EXAMINING THE QUALITY OF A COMPOST PRODUCT DERIVED FROM SARGASSUM (SARGASSUM FLUITANS AND SARGASSUM NATANS)

by

Kevin T. Walsh, B.F.A.

A thesis submitted to the Graduate Council of
Texas State University in partial fulfillment
of the requirements for the degree of
Master of Education
with a Major in Agricultural Education
May 2019

Committee Members:

Tina M. (Waliczek) Cade, Chair

Alice Le Duc

Frank Reilly

COPYRIGHT

by

Kevin T. Walsh

2019

FAIR USE AND AUTHOR'S PERMISSION STATEMENT

Fair Use

This work is protected by the Copyright Laws of the United States (Public Law 94-553, section 107). Consistent with fair use as defined in the Copyright Laws, brief quotations from this material are allowed with proper acknowledgement. Use of this material for financial gain without the author's express written permission is not allowed.

Duplication Permission

As the copyright holder of this work I, Kevin T. Walsh, authorize duplication of this work, in whole or in part, for educational or scholarly purposes only.

DEDICATION

This thesis is dedicated to my late uncle, Brother Stephen Vincent Walsh, who fostered our family's academic aptitude as well as our culinary explorations, and to my late photography professor, Eric Weller, who encouraged me to pursue a Master's degree and passed at the beginning of my first semester in graduate school.

ACKNOWLEDGEMENTS

I would like to thank my mother and father for their support through, what has been, a formative chapter of my life in the wake of the 2015 floods. Without them, completion of my studies would not have been possible, and I owe them a life of gratitude. Many thanks go out to my crew at Bobcat Blend Composting, who worked a dirty job with smiles and cheer, and a special thanks to Jen Sembera for teaching me the art of management. To my committee, thank you for your patient insight and your invaluable wisdom. I can’t thank you enough, Dr. Cade, for all the experiences you have made available for me. It has been an experience that is hard to let go of. Finally, a broad thank the Speleological community, for expanding my explorations in science and ecology, as I move onto the next chapter in life.

TABLE OF CONTENTS

Page

LIST OF TABLES

Table **Page**

ABSTRACT

The free-floating algae known as sargassum (*Sargassum fluitans* and *Sargassum natans*) drifts onto coastlines throughout the Atlantic during spring and summer months. Beach communities, such as those along the Texas Gulf Coast, seek to maintain tourist appeal and therefore remove or relocate the sargassum drifts once it collects on shore. Maintenance efforts have attempted to incorporate the sargassum into dunes and beach sand. However, not all communities have the resources to manage the biomass as such and must dispose of the biomass in a landfill. The utility of the seaweed biomass as a fertilizer for plant growth has been renowned for centuries. Composting practices can manage this biomass in an efficient manner without the need to landfill. The purpose of this project was to evaluate the appropriate proportion of sargassum (*Sargassum fluitans* and *Sargassum natans*) to other compost ingredients to be used in a large-scale composting system. This study used approximately 32 yard^3 of sargassum as part of 96 yard^3 of compost material, which also included food waste, fish waste and wood chips. The final compost products were of equal quality to those required by current compost standards. Therefore, this study determined that waste management industries can utilize sargassum as a feedstock through a large-scale composting system to create a desirable compost product that could be used in the horticulture and agriculture industries.

I. INTRODUCTION

The Sargasso Sea was once a place of frightening legends to sailors of centuries ago, known as a windless and gnarly trap of a distinct flora that shrouded the mysterious waters, hiding alien monsters within its dark waters (Genthe, 1998). This sea's iconic flora has been aptly named sargassum and two species, *Sargassum fluitans* and *Sargassum natans,* create a nest in the North Atlantic that nurses the dynamic assortment of aquatic life (Evolutionary Ecology et al., 2016). Contained by the Atlantic gyre, the Sargasso Sea exists as a unique anomaly as the only sea on earth without a coastline. Comparing the entire Atlantic gyre to a tropical storm system, the Sargasso Sea would be the "eye" of the vortex with calm and still waters (Genthe, 1998). The ocean currents contain the warm waters of the Sargasso Sea like a shallow bowl that is still being sculpted. As life grows inside this bowl and branches out, the ocean currents randomly distribute flora and fauna alike toward coastlines throughout the Atlantic, most commonly in Southern Europe, North America and the Caribbean (Righton et al., 2016).

Sargassum is a planktonic species of the Phaeophyceae class of macroalgae (Wang et al., 2009). These free-floating organisms reach a seasonal peak in growth and mass each year and will typically reach the Texas coast during the summer months (Round, 1981). Once the sargassum touches the shoreline, it forms "mats" which pile up to recorded heights of 4 ft and stretch to the length of multiple football fields (Williams and Feagin, 2007). At this moment, the sargassum begins to decay and releases its fish and crustacean passengers like tourists exiting a cruise ship. Incidentally, actual tourists are attracted to the beach during the same summer months. As the number of beach-goers increases, the more inconvenient a mat of sargassum becomes to maintain tourist appeal (Williams and Feagin, 2006).

Many Texas beach communities employ efforts to physically remove the sargassum. Using front-end loaders, the biomass can be raked or shoveled and often relocated along foredunes, where it can continue to naturally decompose. Another method involves spreading the sargassum evenly along the shore and covering over with sand, therefore rebuilding the shore rather than the dunes (M. Smith, personal communication, July 03, 2014). However, due to either local attitudes or limitations in maintenance, not all communities are able to adopt these methods and will take the more convenient option of having the sargassum removed entirely and disposed in a landfill (Watson, 2008).

There remains much debate on the matter of removing sargassum. When tourists of Matagorda Island, located approximately 30 miles northeast from the collection site of this study, were surveyed, 63.89 % of participants disagreed with the statement, "seaweed should be removed from the beach completely" (Williams, 2010). The city of Galveston, Texas has recently launched a public education campaign to encourage beach-goers to embrace the seaweed and public opinions are beginning to view the biomass as less of a nuisance compared to past views (Rice, 2015).

The utility of the seaweed biomass as a fertilizer for plant growth has been renowned for centuries. Green algae species, such as kelp, have been used as a reliable source of plant nutrients in agricultural applications, most historically notable in Southeast Asia (Win and Saing, 2008). Sargassum itself works as a natural fertilizer for coastal flora along the Texas coast and its use is advocated for the restorative maintenance of dune ecology after hurricanes (Williams, 2010).

Recent research has shown positive results of sargassum used as a feedstock in large-scale composting to produce organic soil amendments, such as compost (Sembera et al., 2018). Limitations and methods of the previous study included incorporating a low percentage of sargassum biomass. The study did not reflect the extremes of sargassum accumulation that coastal beaches might experience (Sembera et al., 2018). Neither did this study examine the potentially high levels of salt, which could have undesirable results on the finish compost product (Illera-Vives et al., 2015).

Compost is the natural process of breaking down organic matter into a usable, waste-free product and is increasingly used as a waste management system. Compost products are a valuable commodity to agricultural, horticultural, and related users (Rynk et al., 1992; Walker et al., 2006). During the active stage of composting, bacteria and other microorganisms consume oxygen and release carbon dioxide, producing a large amount of heat (Rynk et al*.,* 1992). Temperatures must reach over 130 degrees F in order to kill pathogens as well as plant propagules or seeds (Dougherty, 1999). Finished compost can process down to 50 % or less of the original volume of raw material (Rynk et al*.,* 1992) making it an effective means of waste management (Stoffella and Kahn, 2001).

