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BIOFERMENTATION PILOT STUDY

FOR

WATER HYACINTH AND GIZZARD SHAD COMPOSTING

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EXECUTIVE SUMMARY

A pilot study using biofermentation technology developed by Agron Corporation (South Charleston, OH) for composting gizzard shad and water hyacinths was conducted by Agron Corporation for the St. Johns River Water Management District. The purpose of this study was to determine if gizzard shad and water hyacinths can be composted into a product that has market value. Water hyacinths and gizzard shad are potentially harvested in large quantities from lake restoration, aquatic macrophyte management, and fisheries management programs. The subsequent transformation of this raw biomass into a marketable product could function as a partial or full subsidy for these restoration and management programs.

Biofermentation is a process which utilizes naturally occurring aerobic bacteria to biologically alter the characteristics of organic waste. In this pilot study, different mixtures of water hyacinths, gizzard shad, poultry and cattle manure, and scallop offal were biofermented. It was found that water hyacinths alone do not ferment well. Biofermentation was greatly improved when gizzard shad, poultry or cattle manure, or scallop offal were used in conjunction with water hyacinths. In order to reduce the high moisture content of water hyacinths, some dehydration and mixing of the plant biomass with a high carbon material such as sawdust or newspaper was necessary.

The 1:1 ratio of water hyacinths to gizzard shad biomass used in one of the biofermentation trials resulted in odor, fly, and maggot problems during all three stages of the biofermentation process. Consequently, future biofermentation trials using gizzard shad will have to reduce the relative proportion of gizzard shad to help reduce the chances for odor, fly, and maggot problems. None of these problems were observed in any of the other trials in this study; gizzard shad were used in only one trial, however.

Recommendations made by Agron Corporation for future studies of water hyacinth and gizzard shad composting are incorporated into two additional study phases. Phase II would examine the effectiveness of the water hyacinth and gizzard shad Fermway (the biofermentation end-product) as a fertilizer on test plots of vegetables at nearby Lake Apopka muck farms.

Should large scale gizzard shad and water hyacinth harvesting programs be initiated in the restoration of Lake Apopka, a Phase III project could incorporate a full-scale biofermentation center which could utilize harvested water hyacinths and gizzard shad from the lake restoration efforts. A biofermentation center as outlined in Phase III could produce about 8,700 tons of Fermway per year.

INTRODUCTION

Gizzard shad *(Dorosoma cepedianum)* and water hyacinths *(Eichornia crassipes)* are sometimes harvested in large quantities in fish and macrophyte management programs. The growth and harvest of water hyacinths and the harvest of gizzard shad have also been proposed as potential lake restoration techniques. Water hyacinth management programs, typically using herbicides, are widespread in Florida.

The fate of harvested (or herbicided) water hyacinths and gizzard shad is important from an ecological and economic perspective. For instance, if water hyacinth biomass can be converted into a marketable product, then it might be economically advantageous to mechanically harvest water hyacinths rather than employ herbicides. Mechanical harvesting would also function as a nutrient removal technique, as the nutrients bound in water hyacinth biomass would be removed from the aquatic system, rather than being released through decay following herbicide treatment.

The transformation of harvested gizzard shad and water hyacinths from fish and macrophyte management programs, and possibly from lake restoration programs, into a marketable end product may be able to partially or fully subsidize these management programs. The St. Johns River Water Management District (SJRWMD) entered into an agreement with Agron Corporation (South Charleston, OH) to perform a pilot study of gizzard shad and water hyacinth composting using Agron's biofermentation technology.

The Agron-developed biofermentation process used in this study is performed in an insulated enclosure with controlled air flow, thereby maintaining an aerobic environment for composting the enclosed raw materials (biomix). Various forms of organic waste materials, such as poultry and cattle manure, wood chips, sawdust, newspaper, and seafood offal, can potentially be biofermented using this technology.

Previous experience has shown that successful biofermentation requires the biomix have a C:N ratio above 20, a moisture content below 60 percent, and that airflow through the biofermentation chamber be adequate to maintain aerobic conditions (proprietary information, O.C. Thompson, D.V.M., 421 Bluebonnet, Findlay, OH 45840). Experience has also shown that these conditions also prevent odor and fly/maggot problems during and after the biofermentation process (proprietary information, O.C. Thompson, D.V.M., 421 Bluebonnet, Findlay, OH 45840). A study of the microbiological safety of Fermways by deGraft-Hanson et al. (1990) showed that biofermentation temperatures above 142°C for 4 days can greatly reduce the number of pathogens in the original biomix. The biofermentation process, at temperatures above 142°C, can destroy many species of noxious weed seeds (Battelle, 1975); most hard coated weed seeds, however, are unaffected (Dennis 1981). Fermways have also been shown to have some limited nematode control (Barker 1983).

Biofermentation end-products (called Fermways; registered trademark of Agron Corporation) have been used as fertilizers for a variety of plants (Barrett, 1984). Under proper environmental conditions, biofermentation yields a Fermway which has nutrients contained primarily in bacterial biomass (proprietary information, O.C. Thompson, D.V.M., 421 Bluebonnet, Findlay, OH 45840). When used as fertilizers under normal growing conditions, Fermways are assumed to provide a slower nutrient uptake rate by crops; the crop nutrient uptake period is therefore assumed to last substantially longer (Rodabaugh 1986).

When a Fermway made from animal wastes such as cattle manure is used as an organic fertilizer, the amount of mineral fertilizer required to maintain yields is often reduced (Dennis 1981). Phosphorus concentrations in the soil have been shown to increase after several years of biofermentation product application (Dennis 1981), thereby requiring less mineral phosphate fertilizer application. Leaching of nutrients from biofermentation fertilizer is generally assumed to be less than that from mineral fertilizers, as the nutrients are contained in bacterial biomass (Dennis 1981). Nutrient pollution into groundwater and surface waters via leaching and surface runoff might be reduced when a biofermentation fertilizer is used in conjunction with reduced amounts of mineral fertilizers. For instance, the additional use of a biofermentation fertilizer on the muck farms that drain into Lake Apopka, along with reduced amounts of mineral fertilizers, might reduce nutrient loading into Lake Apopka. Reduced leaching of nutrients into ground water and surface water runoff through the use of Fermways has not been documented, however.

METHODS

The Four Biofermentation Trials in this Study. This study included four trials using water hyacinths and/or gizzard shad as the primary raw materials to be biofermented. The trials were performed in a 98 ft^3 biofermentation chamber located at the water hyacinth demonstration farm adjacent to Round Lake, Orange County, Florida. During this study, water hyacinths were being grown and harvested from Round Lake as part of a separate project conducted by Amasek, Inc. and the St. Johns River Water Management District. The four trials performed in this study were:

Trial 1: Water hyacinths were used as the primary raw material, with sawdust and urea nitrogen added as secondary ingredients.

Trial 2: Gizzard shad and water hyacinths were the primary raw materials, with shredded newspaper, wood chips, and OFL Fermway added as secondary ingredients.

Trial 3: A three-layer trial. Layer A consisted of water hyacinths with poultry manure and sawdust added as secondary ingredients. Layer B consisted of water hyacinths with sawdust and poultry manure at a lower initial moisture content added as secondary ingredients. Layer C consisted of water hyacinths with cow manure and sawdust added as secondary ingredients.

Trial 4: A two-layer trial. Layer A consisted of water hyacinths with poultry manure and sawdust added as secondary ingredients. Layer B consisted of scallop offal with shredded newspaper and sawdust added as secondary ingredients.

Water hyacinths were harvested from Round Lake (Orange County, FL). The hyacinth biomass was ground into coarse material, transported as a slurry with lake water through an underground pipe to a holding bin, drained of excess water by gravity, and then laid in long rows on the ground until ready for use in the biofermentation trials. During this storage period the hyacinth biomass lost some moisture and probably partially decomposed.

Gizzard shad were obtained as whole frozen fish from a local fish processor at the time the second trial was begun. The fish were ground into small plug-shaped pieces about 1" long and about 0.5" in diameter by a commercial meat grinder just prior to the pre-mix stage of biofermentation (described later).

Various secondary ingredients were also added to the primary raw materials to be biofermented. These secondary ingredients, sometimes added in amounts equal to that of the primary ingredients, are described below.

Sawdust was added as a secondary ingredient in Trials 1,3, and 4 to serve as an additional source of carbon to enhance microbial decomposition rates, to allow a more uniform air flow, and to absorb excess moisture.

Newspaper was added as a secondary ingredient in Trials 2 and 4 to serve as an additional carbon source and because it has a very low moisture content and can thereby absorb excess moisture in the major raw material to be biofermented. The newspaper was shredded using a commercial portable shredder.

Pine wood chips, about one-inch square and one-sixteenth inch thick, were added as a secondary ingredient in Trial 2 to serve as an additional carbon source to enhance microbial decomposition rates and allow better air flow through the biomix.

