energy indices in organic residues see* R. Parnes, Ph.D Organic and Inorganic Fertilizers 1986. Woods End Laboratory

must consider that not all the total carbon is actually available for microbial use. Or, if nitrogen is lost, C:N ratios may go up not down during late stages of composting. C:N values must be weighed against observed decomposition traits. Compost may be considered finished anywhere around a C:N of 17 or less, all other factors being equal.

MINERALS- Phosphorus, Potassium, Calcium, Magnesium, Sodium: These minerals are reported in their total rather than available forms. The amounts actually available will be an unknown but generally significant fraction. In the case of potassium and sodium experience has shown that more than 80% of the total is likely to be immediately available, whereas with phosphorus, calcium and magnesium the availability will range from as little as 25% up to about 75%. More P, Ca and Mg are available under acidic soil conditions. An optional test can be performed to determine the official amount of available P. For estimating the amount of nutrients available the first season, we suggest you take 50% of the P, Ca and Mg figures and 85% of the K and Na figures. Soil availability may be different than that calculated from compost tests.

CONDUCTIVITY: The measurement of the conductance of a sample paste is used to indicate salt levels. Low levels are expected for potting mixes (<2) whereas in the case of composting the values may be acceptable in the range of from 3-10. Low values will indicate a lack of available minerals, while high values indicating a large amount of soluble minerals which may inhibit biological activity or cause problems with land application if large quantities of the material are used. Generally, manures are never a problem, but composts and materials to which minerals have been added can show very high levels.

OXIDATION:REDUCTION (Redox) POTENTIAL: The redox potential represents a material's internal balance of oxidizing and reducing factors. Low redox values are invariably associated with high moisture levels, oxygen stress and odorous conditions. Qualities such as texture, the type of mineral species present, moisture content and the oxygen supply will all influence the Redox. The cause-effect relations are difficult to isolate , but some occurrences, such as gaseous loss of N and generation of odorous compounds, only occur where the redox potential has already fallen to low levels. Similarly, stabilization of nitrogen as nitrate can not occur if the redox is low, no matter how "ripe" the compost. For further information concerning the stability, the redox test can be repeated after the sample has stood for a period of time. The extent of the drop of the redox is proportional to the oxygen demand. In this regard the redox test provides similar information as the more complicated measurement of oxygen demand.

DECOMPOSITION RATE (Carbon Dioxide Output): This test contributes to understanding microbiological properties. It reports the decomposition rate as the percentage of organic carbon as $CO_2 - C$ respired during incubation at some arbitrary elevated temperature for a selected period of time, usually 1 day. This information aids in deciding when true biological stability has been reached. The higher the decomposition value shown, the more nitrogen expected to be released. The decomposition rate is typically expressed in relative terms as the percentage of organic carbon released as carbon dioxide in a given period of time.

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Figure 11: WILDCAT COMPOST MACHINE USED IN PROJECT

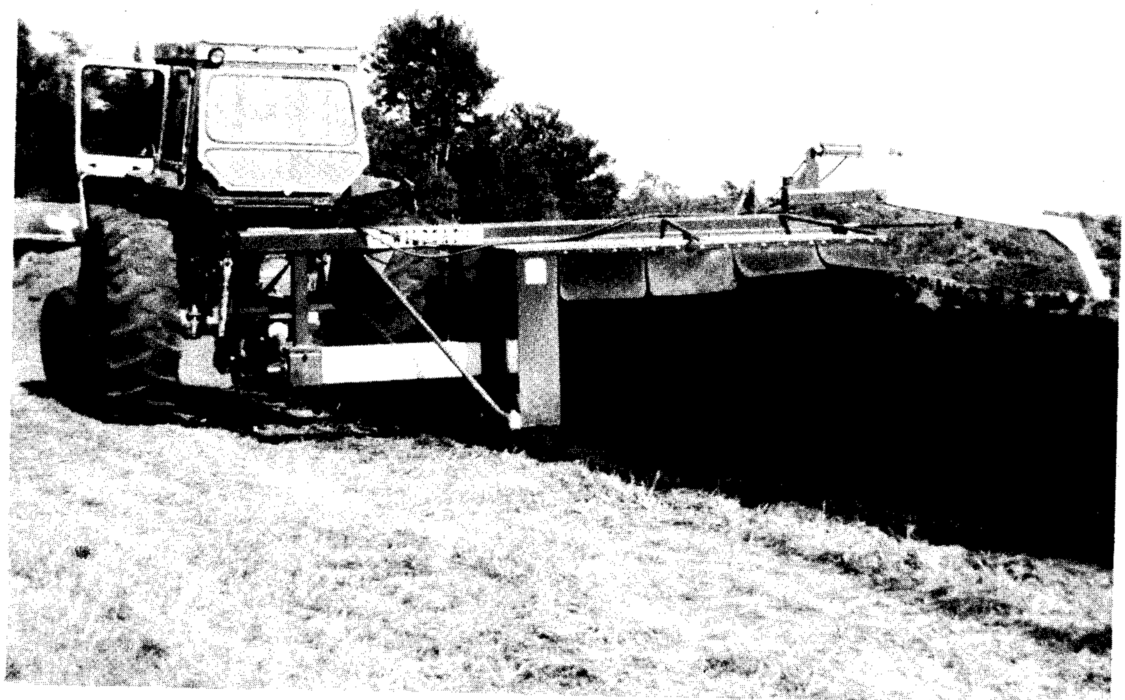

Figure 12: WINDROW TURNING DURING FISH COMPOSTING PROJECT

Photos Courtesy Time & Tide RC&D