Compost is used on an agricultural level as well as a horticultural level. Amended into soil, compost boosts soil fertility and improves soil structure while increasing water holding capacity and decreasing runoff (Rynk et al., 1992). By increasing the number and diversity of microorganisms and enhancing beneficial chemical and physical properties of the soil, plants can develop natural immunities to diseases, insects and parasites. This process is promoted by carbon-based materials that slowly release nitrogen, phosphorus and potassium into the soil over time (Dougherty, 1999; Rynk et al., 1992).

Large scale agricultural practices often result in over-tilled soils that remain bare between growing seasons. Lacking any native organic matter, the soil profile weathers away and loses the essential layer of humus and fungus. Amending soil with some form of organic matter is advised to maintain and sustained soil health (Martin et al., 1992). Compost may reduce the need for the use of inorganic fertilizers in certain situations and allow farmers or gardeners to manage their own organic wastes (Martin et al., 1992).

Problem Statement

This project examines large-scale compost management of *Sargassum fluitans* and *Sargassum natans* (sargassum, collectively) as a method that can be replicated locally near the communities that are burdened by the plant as well as investigates the limits that a compost management system has when using sargassum as a feedstock to create a marketable product for use in agriculture, horticulture and related markets.

Purpose

The purpose of this project was to evaluate the appropriate proportion of sargassum to other compost ingredients to be used in a large-scale composting system.

Objectives

The objectives of this study included, (1) developing a large-scale composting system that utilized the sargassum biomass with common compostable feedstock material, (2) determining the maximum allowable proportion of dried sargassum to other organic feedstock materials that results in a quality compost product, (3) conceptualizing a management system that can be replicated by the communities that are affected by the problematic species, (4) examining the effect of potentially high levels of salinity from the sargassum on the final product, and (5) evaluating if the composted byproduct is a safe, marketable product for the agricultural and horticultural consumers.

Hypotheses

The hypotheses of this study were, (1) there will be a limit found on the amount of sargassum that can be incorporated into a compost management system that creates a beneficial product to the agricultural and horticultural markets and, (2) at the appropriate ratios, a compost product derived from sargassum will produce a similar quality product to those currently available in the agricultural and horticultural markets.

Definition of Terms

Aerobic respiration – “a type of respiration in which foodstuffs (usually carbohydrates) are completely oxidized to carbon dioxide and water, with the release of chemical energy, in a process requiring atmospheric oxygen” (Martin and Hine, 2008).

Algae – “any of various unrelated simple organisms that contain chlorophyll (and can therefore carry out photosynthesis) and live in aquatic habitats and moist situations on land” (Martin and Hine, 2008).

Asexual reproduction – “reproduction in which new individuals are produced from a single parent without the formation of gametes. It occurs chiefly in lower animals, microorganisms and plants. The chief methods are... fission, fragmentation, budding, vegetative propagation and by the formation of spores” (Martin and Hine, 2008).

Bacteria – “a diverse group of ubiquitous microorganisms all of which consist of only a single cell that lacks a distinct nuclear membrane and has a cell wall of a unique composition” (Martin and Hine, 2008).

Biomass – “the total mass of all the organisms of a given type and/or in a given area” (Martin and Hine, 2008).

Compost – “a mixture of decaying organic matter, such as vegetation and manure, that is used as fertilizer. The organic material is decomposed by aerobic, saprotrophic organisms, mostly fungi and bacteria” (Martin and Hine, 2008).

Composting – “managed biological oxidation process that converts heterogeneous organic matter into a more homogenous, fine-particle, humus-like material” (Dougherty, 1999).

Curing – “the last stage of the composting process that occurs after most of the organic feedstock material has been decomposed and stabilized” (Dougherty, 1999).

Ecosystem – “a biological community and the physical environment associated with it” (Martin and Hine, 2008).

Feedstock – “biodegradable material… with the potential to be used for processes such as composting and anaerobic digestion.” (Furniss, 2009).

Foredune – “a dune occurring at the landward margin of the beach and generally forming part of a fore-island dune ridge” (Weise and White, 1980).

Fragmentation – “a method of asexual reproduction in which parts of the organism break off and subsequently differentiate and develop into new organisms” (Martin and Hine, 2008).

Fungus (pl: fungi) – “a spore-producing organism, such as a mushroom, that has no leaves or flowers and grows on other plants or on decaying matter" (Soanes, 2002).

Germinate – "(of a seed or spore) begin to grow and put out shoots after a period of being dormant" (Soanes, 2002).

Humus – "the dark-coloured [sic] material that constitutes the organic components of soil" (Martin and Hine, 2008).

Invasive species (or nuisance species) – "an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health" (NOAA, 1997).

Leachate – "the liquid that results when water comes in contact with a solid and extracts material, either dissolved or suspended, from the soil" (Dougherty, 1999).

Maintenance dune – "a man-made sand dune generally formed along the seaward side of the natural dunes" (Conti; 2008).

Microorganism – "any organism that can be observed only with the aid of a microscope. Microorganisms include bacteria, viruses, protists (including certain algae) and fungi" (Martin and Hine, 2008).

Morphology – "the study of the form and structure of organisms, especially their external form" (Martin and Hine, 2008).

Organic – "1). relating to or derived from living matter; 2). (of food or farming methods) produced or involving production without the use of chemical fertilizers, pesticides, or other artificial chemicals" (Martin and Hine, 2008).

Planktonic – "(of) the small and microscopic organisms drifting or floating in the sea or fresh water, consisting chiefly of diatoms, protozoans, small crustaceans, and the eggs and larval stages of larger animals" (Martin and Hine, 2008).

Plecostomus - "Suckermouth catfish … in the upper San Marcos River … thought to have been introduced through illegal aquarium releases. Loricariid populations in the upper San Marcos River are composed of the species *Hypostomus plecostomus*, which are characterized by a sail-like dorsal fin (<9 rays), a snout with a smooth margin, fused opercular bones, and a spotted pigment pattern." (Pound, 2011)

Thallus – "the entire cellular plant body without differentiation into stems and leaves" (Cook et al., 1974).

Thermophilic – "describing an organism that lives and grows optimally at extremely high temperatures, typically over 40 C (104 F)" (Martin and Hine, 2008).

Limitations

The limitations of this project included the following:

1) Outdoor settings, in which the compost was managed, were subject to various extraneous factors such as weather and animal activity. These extraneous factors may have impacted the results of the study.
2) The composting process occurred at the Texas State Bobcat Blend compost facility located in the Blackland Prairies subregion approximately 4 miles from the Edwards Plateau subregion. These subregions of Texas are subjected to weather and climatic patterns different from the Gulf Coast Prairies and Marshes subregion to where the results were generalized (Lyndon B. Johnson [LBJ] School of Public Affairs, 1978).