Solid urea nitrogen was added as a secondary ingredient in Trial 1 to serve as an additional nitrogen source to enhance microbial decomposition rates.

Ohio Feedlot (OFL) Fermway (the biofermentation end-product from Agron's Ohio Feedlot operations) was added as a secondary ingredient in Trial 2 to increase the bacteria populations in the initial mixture to be biofermented. This was expected to enhance biofermentation rates. The OFL Fermway had been composted, stockpiled, bagged, and stored for one year prior to use. Completed Fermways typically have a significant bacterial community and can thereby act as a bacteria seed culture.

Poultry manure was added as a secondary ingredient in Trials 3 and 4 to serve as an additional nitrogen source to enhance the biofermentation process. The poultry manure was obtained from a cage layer chicken house within one mile of the experiment site.

Cow manure, obtained from a dairy in Leesburg, Florida, was added as a secondary ingredient in Trial 3 to serve as an additional nitrogen source to enhance the biofermentation process. The cow manure was in a slurry form and relatively fresh.

Scallop offal, obtained from an Atlantic coast Florida processor, was added as a secondary ingredient in Trial 4 to serve as an additional nitrogen source to enhance the biofermentation process. The offal was extracted from scallops the previous day and was in a wet state.

The Biofermentation Chamber. The biofermentation chamber used in this study was a 98 ft^3 insulated box, capable of processing approximately 30 to 70 ft^3 of biomix (the raw ingredients to be biofermented) at one time. This volume of biomix corresponds to 1000 to 3000 pounds of raw biomass, depending on density.

The biofermentation chamber allowed the entrance of air into the bottom by an outside blower fan connected to a perforated PVC pipe installed on the floor of the chamber. The blower fan was connected to a timer, set to run for 0.25 to 2 minutes in 10 minute intervals. A manually controlled exhaust was installed in the top of the chamber to assist in the maintenance of aerobic conditions.

The biofermentation chamber had holes at 12-inch vertical intervals from the base through which a 30-inch thermometer probe was inserted to monitor the temperature of the fermenting materials.

Stages of Biofermentation. The biofermentation process occurs in three stages: (1) the pre-heat stage, (2) the biofermentation stage, and (3) the stockpile stage.

(A) Pre-heat stage. This stage is a time period during which the biomix undergoes some anaerobic bacterial decomposition. During this period the temperature of the biomix is allowed to rise to about 100°F before the next biofermentation stage is begun. The pre-heat stage may be done outside or inside the biofermenter.

A one inch square mesh wire cage, 3 feet high and 4.5 feet in diameter, was used to enclose the biomix during this anaerobic pre-heat stage. The cage and biomix were positioned on a concrete slab in an open air pavilion. The biomix during this pre-heat stage was exposed to the outside air, but was shielded from rainfall and the direct sun by an overhead roof. Trials 2 and 3 were pre-heated as described above for three days in the wire cage. Trials 1 and 4 were pre-heated directly inside the biofermentation chamber for one day without the addition of any forced air. The pre-heat period of time is used to get the biomix up to 100°F or higher with anaerobic digestion. The pre-heat stage ends when air is forced through the biomix and aerobic digestion starts.

(B) Biofermentation Stage. Once the biomix had reached 100°F, it was transferred into the biofermentation chamber (if it was pre-heated outside) and the forced air flow cycle was begun. A common 10 minute timer was used to set the fan to run from 15 seconds to two minutes every 10-minute cycle. In this manner biofermentation conditions were changed from anaerobic to aerobic.

Biomix temperatures were measured twice a day by inserting the temperature probe at two or three levels through the holes in the biofermentation chamber. Temperatures were averaged among the layer measurements for reporting purposes. The aerobic biofermentation process was continued for at least 72 hours (and up to seven days) after a biomix temperature of over 142°F was attained.

(C) Stockpile Stage. Once the biomix maintained a temperature of 142°F for more than 72 hours, it was removed from the biofermentation chamber and stockpiled for up to 16 weeks to allow further anaerobic digestion. One-inch square mesh wire cages, 3 feet high and 4.5 feet in diameter, were used for stockpiling. The depth of the material inside each stockpile cage was monitored once every week. Stockpiles were open to the environment, including rainfall and direct sunlight. After 8 weeks the stockpiles were turned with a fork or shovel by transferring to a new stockpile area.

Physical and Chemical Analyses. The percentage moisture of the raw materials was determined after drying in a microwave oven. The density of the raw ingredients and biomixes was measured by weighing one ft^3 of biomass on platform scales.

Concentrations of elemental nitrogen (N), phosphorus (measured as P_2O_5, reported as elemental P after division by 2.29), and elemental carbon were measured in water hyacinths, newspaper, sawdust, wet and dry cage layer poultry manure, and OFL Fermway. Analyses were performed by A&L Great Lakes Laboratories, Inc. (Fort Wayne, IN).

Elemental nitrogen (N), phosphorus (measured as P_2O_5, reported as elemental P), potassium (measured as K_2O, reported as elemental K after division by 1.2), and elemental carbon concentrations were made on the Trial 1 and 2 biomixes before any urea nitrogen addition and before biofermentation. These chemical analyses were also done on all four Fermways immediately after biofermentation, and on all four Fermways after a 2-month stockpiling period. Chemical analyses were performed on all samples by A&L Great Lakes Laboratories, Inc., and by the University of Florida (Gainesville, FL) for samples collected after 2 months of stockpiling.

RESULTS

General Biofermentation Conditions. The percent concentration of nitrogen and carbon in a biomix, expressed as the carbon:nitrogen (C:N) ratio, is important for optimum decomposition conditions without odor and fly problems. Experience has shown that optimum bacterial growth without odor problems occurs at a C:N ratio of 20 to 30 (proprietary information, O.C. Thompson, D.V.M., 421 Bluebonnet, Findlay, OH 45840).

Moisture content of the biomix is also important for the biofermentation process. A moisture range of 40% to 60% appears to be optimum (proprietary information, O.C. Thompson, D.V.M., 421 Bluebonnet, Findlay, OH 45840). If the moisture content is too high, materials such as sawdust or shredded newspaper can be added to reduce the overall moisture content of the biomix.

Large particle size materials up to one-inch (eg. wood chips) can also be added to increase airflow through the biomix during biofermentation.

Physical and Chemical Characteristics of Water Hyacinths. Water hyacinths freshly harvested from Round Lake had a C:N ratio of 23 (Table 1), and a very high moisture content of over 90 percent. Hyacinth nitrogen content (2.21 percent on a dry weight basis) was lower than that for gizzard shad and the manures. Hyacinths also had a

TABLE 1
Biomix Raw Ingredient Characteristics. Percent carbon, nitrogen and phosphorus concentrations are on a dry weight basis.

INGREDIENTS	PERCENT MOISTURE	PERCENT CARBON	PERCENT NITROGEN	PERCENT PHOSPHORUS	CARBON NITROGEN RATIO	DENSITY (lbs/cu.ft)	SOURCE OF ANALYSIS
Water Hyacinths	73	51.00	2.21	0.01	23.08	30.0	A&L
Gizzard Shad	72	47.93	5.50	1.75	8.71	80.0	SJRWMD
Poultry Manure - Wet	75	28.39	3.92	4.00	7.24	43.0	A&L
Poultry Manure - Dry	57	28.39	3.92	4.00	7.24	27.0	A&L
Cattle Manure	81	36.32	3.20	1.00	11.35	45.0	OSU
OFL Fermway	45	43.62	2.46	0.85	17.73	34.0	A&L
Newspaper	1	48.70	0.02	NM	2435.00	9.5	A&L
Wood Chips	5	NM	NM	NM	NM	10.0	A&L
Sawdust	45	37.90	0.35	NM	108.29	15.0	A&L
Urea Nitrogen	NM	NM	45.0	NM	NM	NM	LABEL

NM = Not Measured
A&L = A&L Laboratories, 3505 Canestoga Drive, Fort Wayne, Indiana 46808-4413
SJRWMD = St. Johns River Water Management District, P.O. Box 1429 Highway 100, Palatka, Florida 32178-1429
OSU = Ohio Livestock Waste Management Guide - OSU Cooperative Extension Bulletin 604 College of Agriculture, 2120 Fyffe Rd., Columbus, Ohio 43210
LABEL = Manufacturer's analysis as shown on bottle label.

low phosphorus content (0.01 percent on a dry weight basis), but had a high carbon content (51 percent on a dry weight basis). These data indicated the need to add nitrogen and reduce moisture to enhance the biofermentation process.

To reduce moisture, water hyacinths were either air dried in the sun (reduction of about 10% a day) or mixed with a drier carbon source material such as newspaper or sawdust. Air drying reduced the moisture content in water hyacinths by about 10 percent per day (Amasek, Inc., Cocoa, FL, unpublished data). Newspaper has a very low moisture level and is able to offset the higher than optimum moisture levels of both gizzard shad and water hyacinths.