3) Given the difficulty in sargassum identification and subsequent manual separation, the harvested species were studied collectively.
4) Transportation of sargassum limits the amount of biomass for processing. The most efficient composting practices would be ideally managed locally, near where the biomass collection takes place.

Basic Assumptions

Basic assumptions of this project included the following:

1) All measurement devices used to test compost temperatures, moisture and pH provided valid and reliable readings.
2) Additional feedstocks used in the composting process were consistent in content and readily available within the subregions of the Blackland Prairie, Edwards Plateau, and/or Gulf Coast Prairies and Marshes of Texas.

II. REVIEW OF LITERATURE

Various types of brown algae account for approximately 2,000 of the nearly 10,000 different species of seaweed and algae that thrive in the world's oceans and seas. Algae in the genus *Sargassum* of the family Sargassaceae are considered sargassum. Over 150 species of these sargassum species exist in the warmer tropical and temperate oceans and are distributed throughout the world (Abbott and Dawson, 1978; Fritsch, 1965). The two planktonic species that drift onto the shores of the Texas Gulf Coast are *Sargassum fluitans* and *Sargassum natans,* also known collectively as gulfweed, sea holly or sargassum. Adrift in the ocean, the sargassum hosts a planktonic community, which is uniquely "self-supporting ... together with its associated epiphytic species" (Round, 1981; p. 296). Once the sargassum is beached, the ecosystem is terminated, leading to decomposition. In 2011, *Sargassum fluitans* was added to the Global Invasive Species Database, while *Sargassum natans* remains undocumented by the database (ISSG, 2011).

Sargassum species are visually identified by their brown, yellow or gold color and lateral, branch-like morphology connected between tiny, circular bladders. Leaf-like structures form at the base of the organism with the thallus and branch structure (Fritsch, 1965). The unique circular bladders (pneumatocysts) are filled with gas to keep the sargassum afloat allowing their leaves to photosynthesize. While very similar in appearance, *Sargassum fluitans* can be distinguished from *Sargassum natans* by the presence of winged tissue around the bladder stalk and the lack of spines on bladders (Conti, 2008; Coston-Clements et al., 1991; Rogers, 2011).

In Texas, sargassum inflows predictably occupy the shorelines as beach tourism is at its peak. Therefore, the practice of removal of the biomass is considered a beautification effort (Williams, 2010). Opponents to the removal of sargassum claim that these practices negatively affect the elevation of coastal beaches. However, empirical evidence from recent research showed no decrease in beach elevation on shorelines that had the biomass removed (Williams and Feagin, 2010).

The conservationist view on sargassum maintains that the biomass plays a vital role in beach ecosystems and some coastal communities have promoted public education efforts to bring awareness to the positive impact of sargassum. For example, studies found that sargassum biomass works as a natural fertilizer for dune plants and is largely regarded as an asset to stakeholders in the area (Williams, 2010). In Galveston, Texas, posters are displayed along beaches defending the sargassum with statements such as, "Please excuse the seaweed. Mother nature is at work." The Galveston Park Board has engaged the public to examine the seaweed for crabs and shrimp in an effort which has become very popular amongst children and refutes the position that sargassum does not support aquatic wildlife while on the shore (Rice, 2015). As a result of this educational campaign, Galveston has witnessed an increase in Hotel Occupancy Tax revenue over the past two years without the burden of removing sargassum from the shores. The community has since adopted the motto, "rather than fight it, embrace it" (Rice, 2015).

Sargassum Reproduction and Life Cycle

Sargassum fluitans and *Sargassum natans* reproduce asexually by fragmentation. Fragmentation occurs when older sections of the thallus decay and separate from the younger parts. Fragmentation can also occur accidentally, but younger sections of the plant can still mature into fully formed organisms. Neither asexual reproduction via spores, nor sexual reproduction via seeds, are methods of multiplication employed by *Sargassum fluitans* and *Sargassum natans* (Rogers, 2011; Coston-Clements et al., 1991; Weis, 1968).

Like the most pelagic algae species, *Sargassum fluitans* and *Sargassum natans* survive by the circulation of water and organic components and require an environment that supports continual exposure to nutrients and waste removal. The ocean serves as the perfect growth medium providing a dynamic water system which hosts specific chemical properties in the dissolved gases and salts (Fritsch, 1965; Round, 1981). Sargassum species additionally require warmer temperatures and the ability to remain buoyant so that the plant can successfully photosynthesize. Once removed from the ocean and when some or all elements of this system are missing, *Sargassum fluitans* and *Sargassum natans* are rendered non-viable (Abbott and Dawson, 1978; Fritsch, 1965).

The moment sargassum drifts onto a beach, the circulation of water and fresh nutrients is removed, and the entire biomass begins to decay. The coloration shifts toward a murky brown across all sections of the plant, and the biomass will shrink as the gasses and moisture are released from the plant. This process of decay can occur within a few days to a week and can create a noticeable odor (Biel, 2008).

Management Practices of Sargassum

Texas beaches are known to be some of the most pristine, primitive coastlines in the world while the Padre Island National Seashore is the longest stretch of undeveloped barrier island in the country (Biel, 2008). Various organizations including cities, counties, and private owners maintain beaches for their local needs. Basic beach maintenance objectives include: 1) maintaining safe and sanitary conditions, 2) allowing for the use of recreational activities (e.g. sunbathing, camping, wildlife observation and beach combing), 3) monitoring trash removal, 4) protecting wildlife habitats and 5) limiting the amount of sargassum on the coastline (Biel, 2008; Conti, 2008).

Sargassum inflows are commonly removed from high traffic areas that would be used by both humans and wildlife. Methods of removal include the use of front-end loaders and rakers. Collected sargassum can be placed at the edge of the foredune and allowed to revegetate (Conti, 2008; Watson, 2008). The biomass is also used to create "maintenance dunes" on the seaward side of the natural dunes (Conti, 2008). When dune maintenance is exhausted, the seaweed is dumped back into the ocean or diverted to a landfill (Watson, 2008).

The Process of Compost

Composting is the biological process during which microorganisms, such as bacteria and fungi, convert organic matter into a waste-free, soil-like product (Rynk et al., 1992). Composting can and will happen without human intervention, but the process of decomposition can be accelerated compared to that which occurs in natural environments (Pennsylvania State University, 2012).

Composting is maintained within an ideal C:N ratio (carbon:nitrogen ratio) of 30:1 based on atomic weight (Rynk et al., 1992). Simplifying this ratio is necessary to communicate with the public and to create a method with which can be replicated by municipal solid waste sites to manage compostable materials. Therefore, the ratio is related to 3:1 “brown” to “greens.” Carbon (or “browns”) are derived from dried organic matter such as dried leaves, wood chips, cardboard and paper, all of which may contain varying amounts of nitrogen (Rynk et al., 1992). Primary nitrogen (or “greens”) is sourced from organic materials such as food waste, plant clippings, green yard waste, such as grass clippings, or manure (Rynk et al., 1992).

Active aerated composting involves turning and irrigation of the feedstock material to allow for decomposition of these materials to encourage accelerated activity of the micro-organisms which feed on the organic matter. Composting can take as little as 2 weeks to over 1 year to complete, depending on the amount of human intervention, types of feedstocks used and weather conditions (Pennsylvania Department of Environmental Protection [PDEP], 2012). Water is necessary for the health of the microorganisms. Warm internal temperatures are a byproduct of thermophilic organisms initiating a trophic cycle, which will allow for complete decomposition of the organic materials (Darlington, 2007; Dougherty, 1999; Rynk, 1992).