Poultry and cow manure and urea nitrogen were also added as sources high in nitrogen (Table 1).

Physical and Chemical Characteristics of Gizzard Shad. Recently frozen gizzard shad were 72 percent moisture (Table 1), and had a high nitrogen content (Table 1) relative to the other raw ingredients. The high moisture content of the gizzard shad necessitated adding shredded newspaper to absorb some of the moisture. Although gizzard shad had a similar carbon content to other raw ingredients, its high nitrogen content is reflected in a low C:N ratio of 8.7. The newspaper and wood chips added carbon to the gizzard shad, thereby increasing the C:N ratio of the biomix to 15.2 (Table 2).

TABLE 2
Biomix Composition and Characteristics Prior to Biofermentation.

TRIAL	BIOMIX LAYER	INGREDIENTS	MASS (lbs)	PERCENT MOISTURE	BIOMIX DENSITY (lbs/cu.ft)	BIOMIX PERCENT NITROGEN	BIOMIX PERCENT PHOSPHORUS	BIOMIX PERCENT POTASSIUM	BIOMIX CARBON NITROGEN RATIO
1*	---	Water Hyacinths	1310	71.0					
		Sawdust	288	44.5					
		Urea Nitrogen	7	NM					
		Total	1605	63.0	27.0	1.43	0.12	1.00	31.52
2	---	Ground gizzard shad	500	72.0					
		Water Hyacinths	450	70.0					
		Shredded newspaper	100	1.0					
		Wood chips	200	5.0					
		OFL FermWay	200	50.0					
		Total	1450	57.5	27.0	3.32	0.76	0.95	15.19
3	A	Water Hyacinths	200	82.0					
		Poultry manure - dry	200	74.5					
		Sawdust	200	44.5					
		Total	600	67.0	35	NM	NM	NM	NM
	B	Water hyacinth	200	70.0					
		Poultry manure - wet	200	80.5					
		Sawdust	200	44.5					
		Total	600	57	31	NM	NM	NM	NM
	C	Water hyacinth	150	70					
		Cow manure	150	80.5					
		Sawdust	150	44.5					
		Total	450	65	37	NM	NM	NM	NM
4	A	Water hyacinth	200	NM					
		Poultry manure	200	NM					
		Sawdust	200	NM					
		Total	600	55	NM	NM	NM	NM	NM
	B	Water hyacinth	200	NM					
		Scallops offal	200	NM					
		Shredded newspaper	66	NM					
		Sawdust	184						
		Total	650	56	NM	NM	NM	NM	NM

* - Trial 1 nutrient concentrations measured before adding the urea nitrogen.
NM - Not Measured

Trial 1 - Water Hyacinths. Water hyacinths (1310 lbs, Table 2) constituted the main ingredient in this biomix. Hyacinths were initially at a 71 percent moisture content (Table 2) after three days of air drying. To reduce the moisture content of the biomix, 288 lbs of sawdust (initial moisture content of 44.5 percent) were added. After thorough mixing, the biomix had a 63 percent moisture content, which was slightly above the desired upper range for biofermentation.

The final pre-heating stage temperature of the biomix was 81°F (Table 3), which was substantially below the desired minimum of 100°F. However, aerobic biofermentation was begun because it was felt that further pre-heating would proceed at a very slow rate due to the high moisture content.

The biomix was loaded into the biofermenter (total mass of 1598 lbs) and remained there for 3 days of aerobic biofermentation. After this time, the biomix was removed from the biofermentation chamber and allowed to air dry for 1.5 days on a plastic sheet in the sun in order to further reduce the moisture content. After this additional drying, 7 lbs of urea nitrogen was mixed in as an additional nitrogen source to enhance biofermentation rates. The biomix was then reloaded into the biofermenter and remained there for 3 days, with air flow forced through the chamber every ten minutes for a period of two minutes.

TABLE 3
Average Biofermentation Temperatures (°F)

TRIAL	STARTING TEMPERATURE	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7
1	81.0	91.8	108.3	Air Dried	83.0	92.5	105.5	121.0
2	111.0	170.0	166.2	169.3	169.0			
3	136.0	167.0	169.6	170.2	161.6	164.3	163.3	
4	83.0	111.0	160.5	169.3	164.5	161.2	158.0	

Average daily temperatures of the biomix during biofermentation rose from 83°F (after reloading) to 121°F (Table 3). Biofermentation was terminated before it reached optimal temperatures (above 142°F) so that the next trial could be started. The biofermented mixture, now referred to as a Fermway, was then stockpiled for a period of 16 weeks. The Fermway had no objectionable odor or fly problems after removal from the biofermentation chamber nor later during stockpiling.

Fermway No. 1, after removal from the biofermentation chamber, was relatively low in phosphorus (0.20 percent, Table 4). The C:N ratio was still relatively high (26), and nitrogen and potassium concentrations were also somewhat low but in relatively equal proportions (1.75 percent and 0.97 percent respectively, Table 4).

The average weekly stockpile temperatures of Fermway No. 1 rose from the 121°F when removed from the biofermentation chamber to 142°F during stockpile week 3, and then gradually decreased to 84°F at week 16 (Table 5). After 2 months of stockpiling, phosphorus, nitrogen, and potassium concentrations increased in Fermway No. 1 while the C:N ratio decreased substantially (Tables 6a and 6b). The concentration of nutrients in the Fermway increased because of the continued decomposition of organic matter during the stockpiling stage. The loss of organic matter during decomposition increases the mass percentage of nutrients in the Fermway, although the total mass of nutrients changes very little. The phosphorus concentration in Fermway No. 1 after 2 months of stockpiling (0.34 percent; an average of values in Tables 6a and 6b) is

TABLE 4
Fermway Characteristics Fresh From the Biofermenter.

TRIAL	FERMWAY LAYER	INGREDIENTS	MASS (lbs)	FERMWAY PERCENT NITROGEN	FERMWAY PERCENT PHOSPHORUS	FERMWAY PERCENT POTASSIUM	FERMWAY CARBON NITROGEN RATIO
1	---	Water Hyacinths	1310				
		Sawdust	288				
		Urea Nitrogen	7				
		Total	1605	1.75	0.20	0.97	26.19
2	---	Ground gizzard shad	500				
		Water Hyacinth	450				
		Shredded newspaper	100				
		Wood chips	200				
		OFL FermWay	200				
		Total	1450	3.12	1.16	0.87	15.60
3	A	Water Hyacinth	200				
		Poultry manure	200				
		Sawdust	200				
		Total	600	2.21	1.93	2.24	19.51
	B	Water hyacinth	200				
		Poultry manure	200				
		Sawdust	200				
		Total	600	2.09	1.48	2.26	20.27
	C	Water hyacinth	150				
		Cow manure	150				
		Sawdust	150				
		Total	450	1.25	0.35	0.84	31.61
4	A	Water hyacinth	200				
		Poultry manure	200				
		Sawdust	200				
		Total	600	1.55	3.00	3.25	22.96
	B	Water hyacinth	200				
		Scallops offal	200				
		Shredded newspaper	66				
		Sawdust	184				
		Total	650	1.09	0.13	0.39	43.29

TABLE 5
Average Stockpile Temperatures After Biofermentation (*)

Week	Bay 1 Water Hyacinths	Bay 2 Water Hyacinths & Gizzard shad	Bay 3 Water Hyacinths Manures	Bay 4 Water Hyacinths Scallop Offal
1	130°	159°	153°	146°
2	136°	156°	150°	144°
3	142°	140°	135°	132°
4	131°	130°	135°	128°
5	130°	126°	122°	120°
6	126°	122°	135°	120°
7	122°	112°	120°	110°
8	116°	110°	116°	120° **
9	107°	104° **	130° **	116°
10	100° **	110°	128°	108°
11	99°	90°	130°	106°
12	90°	92°	116°	99°
13	90°	90°	110°	98°
14	88°	92°	106°	
15	88°	86°	110°	
16	84°			

* Temperature was taken three to five times weekly and at 6" and 24" depth from the top center.

** Stockpiles were turned and sampled this week.

TABLE 6a
Fermway Characteristics After Two Months of Stockpiling;
Measured by A&L Laboratories, Fort Wayne, IN.

TRIAL	FERMWAY LAYER	INGREDIENTS	MASS (lbs)	FERMWAY PERCENT NITROGEN	FERMWAY PERCENT PHOSPHORUS	FERMWAY PERCENT POTASSIUM	FERMWAY CARBON NITROGEN RATIO
1	---	Water Hyacinths	1310				
		Sawdust	288				
		Urea Nitrogen	7				
		Total	1605	2.17	0.33	1.37	17.11
2	---	Ground gizzard shad	500				
		Water hyacinths	450				
		Shredded newspaper	100				
		Wood chips	200				
		OFL FermWay	200				
		Total	1450	2.38	1.68	2.05	20.13
3	A	Water hyacinth	200				
		Poultry manure	200				
		Sawdust	200				
		Total	600	1.86	1.83	2.5	19.41
	B	Water hyacinth	200				
		Poultry manure	200				
		Sawdust	200				
		Total	600	2.73	0.31	1.07	13.99
	C	Water hyacinth	150				
		Cow manure	150				
		Sawdust	150				
		Total	450	2.21	1.00	1.89	17.31
4	A	Water hyacinth	200				
		Poultry manure	200				
		Sawdust	200				
		Total	600	1.39	0.22	0.93	14.65
	B	Water hyacinth	200				
		Scallops offal	200				
		Shredded newspaper	66				
		Sawdust	184				
		Total	650	1.73	0.59	0.68	25.05

TABLE 6b
Fermway Characteristics After Two Months of Stockpiling;
Measured by the University of Florida, Gainesville.

TRIAL	FERMWAY LAYER	INGREDIENTS	MASS (lbs)	FERMWAY PERCENT NITROGEN	FERMWAY PERCENT PHOSPHORUS	FERMWAY PERCENT POTASSIUM	FERMWAY CARBON NITROGEN RATIO
1	---	Water Hyacinths	1310				
		Sawdust	288				
		Urea Nitrogen	7				
		Total	1605	2.23	0.35	1.31	17.6
2	---	Ground gizzard shad	500				
		Water hyacinths	450				
		Shredded newspaper	100				
		Wood chips	200				
		OFL FermWay	200				
		Total	1450	1.81	1.3	0.84	24.5
3	A	Water hyacinths	200				
		Poultry manure	200				
		Sawdust	200				
		Total	600	1.62	2.39	2.41	19.7
	B	Water hyacinths	200				
		Poultry manure	200				
		Sawdust	200				
		Total	600	2.32	0.32	0.92	17.1
	C	Water hyacinths	150				
		Cow manure	150				
		Sawdust	150				
		Total	450	1.41	1.72	2.13	25.4
4	A	Water hyacinths	200				
		Poultry manure	200				
		Sawdust	200				
		Total	600	NM	NM	NM	NM
	B	Water hyacinths	200				
		Scallops offal	200				
		Shredded newspaper	66				
		Sawdust	184				
		Total	650	1.73	0.24	1.62	23.0

NM - Not Measured

low compared to common garden fertilizers. After 13 weeks of stockpiling, the volume of Fermway No. 1 had decreased by 23 percent (Table 7).

Trial 2 - Gizzard Shad and Water Hyacinths. Water hyacinths (450 lbs at 70 percent moisture, Table 2) and ground gizzard shad (500 lbs at 72 percent moisture) were the main ingredients in this biomix. Additional secondary ingredients were 100 lbs of shredded newspaper (1 percent moisture), 200 lbs of wood chips (5 percent moisture), and 200 lbs of OFL Fermway (50 percent moisture). The newspaper was added to absorb excess moisture in the water hyacinths and gizzard shad. The newspaper and wood chips increased the carbon content of the biomix, thereby somewhat increasing the low C:N ratio of this biomix (15.2, Table 2). The OFL Fermway was added to enhance the biofermentation rate by increasing the bacterial populations in the biomix. The biomix was much higher in nitrogen and phosphorus before biofermentation than was the biomix with hyacinths alone (Trial 1, Table 2); this was due to the addition of gizzard shad to this biomix.

The biomix was pre-heated for 4 days. After 1 day of pre-heating, the temperature of the biomix was 130°F (Table 3), indicating a much greater bacterial activity than with hyacinths alone in Trial 1. After 3 days of pre-heating, maggots appeared in the biomix. This indicated that perhaps the initial C:N ratio was too low. By the end of the pre-heating stage, the biomix had a temperature of 111°F (Table 3), well

TABLE 7
Fermway Volume Loss (Percent) During 13 Weeks of Stockpiling

Trial 1: Water Hyacinths	Trial 2 Water Hyacinths and Gizzard Shad	Trial 3 Water Hyacinth and Manures	Trial 4 Water Hyacinth and Scallop Offal
23.2	37.4	43.9	43.3

above the minimum desired starting temperature of 100°F for biofermentation. The biomix also had an objectionable odor, and was still infested with maggots.

The biomix, with an initial mass of 1450 lbs, had a moisture content of 57.5 percent (Table 2) after pre-heating for 4 days, which was within the desired moisture range for biofermentation. The C:N ratio of 15.2, however, was at the very low end of the desired C:N ratio range. The biomix was loaded into the biofermenter and underwent aerobic biofermentation for 4 days. Temperatures during aerobic biofermentation increased from 111°F to 170°F (Table 3). The temperature of the biomix was 169°F when removed from the biofermentation chamber.

Odor and maggot problems were evident in Fermway No. 2 when removed from the biofermentation chamber. Nitrogen, phosphorus, potassium and the C:N ratio in Fermway No. 2 after biofermentation were all similar to this biomix before aerobic biofermentation (Table 4). Compared to Fermway No. 1 after removal from the biofermentation chamber, Fermway No. 2 had higher concentrations of nitrogen and phosphorus, but a much lower C:N ratio.

Fermway No. 2 was stockpiled for 16 weeks. In the stockpile, temperatures started out at 159°F, and decreased gradually thereafter. Temperatures remained above 142°F for the first two weeks of stockpiling (Table 5), a temperature minimum thought necessary for effective elimination of possible pathogens in the Fermway. However, odor and maggot problems continued during the early weeks of stockpiling. After about 2 months, the odor and maggot problems disappeared. The C:N ratio at this time had risen to 20 (Tables 6a and 6b).

After 2 months of stockpiling, Fermway No. 2 had a lower nitrogen concentration (1.8-2.4 percent, Tables 6a and 6b), and greater phosphorus and potassium concentrations (1.3-1.7 and 0.8-2.0 percent respectively, Tables 6a and 6b) than it did when first removed from the biofermentation chamber. Phosphorus concentrations in Fermway No. 2 after 2 months of stockpiling (about 1.5 percent, Tables 6a and 6b) were about 4 times greater than in Fermway No. 1. It appears this is due to the addition of gizzard shad to the premix. After stockpiling for 13 weeks, the volume of Fermway No. 2 had decreased by 37 percent (Table 7).

<u>Trial 3 - Water Hyacinths with Poultry and Cattle Manure</u>. This trial had three layers of biomix (Table 2):

(1) Layer A was comprised of water hyacinths (200 lbs at 82 percent moisture) with poultry manure (200 lbs at 74.5 percent moisture) and sawdust (200 lbs at 44.5 percent moisture) for a total biomix layer of 600 lbs at 67 percent moisture.

(2) Layer B was comprised of water hyacinths (200 lbs at 70 percent moisture) with poultry manure (200 lbs at 56.5 percent moisture), and sawdust (200 lbs at 44.5 percent moisture) for a total biomix layer of 600 lbs at 57 percent moisture.

(3) Layer C was comprised of water hyacinths (150 lbs at 70 percent moisture) with cattle manure (150 lbs at 80.5 percent moisture), and sawdust (150 lbs at 44.5 percent moisture) for a total biomix layer of 450 lbs at 65 percent moisture.

Sawdust was added to all biomix layers to reduce the overall moisture content. The poultry and cattle manure were added as secondary ingredients to boost the nitrogen content of the three biomix layers. The moisture level in Layer A poultry manure (74.5 percent) was higher than that in Layer B poultry manure (56.5 percent). However, the water hyacinth moisture level in Layer A (82 percent) was also higher than it was in Layer B (70 percent). Consequently, differences in the Fermways from Layer A and B biomixes could be attributed to higher moisture levels in the poultry manure, higher moisture levels in the water hyacinths, or both.

This biomix was pre-heated for one day. There were no odor or fly/maggot problems with these biomix layers. It was loaded into the biofermentation chamber when it reached 136°F (Table 3). The three layers were carefully transferred from the pre-mix wire cage into the chamber so that the integrity of each layer was maintained. The biomix was aerobically biofermented for 6 days. During the aerobic biofermentation period, temperatures rose to 170°F by the third day, then decreased to 163°F when the Fermway was removed from the biofermentation chamber.

Nutrient concentrations and the C:N ratio immediately after removal from the biofermentation chamber were similar between the two poultry manure moisture level layers (Layers A and B, Table 4). Nitrogen levels in these 2 layers were lower than in the water hyacinth/gizzard shad biomix in Trial 2, but were higher than in the Trial 1 biomix with water hyacinths alone. Phosphorus and potassium concentrations were much higher in both poultry manure layers than in either Trial 1 or 2 biomixes. The C:N ratio of both poultry manure layers (19.5 and 20.3, Table 4) were within the acceptable range (15 to 30) (proprietary information, O.C. Thompson, D.V.M., 421 Bluebonnet, Findlay, OH 45840).