Compost production is essentially a two-stage process: an active stage and a curing stage. The active stage is initiated as soon as the carbon and nitrogen feedstocks are blended together and thoroughly irrigated and gives rise to a bacteria-rich culture. A compost pile should be regularly maintained to encourage airflow in order to allow the microorganisms to consume oxygen. The microorganisms will, in turn, create carbon dioxide (Dougherty, 1999). Temperatures quickly rise to approximately 49 C (120 F) to 60 C (140 F) and should remain at this temperature range for at least 3 weeks to ensure the proper microbial cycles have taken place. Monitoring of the feedstock ratio, moisture content, oxygen content, pH and temperatures must take place during this period of the composting process (Darlington, 2007; Dougherty, 1999; Rynk, 1992). Eventually, the bacteria are consumed by actinomycetes which, in turn, feeds microfauna such as protozoa and nematodes (Lowenfels and Lewis, 2010).

As microbial activity dissipates and internal temperatures lower, macro-decomposers, such as worms, millipedes and other arthropods, continue to break down the biowaste for the remainder of the active stage. Fungal growth continues as the compost matures through all stages. The compost is ready to cure once the feedstocks produce no odor and most of the organic material has been decomposed into a nearly homogenous humus-like material (Dougherty, 1999; p. 15).

The Value of Compost

Compost is used on an agricultural level as well as a horticultural level. Amended into soil, compost boosts soil fertility and improves soil structure while increasing water holding capacity and decreasing runoff (Rynk et al., 1992). Unlike inorganic fertilizers that are commonly limited to release the key macronutrients (nitrogen, phosphorus and potassium), compost is diverse is various micronutrients which will assist in plant health (Dougherty, 1999; Rynk et al., 1992).

Large scale agricultural practices often result in over-tilled soils that remain bare between growing seasons. Lacking any native organic matter, the soil profile weathers away and loses the essential layer of humus and fungus. Amending soil with some form of organic matter is advised to maintain and sustain soil health (Martin et al., 1992). Farmers can use methods to create compost on-site (Rynk et al., 1992). Used on a small scale, such as a backyard garden, compost may reduce the need for inorganic fertilizers in certain situations and allow the home gardener to manage their own organic wastes (Martin et al., 1992).

Sargassum Utilization and Application

A variety of studies have concluded that sargassum can be utilized in a number of ways. Even outside of the agricultural and horticultural scope, sargassum biomass shows potential to be a renewable energy resource via methane production and combustion (Wang et al., 2009). Agricultural applications using the extract of sargassum species have been shown to be an excellent alternative to inorganic fertilizers (Win and Saing, 2008). The simple method of incorporating the sargassum into a compost feedstock have been investigated and have shown no disruptive characteristics despite the high salinity and presence of naturally-occurring tar in the feedstock prior to treatment (Sembera et al., 2018).

Seaweed and its byproducts have been used for centuries to enhance plant growth and productivity, most notably in coastal Asia (Eyras et al., 2008; Win and Saing, 2008). Seaweed algae has physical and chemical attributes useful for maintaining plant health, improving root growth, increasing plant yield, increasing seed germination and enhancing plant resistance to disease (Dougherty, 1999; Eyras et al., 2008; Win and Saing, 2008).

Seaweed extracts and compost promote fungal growth in soil, which then invites the presence of fungal hyphae, which will interact with plant roots to extract water and nutrients previously unavailable to the plant (Lowenfels and Lewis, 2010). Highly valued horticultural and agricultural products like liquid seaweed, seaweed extract, foliar spray and seaweed meal are commonly derived from green algae and require sophisticated techniques to create these products. However, the simple applications of composting sargassum, specifically *Sargassum fluitans* and *Sargassum natans*, have yet to be reviewed (Chennubhotla et al., 1981; Klock-Moore, 2000; Win and Saing, 2008).

III. METHODS

Purpose

The purpose of this project was to evaluate the appropriate proportion of sargassum (*Sargassum fluitans* and *Sargassum natans*) to other compost ingredients to be used in a large-scale composting system.

Objectives

The objectives of this study included, (1) developing a large-scale composting system that utilizes the sargassum biomass with common compostable feedstock material, (2) determining the maximum allowable proportion of dried sargassum to other organic feedstock materials that results in a quality compost product, (3) conceptualizing a management system that can be replicated by the communities that are affected by the problematic species, (4) examining the effect of potentially high levels of salinity from the sargassum on the final product, and (5) evaluating if the composted byproduct is a safe, marketable product for the agricultural and horticultural consumers.

Harvesting of Sargassum

The sargassum was manually harvested from shores of Mustang Island State Park by the Corpus Christi, Texas Parks and Recreation. Sargassum biomass was collected from the shoreline by front-end loader and placed into vehicles for transportation. Supervision of the removal and collections of the sargassum biomass was managed by the City of Corpus Christi Parks and Recreation Department according to the permit established by the U.S. Corps of Engineers and the City of Corpus Christi Beach adaptive management plan. Additional supervision by the Turtle Patrol, overseen by Texas Parks and Wildlife Department, ensured that habitat of the Kemp's ridley sea turtle was not disturbed.

Approximately 80 cubic yards of "fresh" sargassum (sargassum biomass that arrived on the shoreline during the previous 24-h) was harvested from the City of Corpus Christi for this study. Significant dry-down occurred immediately after harvesting, due to natural processes after it was removed from its saline, aquatic environment, altering the biomass to relatively 50 % less volume than the amount originally harvested.

Compost Site

The compost piles were created at the Bobcat Blend Compost Site, located on a 5-acre plot of land within the Muller Farm, owned by Texas State University, San Marcos, TX. Compost site activity occurs on approximately 2.5 acres with the surrounding 2.5 acres dedicated as run-off space with a catchment pond that can withstand a 25-year 24-h flooding event (Sembera et al., 2018). This site is a fully functional large-scale compost facility that utilizes an active-aerated composting process. All compost was produced at this location allowing for extraneous sources of error (e.g. weather) to be constant. Piles were turned every 7 days (when environmental conditions allowed). Turning of the compost ensured that formerly outer exposed surfaces were buried within the pile (Rynk et al. 1992). Regular irrigation of the piles was performed to maintain a moisture reading of approximately 50 %.

Additional Feedstocks

For this research study, university cafeteria food waste was used as the primary nitrogen source. Cafeteria food waste included vegetable, meat, dairy and bread products processed through a grinder, which rendered all of the food waste into an even consistency resembling "ground meat."

Fish waste was used as an additional nitrogen input. Plecostomus (*Hypostomus plecostomus*) and Tilapia (*Oreochromis spp.)* were collected as part of ongoing invasive species removal, contracted by the City of San Marcos, Texas. For this study, 2 yard^3 were incorporated into two of the four recipes.