Layer C, the cattle manure and water hyacinth layer, had lower nitrogen, phosphorus, and potassium concentrations after removal from the biofermentation chamber (Table 4) than the two poultry manure layers. The C:N ratio of the cattle manure layer was much higher (31.6, Table 4) than the two poultry manure layers immediately after aerobic biofermentation. This suggests that the cattle manure/water hyacinth layer had been decomposed much less than the two poultry manure layers. This could be caused by insufficient bacterial populations in the cattle manure compared to the poultry manure, or by insufficient nitrogen in the biomix; these hypotheses were not tested, however. The cattle manure/water hyacinth layer, after aerobic biofermentation, compared best with the nutrient concentrations and the C:N ratio of the Trial 1 Fermway made from water hyacinths alone.

The average temperature of Fermway No. 3 at the beginning of the 16 week stockpiling stage was 153°F, and decreased steadily thereafter (Table 5). The temperature remained above 142°F for the first two weeks of stockpiling. Unlike Fermway No. 2 with water hyacinths and gizzard shad, Fermway No. 3 had no odor problems or fly/maggot problems during the stockpiling period.

After 2 months of stockpiling, the nitrogen concentration of the dry poultry manure Fermway (Layer B) was highest (2.7 percent, Tables 6a and 6b), while that of the cattle and wet poultry manure Fermways (Layers C and A respectively) were similar to Fermway Nos. 1 and 2. The phosphorus and potassium concentrations of the dry poultry manure layer (Layer B) decreased significantly after 2 months of stockpiling (Tables 6a and 6b), while those of the cattle manure Fermway (Layer C) increased significantly. The C:N ratio of the cattle manure Fermway (Layer C) still remained high after 2 months of stockpiling. The volume of Fermway No. 3, after 13 weeks of stockpiling, had been reduced by 43.9 percent (Table 7).

<u>Trial 4 - Water Hyacinths with Poultry Manure and Scallop Offal</u>. This trial had two layers of biomix (Table 2):

(1) Layer A consisted of 200 lbs of water hyacinths (moisture level not measured), 200 lbs of dry poultry manure (moisture level not measured), and 200 lbs of sawdust (44.5 percent moisture level). The combined biomix for Layer A was 600 lbs in mass at an acceptable moisture level of 55 percent.

(2) Layer B consisted of 200 lbs of water hyacinths (moisture level not measured), 200 lbs of a fresh scallop offal liquid slurry (moisture level not measured), 184 lbs of sawdust (44.5 percent moisture level), and 66 lbs of shredded newspaper (moisture level not measured). The newspaper had been run through a mill that shreds it into about 0.25 inch narrow strips. The shredded paper mixed well in the biomix and absorbed excess moisture in the liquid scallop offal. The combined biomix for Layer B was 650 lbs in mass at an acceptable moisture level of 56 percent.

Sawdust was added to both layers to offset the moisture content of the water hyacinths. Poultry manure was added to Layer A to increase the nitrogen concentration of that biomix, since water hyacinths are low in nitrogen.

The Trial 4 biomix was pre-heated for one day in the biofermenter. The biomix was 83°F when loaded into the biofermentation chamber (Table 3), and reached the target temperature of 100°F the next day. The biomix was aerobically biofermented for 6 days. During the aerobic biofermentation period, temperatures rose to 169°F by the third day, then decreased to 158°F when the Fermway was removed from the biofermentation chamber (Table 3).

The nitrogen concentration in the poultry manure Fermway (Layer A) immediately after aerobic biofermentation was slightly lower than in the two poultry manure Fermways in Trial 3 (Layers A and B), while phosphorus and potassium concentrations were much higher (Table 4). The C:N ratio was only slightly higher in Layer A of Trial 4 than the two poultry manure layers in Trial 3.

The nitrogen, phosphorus, and potassium concentrations in the scallop offal Fermway (Layer B) immediately after aerobic biofermentation were lower than in the other biomixes in Trials 1-3 (Table 4). The phosphorus and potassium concentrations, in particular, were quite low in this Fermway. The extremely high C:N ratio of this layer (43.3, Table 4) indicates that this biomix was probably too low in nitrogen or bacterial populations were too low for adequate aerobic bacterial decomposition.

The average temperature of Fermway No. 4 at the beginning of the 16 week stockpiling stage was 146°F, and decreased steadily thereafter (Table 5). The temperature remained above 142°F for the first two weeks of stockpiling. Fermway No. 4 had no odor problems or fly/maggot problems during the stockpiling period.

After 2 months of stockpiling, the nutrient concentrations in the poultry manure Fermway in this trial (Layer A) were lower than in all other Fermways in this study (Table 6a). Nutrient concentrations were most similar to those in the dry poultry manure Fermway (Layer B) of Trial 3, although the nitrogen concentration in the Trial 4 layer was much lower than in Trial 3 (Table 6a).

The scallop offal and water hyacinth Fermway (Layer B) of Trial 4, after two months of stockpiling, had similar nutrient concentrations to those in the poultry manure mixture (Layer A) of this trial (Table 6a). The C:N ratio of the scallop offal Fermway, however, was much higher than in the poultry manure Fermway, although the difference decreased during the stockpiling period. The volume of Fermway No. 4 was reduced by 43.3 percent after 13 weeks of stockpiling (Table 7).

DISCUSSION

The purpose of Trial 1 was to examine the biofermentation process using water hyacinths as the single primary ingredient. The high moisture content of hyacinths after harvesting (90 percent or more) required additional drying of the hyacinth biomass and also the addition of secondary ingredients to absorb some of the excess moisture and thereby reduce the overall moisture content of the biomix. Even after adding sawdust to the Trial 1 biomix, the moisture content was 63 percent, above the 60 percent upper limit for desired moisture content of a biomix prior to aerobic biofermentation.

Although the C:N ratio of the freshly harvested hyacinths (23.2) was within the desired range, it increased during the pre-heat stage (31.5). This was probably due to the addition of the sawdust, which had a very high C:N ratio (108.2). The result of adding secondary ingredients with high C:N ratios is that the carbon concentration of the resulting biomix is increased and the nitrogen concentration is decreased. With water hyacinths, the high C:N ratio of the biomix in Trial 1 may have caused the slow rates of aerobic biofermentation, as indicated by the suboptimal temperatures recorded during the aerobic biofermentation process. Even after adding 7 pounds of urea nitrogen and subsequent aerobic biofermentation, the C:N ratio of the Fermway from Trial 1 was 26.2.

The stockpile volume reduction, 23.2 percent, was the lowest of all the Fermways tested in this study. The Fermway from Trial 1 did not have an odor or fly problem, and had a favorable texture for use as a fertilizer. The phosphorus concentration of Fermway No. 1 after 2 months of stockpiling, however, was extremely low (0.34 percent) for use as a general garden fertilizer.

The results from Trial 1 suggested that additional nitrogen sources need to be added to water hyacinths, and that secondary ingredients capable of absorbing more moisture need to be added as well. The addition of an ingredient with a higher phosphorus concentration or the use of water hyacinths with higher phosphorus concentrations (Round Lake hyacinths used in this study had a phosphorus concentration of 0.01 percent, those collected from Round Lake one year earlier had a 0.09 percent phosphorus concentration) would increase the phosphorus concentration of the resulting Fermway and thereby improve its characteristics as an organic fertilizer.

Ground gizzard shad are very high in nitrogen and phosphorus compared to freshly harvested water hyacinths. This high nitrogen content, however, yields a very low C:N ratio (8.7) for freshly harvested gizzard shad. Freshly harvested gizzard shad are also high in moisture (72 percent); drying of the fish biomass is not a viable option because of the attendant odor and fly problems.

In Trial 2, shredded newspaper and wood chips were added to help absorb some of the moisture associated with the gizzard shad and water hyacinth biomix. This reduced the overall moisture content of the biomix to 57.5 percent. The addition of water hyacinths and the secondary ingredients to the gizzard shad in the Trial 2 biomix decreased the nitrogen concentrations and increased the C:N ratio over that in raw gizzard shad.

However, the C:N ratio of the Trial 2 biomix, even after aerobic biofermentation, was still quite low. Odor and fly (maggot) problems were present during the pre-mix stage and after aerobic biofermentation. Experience has shown that odor and fly problems can arise if the C:N ratio is not kept at 20 or above (proprietary information, O.C. Thompson, D.V.M., 421 Bluebonnet, Findlay, OH 45840). The high temperatures reached during the aerobic biofermentation stage indicate a high level of chemical and biological activity. In the stockpile, the fish odor and maggot problems were nearly reduced after 1 week. Two months after stockpiling, the C:N ratio was 20.13. The product no longer smelled fishy or contained maggots.