Wood chips and leaf litter were needed as the primary carbon input and as a bulking agent to promote airflow through the compost piles. Tree and shrub trimmings of various species were processed into a single grind mulch-like material. Leaf litter was also used as a cover for the compost piles to limit the gestation of flies. This material originated from citywide collections and were also from various species of trees and shrubs in San Marcos, Texas. Species of trees and shrubs common to the gulf coast were not specifically included in this material.

Compost Recipes

A previous study included sargassum at an amount of 2 % and did not reflect the extremes of sargassum accumulation that coastal beaches might experience (Sembera et al., 2018). Therefore, the recipes used included the proportions of 25 % and 41.6 % sargassum. A total of 31.8 yard^3 of sargassum was used for the project. Wood chips, used for bulking agent and primary carbon source, was included in the recipes at the proportions of 41.5 % (3.3 yard^3) and 50 % (4 yard^3) and balanced with the percentage of sargassum so that there were equal amounts of wood chips to sargassum or twice the amount of wood chips to sargassum. A total of 43.8 yard^3 of wood chips was used. The remaining proportion of the recipes was allocated to the nitrogen-heavy material, such as food waste, which accounts for 16.6 % (1.4 yard^3) and 25 % (3.3 yard^3) of the recipes. In two of the recipes, fish waste was substituted for 4 % (0.4 yard^3) of food waste. A total of 18 yard^3 of food waste and 2.4 yard^3 of fish waste was used. These proportions were divided into 3 piles per recipe with 8 yard^3 of mixed material per pile. A total of 96 yard^3 of compost material was initially mixed. The four recipes, each totaling 24 yard^3 of material, were created following each of the recipes shown in Table 1.

TABLE 1.

Four compost recipe percentages per pile and total yard^3 of feedstocks including untreated brown algae (*Sargassum* spp.) and other compostable materials.

Recipe Group	**Food Waste**	**Wood Chips**	**Sargassum**	**Fish Waste**	**Total Pile Number and (Amount)**
A	17 %	41.5 %	41.5 %	- -	3
Amount	1.4 yard^3	3.3 yard^3	3.3 yard^3	- -	(8 yards)
B	13 %	41.5 %	41.5 %	4 %	3
Amount	1 yard^3	3.3 yard^3	3.3 yard^3	0.4 yard^3	(8 yards)
C	21 %	50 %	50 %	4 %	3
Amount	1.6	4 yard^3	4 yard^3	0.4 yard^3	(8 yards)
D	25 %	50%	25%	- -	3
Amount	2 yard^3	4 yard^3	4 yard^3	- -	(8 yards)
				Total Pile Number and (Amount)	12 (96 yards)

Compost Pile Monitoring and Processing

The compost produced at the university compost site allowed for extraneous sources of error (e.g. weather) to be constant. Every 5 to 7 days, five readings were taken from sample locations in the pile and averaged to ensure the following ideals were reached: pH between 5.5 and 9.0 (Soil pH Tester, Kel Instruments Co., Wyckoff, NJ), a moisture content between 40 and 65 % (24-inch Moisture Meter, Lincoln Irrigation, Lincoln NE) and temperatures above 62 C (143.6 F) for a minimum of three days (60-inch Compost Thermometer Probe, ReoTemp Instrument Co., San Diego, CA) (Dougherty, 1999). Piles were monitored and remained in the active state until feedstocks showed the following signs of curing: a lack of strong odor, a lowering and stabilization of temperature, material consistency, and a stabilization of pH readings. Once active composting had completed, regular turning and irrigation was halted and piles were allowed to cure for 4 to 8 weeks. On average, the total composting process lasted five months (Dougherty, 1999, Rynk, 1992).

Cured Compost Sampling

Composite samples were obtained by drawing 3.8 liters (1 US Gallon) at 15 locations from 3 depths for a total 170.3 liters (45 US gallons) collected from each of the recipes. This sampling method was performed as instructed by Pennsylvania State Agricultural Analytical Services Laboratory (Pennsylvania State University, 2016). Composite samples were screened through ¼ inch expanded metal sheeting to remove excess bulking agents (Rynk et al., 1992). Approximately 40-50% of the final product comprised these uncomposted materials, which were mostly larger remains of the single grind wood chips. Fish scales were present in the two recipes using fish waste and a significant quantity of beach sand was present in the final screened product of all four recipes.

Compost Quality Tests

From the screened samples, 1 liter (0.26 US gallons) samples of each of the four recipes were pulled and sent to the U.S. Compost Council's Seal of Testing Approval (STA) Program for analysis. Compost was tested for quality variables of pH, soluble salts, percentage of solids, percentage of moisture, percentage of organic matter, total nitrogen, total carbon, carbon to nitrogen ratio and the following macronutrients and micronutrients: phosphorus, potassium, calcium, magnesium, sulfur, sodium, aluminum, iron, manganese, copper and zinc.

Data Collection and Analysis

After compost quality testing was performed, data was entered into a Microsoft Excel^{TM} file (Seattle, WA) and then analyzed using the Statistical Package for the Social Sciences (SPSS$^{®}$) Version 20.0 (Chicago, IL). Statistical analyses included conducting tests for descriptive statistics, frequencies, and t-tests.

IV. RESULTS

Purpose

The purpose of this project was to evaluate the appropriate proportion of sargassum (*Sargassum fluitans* and *Sargassum natans*) to other compost ingredients to be used in a large-scale composting system.

Objectives

The objectives of this study included, (1) developing a large-scale composting system that utilizes the sargassum biomass with common compostable feedstock material, (2) determining the maximum allowable proportion of dried sargassum to other organic feedstock materials that results in a quality compost product, (3) conceptualizing a management system that can be replicated by the communities that are affected by the problematic species, (4) examining the effect of potentially high levels of salinity from the sargassum on the final product, and (5) evaluating if the composted byproduct is a safe, marketable product for the agricultural and horticultural consumers.

Compost Management Results

The first objective of the study was to develop a large-scale composting system that utilized the sargassum biomass with other organic feedstock material. In addressing this objective, the nature of the sargassum required an intuitive understanding so that processing methods could be easily relatable to the waste management industry. To achieve an effective composting process with consistent thermophilic activity, a carbon to nitrogen ratio of 30:1 must be achieved (Rynk, 1992). This ratio can be simplified to 3:1 for carbon-rich feedstocks to nitrogen-rich feedstocks, or “browns” to “greens” (Martin et al., 1992). Carbon-rich feedstocks include organic materials such as leaf litter or wood chips, whereas nitrogen-rich feedstocks include organic materials such as manure or food waste (Rynk, 1992). To determine the role of dried sargassum in regard to nitrogen-rich versus carbon-rich feedstocks, two test recipes were mixed and observed over 7 days for signs of thermophilic activity. To create a quality compost product, thermophilic activity must be evenly maintained, with internal temperatures at 62 C (143.6 F) to 71 C (159.8 F) for a minimum of 3-d during the active stage, to ensure that pathogens and invasive plant seeds are killed. These conditions are maintained through aerobic respiration by thoroughly mixing and irrigating the feedstocks over this time period (Sembera et al., 2018).

The first test recipe incorporated sargassum as a nitrogen-rich feedstock, using a mixture of 25 % sargassum (2 yard^3) to 75 % wood chips (6 yard^3). No thermophilic activity was present, and the mixture was lacking moisture despite regularly controlled irrigation as needed to maintain 50 % moisture content, a recommended moisture level for optimal composting (Rynk, 1992).