Results from Trial 2 suggest that gizzard shad must be mixed with additional ingredients which have a high C:N ratio. This could be accomplished by increasing the proportion of water hyacinths in the mixture, or increasing the proportion of newspapers, sawdust, and other high C:N ratio, moisture-absorbing ingredients. Nutrient characteristics of Fermway No. 2 were more acceptable for use as an organic fertilizer than those from Trial 1 using water hyacinths alone, as phosphorus concentrations were much higher.

Trial 3 was designed to test the importance of manures as added ingredients in the biofermentation of water hyacinths. The addition of dry poultry manure in Layer B yielded higher nitrogen concentrations in the Fermway after 2 months of stockpiling than the wet poultry manure or cattle manure additions in Layers A and C respectively. Nitrogen concentrations in Layer B after 2 months of stockpiling were also higher than in all other Fermways produced during this study. Phosphorus and potassium concentrations in the dry poultry manure layer of Trial 3 after 2 months of stockpiling were much lower than in the wet poultry manure or cattle manure layers of this trial.

While the cattle manure and wet poultry manure layers in Trial 3 compare favorably with respect to the use of the resulting Fermway as an organic fertilizer, the wet poultry manure layer yielded higher concentrations of phosphorus and potassium. There were no odor or fly/maggot problems with any of the layers in Trial 3.

Trial 4 was designed to see if waste from the seafood industry could be used in the biofermentation of water hyacinths. The C:N ratio of the scallop offal biomix layer in Trial 4 was 43.3 immediately after aerobic biofermentation, the highest of all biomixes tested in this study. The nitrogen concentration of this biomix was the lowest of all biomixes as well. While water hyacinths are low in nitrogen, apparently scallop offal is even lower (scallop offal nutrient characteristics were not measured, however). The scallop offal was very wet and the addition of shredded newspaper reduced the moisture problem very well.

Nutrient concentrations in the poultry manure layer (Layer A) of Trial 4, after 2 months of stockpiling, compared well with those from the dry poultry manure layer (Layer B) of Trial 3, although nitrogen concentrations in Layer A of trial 4 were lower. Nutrient concentrations in the scallop offal layer were also similar to those in the dry poultry manure layer of Trial 3, although nitrogen concentrations were lower and the C:N ratio was much higher in the scallop offal Fermway.

The stockpiles of Trials 2, 3, and 4 had high temperatures and experienced greater volume reduction than Trial 1. Reduced volume and mass is an asset when transporting and applying the Fermways to soil with conventional agricultural equipment, although the loss in mass means there is less Fermway product for potential sale.

These four trials suggest that the biofermentation of water hyacinths requires the addition of an ingredient high in nitrogen (to offset the low nitrogen concentrations in water hyacinths) and ingredients with a high C:N ratio capable of absorbing the excess moisture found in water hyacinths. Shredded newspaper and sawdust appear to fulfill the latter requirements. The addition of gizzard shad biomass potentially could fulfill the former requirement. However, the proportion of gizzard shad in the biomix must be reduced from that used in Trial 2 so that odor and fly/maggot problems do not arise. The nutrient quality of the resulting Fermway from the biofermentation of water hyacinths would also be improved if an ingredient comparatively high in phosphorus, such as gizzard shad, were also added.

The biofermentation of gizzard shad requires the addition of ingredients with a high C:N ratio capable of absorbing the excess moisture in gizzard shad, and the addition of an ingredient with a high C:N ratio to offset the high nitrogen concentrations and low C:N ratio in gizzard shad. Water hyacinths and shredded newspapers can fulfill these requirements.

Poultry and cattle manure, and scallop offal, appear to be viable substitutes for gizzard shad in the biofermentation of water hyacinths. Of these alternative ingredients, wet poultry manure and cattle manure appear to be better with respect to the nutrient concentrations in the stockpiled Fermway.

With respect to utilizing water hyacinths and gizzard shad together in a biofermentation process, the following proportions are suggested for a biomix which would optimize biofermentation conditions and the nutrient quality of the resultant Fermway:

Ingredient	Biomix Mass
Gizzard Shad (ground)	11.75 %
Sawdust	15.00 %
Newspaper (shredded)	10.00 %
Water hyacinths (at 60% moisture)	63.25 %

The rationale used in establishing the suggested proportions is described below. The slow temperature rise in Trial 1 indicates that water hyacinths by themselves are not actively digested, even though the C/N ratio of water hyacinths (23.08, Table 1) is within the optimum range of 20 to 30. It is hypothesized that the nitrogen in water hyacinth tissue is not rapidly decomposed by bacteria in the biofermentation environment. It is further hypothesized that nitrogen in animal tissue and waste products are rapidly digested by bacteria, as demonstrated by the high biofermentation temperatures reached in Trial 2. The water hyacinths therefore need to be complemented by animal tissue or waste products to attain desirable decomposition rates.

The mass of gizzard shad, a source high in animal tissue nitrogen, needs to be reduced below that used in Trial 2 in order to avoid fly/maggot problems. Since the C:N ratio of water hyacinths is acceptable, the approach taken in determining the proper proportions of ingredients was to add enough secondary ingredients to raise the C:N ratio of the gizzard shad to that of the water hyacinths (23.08). The following is a description of how the mass of secondary ingredients was determined.

One lb of gizzard shad has 0.055 lbs nitrogen and 0.479 lbs carbon (C:N = 8.71, Table 1). Given this 0.055 lbs of nitrogen, enough secondary ingredient carbon needs to be added to raise the total carbon mass in the gizzard shad-secondary ingredient mixture to 1.269 lbs. Since gizzard shad already have 0.479 lbs of carbon, 0.79 lbs of carbon from secondary ingredients needs to be added.

Amount	Ingredient	Mass of carbon	Mass of nitrogen	C:N Ratio
1.00 lb	Gizzard shad	0.479	0.055	8.71
	Secondary Ingredients	0.7904	0	---
	Total	1.2694	0.055	23.08

Because of the low density of newspapers, it was determined that the secondary ingredients should be comprised of 60 percent sawdust and 40 percent newspapers. Given this ratio, one pound of secondary ingredients has the following characteristics:

Amount	Ingredient	Carbon	Nitrogen	Nitrogen Times 23.08	Net Carbon
0.60 lb	Sawdust	0.2274	0.0021	0.0485	0.1789
0.40 lb	Newspapers	0.1948	0.0001	0.0018	0.1930
1.00 lb	Total Secondary Ingredients	0.4222	0.0022	0.0508	0.3714

The nitrogen content in the secondary ingredients needs to be accounted for in the determination of secondary ingredient amounts. The column "Nitrogen times 23.08" is the amount of carbon needed to reach a C:N ratio of 23.08 for this amount of nitrogen in the secondary ingredient. The last column "Net Carbon" therefore is the net amount of "excess" carbon above that amount necessary to keep the C:N ratio of the secondary ingredient at 23.08. For every pound of the secondary ingredient mixture, 0.3719 pounds of net carbon are available to increase the C:N ratio of the gizzard shad.

Since the total amount of carbon needed from secondary ingredients to bring one pound of gizzard shad up to a C:N ratio of 23.08 is 0.7904 lbs, the mass of secondary ingredients needed per pound of gizzard shad is 2.1280 lbs (0.7904 / 0.3719):

Amount	Ingredient	Carbon	Nitrogen	C:N Ratio	Net Carbon
2.1280 lb	Secondary Ingredients	0.8985	0.0047	191.17	0.790

It was determined that the secondary ingredients should comprise 25 percent of the total biomix. For every 2.128 lbs of secondary ingredients necessary for one pound of gizzard shad, the total mass of biomix ingredients needs to be 8.512 lbs (4 times 2.128 lbs). Consequently, 5.384 lbs of water hyacinths are necessary to make up the remaining 75 percent of the non-secondary ingredient components:

Ingredient	Biomix Mass	Mass of Carbon	Mass of Nitrogen	C:N Ratio
Gizzard Shad	1.0000 lb	0.4790 lb	0.0550 lb	8.71
Sawdust	1.2768 lb	0.4839 lb	0.0045 lb	107.53
Newspaper	0.8512 lb	0.4145 lb	0.0002 lb	2072.50
Hyacinths	5.3840 lb	2.7458 lb	0.1190 lb	23.08
Totals	8.5120 lb	4.1232 lb	0.1787 lb	23.08

On a mass percentage basis, the biomix formula is therefore:

Ingredient	Percent of Mass	Percent of Carbon	Percent of Nitrogen
Gizzard Shad	11.75 %	11.62 %	30.78 %
Sawdust	15.00 %	11.74 %	2.52 %
Newspaper	10.00 %	10.05 %	0.11 %
Water hyacinths	63.25 %	66.59 %	66.59 %

Fly and maggot problems resulted from the ingredient formula used in Trial 2 in this study. However, the suggested formula above differs from that used in Trial 2. Gizzard shad comprised about 34 percent of the biomix mass in Trial 2, while it comprises only 11.75 percent in the suggested formula. The C:N ratio in Trial 2 was 15.2, rather than the 23.1 using the suggested formula. Further, 57.1 percent of the nitrogen in the Trial 2 biomix came from gizzard shad, while only 30.8 percent of the nitrogen in the suggested formula comes from gizzard shad. It is hypothesized that a significant reduction in the percentage of biomix mass and biomix nitrogen coming from gizzard shad will prevent the occurrence of fly and maggot problems as observed in Trial 2. Actual tests will be necessary to establish the proper proportions of gizzard shad and water hyacinths to use in a biomix for aerobic biofermentation without fly/maggot problems.