The second test recipe used 25 % food waste (2 yard^3), 50 % wood chips (4 yard^3), and 25 % sargassum (2 yard^3), which applies sargassum as a carbon-rich feedstock. Acceptable thermophilic activity was initiated in this recipe, as observed by a recorded temperature range of 54 C (129.2 F) to 62 C (143.6 F) within 24-h of mixing. The second test recipe also retained adequate moisture. It was clear from this pilot test that sargassum acted as a carbon-rich feedstock in this study.

This designation is an important distinction to make as sargassum (sometimes referred to as “brown algae”) is not identified within composting literature and could be otherwise interpreted to share typical characteristics of “seaweed” (or “green algae”), which has a high nitrogen content between 1.2 – 3 % at dry weight (Rynk, 1992). In comparison, food waste has a nitrogen content of 1.9-2.9 % at dry weight (Rynk, 1992). Without a distinction between seaweed and sargassum, an improper application of sargassum could produce an ineffective, unsafe, and unmarketable compost product. For the purposes of this study, this designation determined that sargassum would need to be mixed with a reliable nitrogen-rich feedstock.

The second objective of the study was to determine the maximum allowable proportion of dried sargassum to other organic feedstock materials that resulted in a quality compost product. While it has been determined that sargassum should be handled as a carbon-rich feedstock, there was one other notable characteristic of the feedstock that influenced decisions regarding proportions to use for the study recipes in the compost piles. Due to the high amount of beach sand harvested and contained within the sargassum, the feedstock was prone to compaction that would hinder airflow. This, then, required the sargassum be mixed with another coarse, bulky, and carbon-rich feedstock in order to increase airflow and allow for aerobic respiration while maintaining thermophilic activity. Therefore, woodchips were used as bulking agents to mitigate the hazards associated with anaerobic decomposition.

Recipes A and B were assigned a percentage of sargassum equal to that of the wood chips and included less nitrogen-rich feedstock than a typical 3:1 recipe would allow. This ratio assignment was based on the objective to identify the maximum amount of sargassum that would be acceptable within the piles. Recipes C and D were assigned twice the amount of wood chips to sargassum and included an appropriate percentage of nitrogen-rich feedstocks compared to that which a 3:1 carbon to nitrogen ratio would allow.

Compost Recipes

Each of the 4 recipes were replicated 3 times into piles containing of 8 yd^3 feedstocks per pile. Recipe A included 17 % food waste (1.4 $yard^3$), 41.5% wood chips (3.3 $yard^3$) and 41.5% sargassum (3.3 $yard^3$). Recipe B included 13 % food waste (1 $yard^3$), 41.5 % wood chips (3.3 $yard^3$), 41.5 % sargassum (3.3 $yard^3$) and 4 % fish waste (0.4 $yard^3$). Recipe C included 21 % food waste (1.6 $yard^3$), 50 % wood chips (4 $yard^3$), 25 % sargassum (2 $yard^3$) and 4 % fish waste (0.4 $yard^3$). Recipe D included 25 % food waste (2 $yard^3$), 50 % wood chips (4 $yard^3$) and 25 % sargassum (2 $yard^3$). A total of 12 piles were created, 6 ft in height and 8 ft in diameter, with the total amount of feedstocks equaling 96 $yard^3$.

Compost Pile Creation and Management

The third objective of the study was to conceptualize a management system that can be replicated by the communities that are affected by the problematic species. As the sargassum was expected to act as a carbon-rich feedstock, nitrogen-rich feedstocks that would be unique to the region were identified. The thriving tourist industry in the region had created a reliable source of food waste, which includes an abundance seafood and related wastes from fish processing. The fishing industry of the Texas Gulf Coast generated 97 million pounds of fishery products in 2001 (Adams, 2006). Seafood production generally averages a yield of 40% of the harvest weight, which would mean that 58.2 million pounds of fish waste could have potentially been generated 2001 (Martin, 2012). Further inland, in San Marcos, the same quantities of commercial fish waste are not available. Fortunately, during the study, the San Marcos River was being managed for invasive fish removal. Two species, plecostomus (*Hypostomus plecostomus*) and tilapia (*Oreochromis spp.)*, were collected by Atlas Environmental (San Marcos, TX) as part of an ongoing invasive species removal project. The collected fish waste was divided in half and applied to recipes B and C.

There was also consideration given to the carbon-rich feedstocks that would be commonly available or locally unique to the Texas Gulf Coast. Wood chips generically function in many regions of the United States as a carbon-rich feedstock that also acts as a bulking agent (Rynk, 1992). Leaves of various palm tree species and related feedstocks were investigated for potential incorporation in the study recipes. However, a reliable supply of this feedstock could not be established for a functional proportion within the recipes in the San Marcos, TX region. According to literature, palm leaves and wood chips are similar in terms of C:N ratio and total nitrogen percentage (Rynk, 1992). Furthermore, the abundance of mesquite in the Gulf Coast region, and the frequency which it is cleared for cattle grazing, creates an inordinate amount of wood chips which require disposal or reuse (Mohamed et al, n.d). Therefore, the use of wood chips in the study recipes was representative of the materials available in the Texas Gulf Coast.

The final objectives of the study were to examine the effects of potentially high levels of salinity from the sargassum and to evaluate if the composted byproduct is a safe, marketable product for the agricultural and horticultural consumers. The results for pH, soluble salts, nitrogen, carbon, carbon to nitrogen ratio, bioassay and respirometry tests were within the normal range and all samples met quality compost product standards (Table 2).

Compost Quality and Test Results

The recorded levels of soluble salts indicated that salinity was not an issue when using sargassum as a primary feedstock (Table 1). The analyses identified the final compost product in all recipes as having a soluble salt content that ranged from 2.92 to 4.2 mmhos/cm and was well within the acceptable range of 1.0 to 10.0 mmhos/cm (Pennsylvania State University, 2016). While these levels are safe, there was a notable increase in soluble salt content from a previous study on composting sargassum, which had detected a range of 1.10 to 1.59 mmhos/cm in soluble salts (Sembera et al., 2018). This was likely due to the increased proportions of sargassum biomass incorporated in this study.

During the collection process of the sargassum biomass, the front-end loader inadvertently collects beach sand along with the biomass. The beach sand became mixed with the sargassum during the loading procedure before being transported to the university compost site. The sand was not removed and was incorporated into the compost piles with the biomass. The characteristics of sand are reflected in the results for percentage solids, moisture and organic matter. Results for the percentage of solids for the overall recipe results ranged from 63.6 % to 71.2 %, outside of the recommended levels of 50-60 % (Pennsylvania State University, 2016). The results for the percentage of moisture were below normal values (40-50 %) and ranged from 28.8–36.4 % in all recipes (Table 2). Three of the four samples exhibited lower than normal percentages of organic matter. Noting these qualities, this sargassum-based compost product would provide slightly less organic matter while potentially providing improved drainage and aeration in a “landscape mix” type of application and/or would be suited for clay-heavy soils (Rynk, 1992).