The water hyacinths used in future biofermentation studies will likely contain more phosphorus than those used in this study. This will improve the nutrient quality of the resulting FermWay over that produced in Trial 1. It seems likely that the Fermway produced using the suggested formula will have nutrient characteristics intermediate between the Fermways produced from Trials 1 and 2 in this study. While using a lower percentage of gizzard shad will reduce nutrient concentrations below that in the Trial 2 Fermway, the use of higher phosphorus water hyacinths will in part compensate for this.

The nutrient quality of the resulting Fermway needs to be considered in establishing the optimum ingredient formula. Further study is necessary to examine what effect changes in the suggested formula result in improvements in the Fermway nutrient characteristics. The fertilizer needs of the end user of the Fermway also needs to be considered in establishing the optimum ingredient formula.

The use of water hyacinths with cattle or wet poultry manure produces a Fermway with acceptable nutrient concentrations for use as an organic fertilizer. While such a combination would not utilize gizzard shad, it could possibly provide some subsidy for surface water management projects involving water hyacinth removal. The use of water hyacinth Fermways as a means of subsidizing these management projects remains uncertain, however, as a reliable economic feasibility analysis has not been pursued to date.

CONCLUSIONS

The low nitrogen concentration and the high C:N ratio in water hyacinths in Trial 1 resulted in low biofermentation temperatures. The low phosphorus content in the Fermway from this Trial discourages the use of water hyacinths alone for producing an acceptable general organic fertilizer. In addition, pathogens and weed seeds may not be destroyed.

The addition of dry poultry manure to water hyacinths reduced the initial C:N ratio, but did not improve nutrient characteristics of the Fermway after 2 months of stockpiling. The addition of scallop offal to water hyacinths increased the C:N ratio compared to the hyacinth-alone biomix, and resulted in similar (except for lower nitrogen concentrations) nutrient concentrations in the 2 month old Fermways.

The addition of cattle manure resulted in a Fermway similar to that from a hyacinth-alone biomix, except that phosphorus concentrations were greatly increased by the addition of the cattle manure. The addition of wet poultry manure increased both phosphorus and potassium concentrations compared to a hyacinth-alone Fermway, although nitrogen concentrations were slightly less.

The addition of gizzard shad to water hyacinths, in approximately a 34-31 percent mixture, increased the phosphorus concentrations in the resulting Fermway compared to that in a hyacinth-alone biomix. However, there were significant odor and fly/maggot problems associated with this biomix during all three stages of the biofermentation process.

The results of this pilot study indicate that water hyacinths, because of high moisture levels and low initial nitrogen and phosphorus levels, are not a good single ingredient for biofermentation. The combination of water hyacinths and gizzard shad shows promise. Some experimentation with various proportions of gizzard shad and water hyacinths is necessary to determine the best combination for odor and fly/maggot control, for adequate biofermentation and stockpile temperatures to control pathogens and weed seed germination, and for acceptable nutrient concentrations in the Fermways for use as an organic fertilizer.

RECOMMENDATIONS FOR FUTURE STUDY

Phase II Recommended Study.

Agron, Inc., has recommended a second study phase to further examine the feasibility of using the biofermentation of water hyacinths and gizzard shad as a means of subsidizing surface water management projects which involve water hyacinth and gizzard shad removal and/or control. This second phase would be aimed at accomplishing the following:

(1). Determine the optimum formula for a water hyacinth and gizzard shad biomix which will prevent fly and maggot problems while producing a Fermway with desirable nutrient characteristics. The desired Fermway nutrient characteristics will be established after an analysis of the current nutrient requirements of the muck farms at Lake Apopka. The optimum formula will be determined from five one-ton biofermentation trials using a one-ton experimental biofermentation chamber. Water hyacinths from typical surface waters (lakes and/or rivers) will be used so that nutrient concentrations in the water hyacinths are typical of those collected from water hyacinth management and control projects. Nutrient characteristics will be measured for the biomix ingredients, for the biomix before pre-heating, for the Fermway immediately after biofermentation, and for the Fermway after several months of stockpiling.

Five separate biomix formulas will be tested. The primary difference being tested among the formulas is the mass percentage of gizzard shad in the biomix. The mass percentages of gizzard shad in the biomixes to be tested are: 5.875, 11.750, 17.625, 23.500, and 29.375 percent. However, the mass percentages of the secondary ingredients and water hyacinths will also differ among the tested formulas. This is because the amounts of these other ingredients is based on the amount of gizzard shad used. The approach discussed on pages 36-39 will be used to establish the amounts of secondary ingredients and water hyacinths in each formula.

(2). The optimum ingredient formula established in task 1 will be used in either five one-ton biofermentation trials using a one-ton experimental biofermentation chamber, or a single trial using a leased 50-ton biofermentation chamber. Water hyacinths from typical surface waters (lakes and/or rivers) will be used so that nutrient concentrations in the water hyacinths are typical of those collected from water hyacinth management and control projects. Nutrient characteristics from each biofermentation trial in this task will also be measured, as described in task 1.

(3). The Fermway produced in task 2 will be applied to test plots on Lake Apopka muck farms to assess its value as an agricultural crop fertilizer. Test plots will utilize replications of various treatment applications of Fermway and other fertilizers in a test plot trial design coordinated with muck farmers, the St. Johns River Water Management District, and a University of Florida agronomist. The vegetables to be grown on the plots will include sweet corn, carrots, radishes, bib lettuce, and parsley. Four replications will be tested for each vegetable. Randomized plots will be utilized in homogenous muck land. A single test plot will be 200 ft^2 if 5 tons of Fermway are produced, or 2000 ft^2 if 50 tons of Fermway are produced. The agronomy study will be under the direction of Dr. Marion White of the University of Florida. The following are the suggested treatments:

(1). No Fermway applied, but the normal amount of nitrogen, phosphorus, and potassium (in the same form as usually applied by the farmers to these muck soils) is to be applied to the plot.

(2). One pound of Fermway per 10 ft^2 of plot area, plus sufficient nitrogen, phosphorus, and potassium as required to maintain the normal nutrient application rates to the muck soils.

(3). Two pounds of Fermway per 10 ft^2 of plot area, plus sufficient nitrogen, phosphorus, and potassium as required to maintain the normal nutrient application rates to the muck soils.

(4). Four pounds of Fermway per 10 ft^2 of plot area, plus sufficient nitrogen, phosphorus, and potassium as required to maintain the normal nutrient application rates to the muck soils.

(5). Eight pounds of Fermway per 10 ft^2 of plot area, plus sufficient nitrogen, phosphorus, and potassium as required to maintain the normal nutrient application rates to the muck soils.

Normal insect and disease control is to be followed as usual for these muck soil plots. The data to be collected include soil characteristics both before treatments are applied to the plots and after harvest, plant tissue tests for nutrient concentrations, days to harvest, yield, quality of product, irrigation required, plant stress indicators, and other data as may be appropriate.

This final task is designed to answer the following questions:

(1). Does a Fermway made from gizzard shad and water hyacinths have an advantage over the typical nutrients forms applied to these muck soils? Are vegetable yields increased if a Fermway partially replaces the typical nutrient sources?

(2). Is there an economic advantage for the farmer using a Fermway instead of or in addition to the typical nutrient sources used on these soils?

The information obtained from this phase II study will be used to prepare a complete economic analysis of biofermenting water hyacinths and gizzard shad for the purpose of subsidizing hyacinth and gizzard shad removal projects.

A preliminary budget for the Phase II study is shown below. This budget is based on assumptions that a 50-ton trial would be conducted for task 2, that test plots 2000 ft^2 in area will be used, and that the maximum mass of gizzard shad and water hyacinths will be utilized in the 50-ton biofermentation trial. Given these assumptions, approximately $ 43,100 would be required to fund Phase II.

Item	
Lease of 50-ton biofermenter and labor	$ 2,000
38 tons water hyacinths ($100/ton)	$ 3,800
16 tons gizzard shad ($400/ton)	$ 6,400
9 tons sawdust ($ 20/ton)	$ 180
6 tons newspaper ($ 20/ton)	$ 120
Transportation of materials to the site	$ 1,500
Travel	$ 5,000
Chemical Analyses	$ 1,000
Consulting Fees	$15,000
Agronomy Package	$ 8,100
TOTAL	$ 43,100

Phase III: Full-Scale Project.

If full-scale restoration projects involving (1) the growth and harvest of water hyacinths from Lake Apopka, and (2) the harvest of gizzard shad from Lake Apopka are implemented, and if the results from the Phase II study are positive and show a favorable economic feasibility analysis, then a full-scale Phase III project could be contemplated as a means of subsidizing these two restoration projects.

The full-scale Phase III project, as envisioned by Agron, Inc., would involve the construction of a permanent biofermentation facility (including stockpile and preheat facilities). Six 50-ton capacity biofermentation bays would be included in the facility. On-site warehouses would also be constructed to store a two-week supply of water hyacinths and up to six months' worth of Fermways. Newspaper would be warehoused in a 70' x 100' clear span building which would accommodate a hammer mill and cyclone for grinding newspaper. Sawdust would be warehoused in a 70' x 100' steel clear span building. A cold storage facility for storing up to 180 tons of gizzard shad would also be constructed. A central office, rest rooms, instrument room, and laboratory would also be constructed at the biofermentation facility.

The biofermentation facility would also include a five-ton per hour fish grinder capable of discharging ground fish into a mixer truck. The mixer truck would have the mixer on load cells for weighing ingredients. Additional necessary equipment is a payloader, pick-up truck, skid steer loader, stockpile conveyor, and pallet truck.

The biofermentation process at this large-scale facility would require that gizzard shad and water hyacinths be brought to the site. Normal operating procedure would be for gizzard shad to be ground, mixed with newspaper and sawdust, then mixed with ground and pre-heated water hyacinths, and then placed in the biofermenter the same day the same day the gizzard shad is delivered. During months when excess gizzard shad are delivered to the site, the excess fish would be placed in cold storage at the biofermentation facility. During months when an insufficient amount of gizzard shad are delivered, the deficit would be made up from gizzard shad in cold storage.

The six biofermenter bays each would have a capacity of 50 tons. It is expected that each bay will be filled to 80 percent capacity, so that 240 tons of raw biomix could be processed per week. Consequently, approximately 12,480 tons of biomix could be biofermented per year. The following ingredient formula is used only for the purposes of establishing a preliminary budget for the Phase III project. The actual ingredient formula used would depend on the results from the Phase II study.

Ingredient	Mass (tons)
Water Hyacinths at 60 percent moisture	25.3
Sawdust	6.0
Gizzard Shad (wet weight)	4.7
Newspaper	4.0
Total biomix mass per biofermenter bay per week	40.0

The average total phosphorus content in water hyacinths grown in open enclosures in Lake Apopka as part of the St. Johns River Water Management District's "Water Hyacinth Demonstration Project" was 0.145 percent on a dry weight basis, while the average total nitrogen content was 1.863 percent on a dry weight basis (Shuman, personal communication). The average total phosphorus content in gizzard shad is about 1.75 percent on a dry weight basis, while the average total nitrogen content in gizzard shad is about 5.5 percent (Godwin, personal communication). Given these nutrient concentrations and the biomix formula shown above (multiplied by 6 biofermentation bays per week times 52 weeks), the following gross mass of nutrients would be expected to be exported from Lake Apopka each year:

Ingredient	Mass of Phosphorus (tons)	Mass of Nitrogen (tons)
Water Hyacinths	4.58	58.82
Gizzard Shad	7.19	22.58
Total	11.77	81.40

Consequently, approximately 12 tons of total phosphorus per year and approximately 81 tons of total nitrogen per year would be exported from Lake Apopka by removing this amount of gizzard shad and water hyacinths. The amount of nutrients contained in water hyacinths is the gross nutrient content; it does not account for the nutrients in the hyacinths stocked into Lake Apopka as part of the project.

The preliminary budget for the Phase III project was divided into two sections: capital outlay and operating costs. Capital outlay costs include land costs, building and construction costs, and heavy equipment costs (Table 8). The heavy equipment costs are amortized over 5-year periods. The land, building, and construction costs are amortized over a 20-year period. The per-year capital costs used in the preliminary budget therefore assume a 20-year operation of the biofermentation facility. If the facility is operated less than 20 years, then the total capital costs will be higher than shown in the proposed budget because not all capital outlays (eg. service road construction, concrete pads and walls) will be fully paid for from the per-year costs and any resale/reuse after the project. The total capital outlay for a 20-year operation period is estimated to be \$ 1,746,200 (Table 8). Assuming a 20-year period of operation, the average annual capital outlay cost would be \$ 87,310 (Table 8).

Operational costs include the cost of the biomix ingredients and actual operation costs. The cost for the biomix ingredients is estimated to be \$1,350,202 per year. It is assumed that a municipal solid waste disposal would donate the newspaper.

TABLE 8
Phase III Study Capital Outlay Budget

Land	10 acres	$	50,000
Facilities	6 Bay Biofermenter	$	280,000
	2 Clear Span Buildings		80,000
	Concrete Pad 80′ x 100′		12,000
	8′ Retaining Wall 280′		5,600
	Office & Restroom 18 x 24		21,600
	Septic Tank		10,000
	Well		5,000
	Electric Service		10,000
	Fuel Tank		2,000
	Site Development		5,000
	Stockpile 80′ x 200′		24,000
	Retaining Walls		8,000
	Scales		15,000
	Loading Deck		10,000
	Service Roads		
	Storage ends		30,000
	Connecting Road		12,000
	Building Floors		21,000
	Building Area		16,000
	Main Road		20,000
	Cooler		80,000
	Contingency		25,000
Total Cost Assuming 20-year amortization		$	692,200
Annual cost over a 20 year period		$	34,610

TABLE 8 - (continued)
Phase III Study Capital Outlay Budget

Equipment

1 JD 444 Payloader	$	70,000
1 Cab Chassis		28,000
1 Mixer Load Cells		30,000
1 Pickup		12,000
1 Skid Steer Loader		18,000
1 Office Furniture & Tools		10,000
1 Conveyor		16,000
1 Kelley-Duplex Hammermill		27,000
1 Fish Grinder		10,000
1 Pallet Truck		20,000
Contingency		10,000
Total	$	251,000
Total cost over 20-years assuming a 5-year amortization	$	1,004,000
Annual cost over a 20 year period	$	50,200

Total Capital Outlay	Land	$	50,000
	Facilities		692,200
	Equipment		1,004,000
TOTAL OVER A 20-YEAR PERIOD		$	1,746,200
AVERAGE ANNUAL COST ASSUMING 20-YEARS OF OPERATION		$	87,310

Item	Amount	Unit Cost	Cost
Water Hyacinths	7,894 tons	$100/ton	$ 789,400
Gizzard Shad	1,466 tons	$357.00/ton	$ 523,362
Sawdust	1,872 tons	$20/ton	$ 37,440
Newspaper	1,248 tons	Donated	Donated
Total Cost Per Year			$ 1,350,202

Other operational costs are shown in Table 9. The total operational cost, per year, including the cost of ingredients, is $ 1,643,192. Adding the annual capital cost amortization (assuming a 20-year project) of $ 87,310, the total project cost would be $ 1,730,502 per year, or $ 34,610,040 over the 20-year operational period.

Assuming there is an average 30 percent reduction in mass of Fermway after six months of stockpiling, the 12,480 tons of raw biomix ingredients would reduce to 8,736 tons of Fermway. Therefore, for this project to be financially self-sufficient, Fermway from this project would have to be sold for approximately $200 per ton.

If the cost of the gizzard shad and water hyacinths are removed from these calculations, then the total project cost per year would be $ 380,300 (assuming a 20-year project operation). With an annual production of 8,736 tons of Fermway, the Fermway would have to be sold for at least $44 per ton for this project to provide any subsidy to the water hyacinth or gizzard shad removal projects on Lake Apopka.

TABLE 9

Phase III Study Annual Operational Costs Budget

Operational Costs Do Not Include Biomix Ingredient Costs

Labor	$ 104,000
Fringe	26,000
Administration	12,000
Electric	7,500
Fuel	5,000
Insurance	12,000
Taxes	13,200
Maintenance	10,000
Depreciation-Facility	34,610
Depreciation-Equipment	50,200
Outside Labs	6,000
Royalty	12,480
Total Annual Cost	$ 292,990
Total Cost Over 20-Years of Operation	$ 5,859,800

The Fermway would most likely have to be sold at more than $44 per ton before any subsidy would be accrued. While water hyacinths and gizzard shad are assumed to cost nothing under this latter economic scenario, there would in fact be a delivery cost associated with getting these materials to the biofermentation facility. Competition with other market avenues for harvested water hyacinths and gizzard shad could increase in time, thereby increasing the potential value of these harvested materials and comparatively reducing the potential subsidy from biofermentation. Consequently the subsidy from biofermentation would have to be greater than the subsidy provided from alternative market avenues for these harvested materials.

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