Recipe B, which paired the highest percentage of sargassum with the inclusion of fish waste, showed results of organic matter within the acceptable range (Table 2). This showed that increasing the amounts of nitrogen-rich feedstocks resulted in more desirable qualities in this study when incorporating sargassum into compost in high proportions.

Statistical Comparisons of Recipes

An independent t-test was conducted using SPSS® (version 20.0; IBM Corp., Armonk, NY) to statistically compare compost quality test results from the four recipes. The results of the t-tests showed significant differences in all variables tested. Descriptive statistics were used to differentiate where differences occurred within the recipes on each variable.

Results for Recipe A

Recipe A incorporated the greatest amount of sargassum (~ 41.5 %), which was equal to the percentage of wood chips. The only “green” feedstock in this recipe was food waste (~17 %) and the recipe contained no fish waste (Table 1). Of the four recipes, recipe A produced the least desirable results for a quality compost product. As previously discussed, recipe A exhibited low percentages of organic matter and moisture and a high percentage of solids. While all the results for recipe A were within quality compost standards, the results for total nitrogen (0.54 % as is; 0.84 % dry weight), carbon (8.014 % as is; 12.6 % dry weight), phosphorus (0.2998 % as is; 0.471 % dry weight) and potassium (0.2226 % as is; 0.35 % dry weight) were the lowest of all the recipes. The results of secondary macronutrients (i.e. calcium, magnesium and sulfur) and many of the micronutrients (i.e. sodium, aluminum, iron and zinc) also were the lowest of all recipes. However, results for two other nutrients showed higher concentrations compared to the other recipe results. Recipe A had the greatest amount of manganese (131.19 mg/kg as is; 206.26 mg/kg dry weight) and the second greatest amount of copper (12.142 mg/kg as is; 19.09 mg/kg dry weight) (Table 2).

Results for Recipe B

Recipe B produced the most desirable results of the four recipes. This recipe mirrored the proportions of sargassum (41.5 %) and wood chips (41.5 %) within recipe A. However, the inclusion of fish waste (4 %) thus required a smaller amount of food waste (13 %) compared to recipe A (Table 1). While the percentage of solids and moisture were higher and lower (respectively) when compared to normal ranges of compost quality standards, recipe B was the only recipe in the study to exhibit an organic matter percentage within normal range. Recipe B also had the highest concentrations of total nitrogen (1.019 % as is; 1.56 % dry weight), carbon (15.409 % as is; 23.6 % dry weight), phosphorus (0.5504 % as is; 0.0.842 % dry weight) and potassium (0.3172 % as is; 0.49 % dry weight) of the four recipes. Results for recipe B also show higher concentrations of many secondary nutrients and micronutrients with some notable exceptions. The results for sulfur (0.1515% as is; 0.23% dry weight) and iron (2841.64 mg/kg as is; 4348.22 mg/kg dry weight) are very close to the results of recipe C which had slightly lower sulfur content (0.1450% as is; 0.21% dry weight) and slightly higher iron content (2901.24 mg/kg as is; 4193.09 mg/kg dry weight). Both recipe B and C had higher amounts of these two nutrients, showing a common trait between the two compost recipes that incorporated fish waste. Recipe B had the highest concentration of calcium

(12.1925% as is; 18.66% dry weight) and was significantly higher compared to the results from the other three recipes (Table 2).

Results for Recipe C

Recipe C incorporated a lower percentage of sargassum (~25 %) in contrast to recipes A and B and also included fish waste (4 %) (Table 1). This recipe had percentages of solids, moisture and organic matter just slightly out of normal range. The concentration of total nitrogen (0.805 % as is; 1.16 % dry weight), carbon (10.655 % as is; 15.4 % dry weight), phosphorus (0.5517 % as is; 0.797 % dry weight) and potassium (0.3145 % as is; 0.45 % dry weight) were lower when compared to recipe B but were still within normal ranges to create a quality compost product and had the second best results in regard to macronutrients such as nitrogen, phosphorus and potassium (Table 2).

Results for Recipe D

Recipe D mirrored the amount of wood chips (50 %) and sargassum (25 %) as those used in recipe C. Food waste (25 %) was the only "green" feedstock (Table 1). The results exhibited are well within normal compost quality standards but did not generate as high of percentages of macronutrients as recipes B and C. As is apparently common for these recipes, due to the sand incorporated from the sargassum, percentages of solids were higher than those recommended within compost quality standards while percentages of moisture and organic matter were lower than normal ranges. However, the concentrations of total nitrogen (0.752 % as is; 1.06 % dry weight), carbon (10.457 % as is; 14.7 % dry weight), phosphorus (0.6155 % as is; 0.864 % dry weight) and potassium (0.3051 % as is; 0.43 % dry weight) were at ideal compost quality levels and were higher than those in recipe A (Table 2).

TABLE 2.

Independent t-test comparisons of results of as-is and dry weight compost quality of recipes A, B, C, and D in the study to evaluate the appropriate proportion of brown algae (*Sargassum fluitans* and *Sargassum natans*) to other compost ingredients to be used in a large-scale composting system.

Variable (Units)	**Recipe A Results (As is basis)**	**Recipe A Results (Dry weight basis)**	**Recipe B Results (As is basis)**	**Recipe B Results (Dry weight basis)**	**Recipe C Results (As is basis)**	**Recipe C Results (Dry weight basis)**	**Recipe D Results (As is basis)**	**Recipe D Results (Dry weight basis)**	**Normal Range (TMECC 2002)** ^{z}	**t**	**df**	***P***
pH	7.3	- -	7.3	- -	7.8	- -	7.2	- -	5–8.5	54.653	3	0.000
Soluble Salts (1 : 5 w : w) (mmhos/cm) ^{y}	2.92	- -	4.2	- -	3.87	- -	3.01	- -	1–10	11.052	3	0.002*
Solids (%)	63.6	- -	65.4	- -	69.2	- -	71.2	- -	50–60	38.825	3	0.000
Moisture (%)	36.4	- -	34.6	- -	30.8	- -	28.8	- -	40 – 50	16.987	3	0.000
Organic Matter (%)	13.74	21.6	23.81	36.4	17.94	25.9	15.43	21.7	30–70	8.049	3	0.004*
Total Nitrogen (%)	0.534	0.84	1.019	1.56	0.805	1.16	0.752	1.06	0.5–2.5	7.807	3	0.004*
Carbon (%)	8.014	12.6	15.409	23.6	10.655	15.4	10.457	14.7	<54	7.2	3	0.006*
Carbon : Nitrogen Ratio	15	13.2	15.1	15.1	13.2	13.2	13.9	13.9	< 20	31.33	3	0.000

TABLE 2. Continued

Variable (Units)	**Recipe A Results (As is basis)**	**Recipe A Results (Dry weight basis)**	**Recipe B Results (As is basis)**	**Recipe B Results (Dry weight basis)**	**Recipe C Results (As is basis)**	**Recipe C Results (Dry weight basis)**	**Recipe D Results (As is basis)**	**Recipe D Results (Dry weight basis)**	**Normal Range (TMECC 2002)** ^{z}	**t**	**df**	***P***
Phosphorus (%)	0.2998	0.471	0.5504	0.842	0.5517	0.797	0.6155	0.864	- -	7.22	3	0.005*
Potassium (%)	0.2226	0.35	0.3172	0.49	0.3145	0.45	0.3051	0.43	- -	12.844	3	0.001*
Calcium (%)	7.6428	12.02	12.1925	18.66	9.9456	14.37	8.7006	12.22	- -	9.837	3	0.002*
Magnesium (%)	0.2513	0.4	0.3035	0.46	0.2798	0.4	0.2321	0.33	- -	16.979	3	0.000
Sulfur (%)	0.1127	0.18	0.1515	0.23	0.1450	0.21	0.1294	0.18	- -	15.545	3	0.001*
Sodium (mg/kg) ^{x}	896.97	1410	1729.206	2646	1413.84	2043	1146.58	1610	- -	7.257	3	0.000
Aluminum (mg/kg) ^{x}	2463.02	3872.52	3631.21	5556.41	311.2	4496.53	3309.16	4646.16	- -	12.698	3	0.001*
Iron (mg/kg) ^{x}	2501.11	3932.41	2841.64	4348.22	2901.24	4193.09	2971.81	4172.5	- -	26.860	3	0.000

TABLE 2. Continued

Variable (Units)	**Recipe A Results (As is basis)**	**Recipe A Results (Dry weight basis)**	**Recipe B Results (As is basis)**	**Recipe B Results (Dry weight basis)**	**Recipe C Results (As is basis)**	**Recipe C Results (Dry weight basis)**	**Recipe D Results (As is basis)**	**Recipe D Results (Dry weight basis)**	**Normal Range (TMECC 2002)** [z]	**t**	**df**	***P***
Manganese (mg/kg) [x]	131.19	206.26	101.88	155.9	129.98	187.86	103.6	145.46	- -	14.493	3	0.001*
Copper (mg/kg) [x]	12.142	19.09	10.284	15.74	12.315	17.8	11.955	16.78	- -	24.884	3	0.000
Zinc	31.17	49.01	40.05	61.29	41.51	59.99	42.11	59.13	- -	15.179	3	0.001*
Bioassay: Emergence (% of control)	100	- -	100	- -	100	- -	100	- -	> 90 (very mature)	- -	- -	- -
Bioassay: Seedling Vigor (%)	100	- -	100	- -	100	- -	100	- -	> 95 (very mature)	- -	- -	- -

[z] U.S. Composting Council (USCC), 2002. Test methods for the examination of composting and composts. Composting Council Research and Education Foundation, Holbrook, New York. CDROM Only.

[y] 1 mmho/cm = 1 $dS \cdot m^{-1}$

[x] 1 $mg \cdot kg^{-1}$ = 1 ppm

* statistically significant at P<0.05

Discussion of Results

As salt content, pH and nutrients levels are concerned, all samples of the four recipes show results that were within quality compost standards (Table 2). Noting the low percentage of organic matter in recipe A, as compared to B or C, it is apparent that sargassum needs to be balanced with appropriate nitrogen-supplying feedstocks, such as food waste and fish waste. Fish waste improved the quality of compost, as was observed in comparisons of recipe A to recipe B. However, increasing the proportion of other nitrogen-rich feedstocks can also improve the quality of a sargassum-heavy compost recipe, as shown in recipe D when compared to recipe A. Despite these differences, all compost recipes exhibited an appropriate pH and successful bioassay results. Although statistical analysis showed a significant difference in the results of pH values between the four recipes, there is little distinction in the range of pH values in regard to horticultural practices. The range of 7.2 to 7.8 is a perfectly acceptable pH range for a neutral compost product (Rynk, 1992). Soluble salts, one major concern in the processing of sargassum, were also well within normal range for all recipes. It should be noted that the soluble salt content was higher when compared to values recorded from a previous study which incorporated a much lower proportion of sargassum (Sembera et al., 2018).

While it may appear that recipe B and recipe C, the two recipes that incorporated fish waste, achieved the most desirable qualities, there are some notable results that allow the other recipes to stand out. As previously discussed, recipe A had the highest amount of manganese (131.19 mg/kg as is; 206.26 mg/kg dry weight), which is an important secondary nutrient for plant health, and the second highest amount of copper (12.14 mg/kg as is; 19.09 mg/kg dry weight), an important micronutrient. In comparison, recipe C had the second highest amount of manganese (129.98 mg/kg as is; 187.86 mg/kg dry weight) and the highest amount of copper (12.315 mg/kg as is; 17.8 mg/kg dry weight). These results are the most curious as recipes A and C have little in common of the four recipes, with the exception to the similar proportions of food waste. Recipe A used 17 %

food waste while recipe C used 21 % food waste. Recipe B used much less food waste at 13 % and recipe D used much more at 25 %.

V. DISCUSSION

Purpose

The purpose of this project was to evaluate the appropriate proportion of sargassum (*Sargassum fluitans* and *Sargassum natans*) to other compost ingredients to be used in a large-scale composting system.

Objectives

The objectives of this study included, (1) developing a large-scale composting system that utilizes the sargassum biomass with common compostable feedstock material, (2) determining the maximum allowable proportion of dried sargassum to other organic feedstock materials that results in a quality compost product, (3) conceptualizing a management system that can be replicated by the communities that are affected by the problematic species, (4) examining the effect of potentially high levels of salinity from the sargassum on the final product, and (5) evaluating if the composted byproduct is a safe, marketable product for the agricultural and horticultural consumers.

Compost Management Results

A total of 12 piles approximately 1.8 m in height and 3 m in length were created. Each pile contained 8 cubic yards of feedstocks including sargassum (*Sargassum fluitans* and *Sargassum natans*), food waste from cafeterias at Texas State University and wood chips. Two of the piles included fish waste derived from two species that are invasive to the San Marcos River, plecostomus (*Hypostomus plecostomus*) and tilapia (*Oreochromis spp.)*. A total of approximately 96 cubic yards of feedstocks were used. Approximately 31.8 yard^3 of the sargassum was harvested for the compost management component of this study. A pilot test of recipe ratios determined the appropriate ratios to maintain proper C:N ratios and achieve temperatures required for adequate decomposition (Rynk, 1992). Following the decomposition of materials during the composting process, approximately 50 yard^3 of cured compost were created.

Compost Quality and Testing Results

Quality testing was conducted by the U.S. Composting Council's Seal of Testing Approval (STA) Program at Pennsylvania State University to evaluate whether treatment methods on piles rendered the final compost product safe and valuable. Quality tests conducted on the representative samples identified the final compost products to have quality levels considered safe and desirable by the composting and horticultural industries. The final compost products created did not include salinity levels potentially harmful to plants and can be used to promote plant growth and health (Pennsylvania State University, 2016).

Results from the STA tests concluded that pH and nutrient levels were well within an acceptable range for quality compost. All four recipe samples exhibited low levels of organic matter and moisture along with high levels of solids which can be attributed to the presence of beach sand in the final product. While some of these results were just barely out of the normal range, recipe B showed improved organic matter content within the normal range. This was due to the addition of fish waste, which is known to have higher nitrogen and moisture as compared to food waste.

According to literature, specific manures, such as cattle or poultry manure, could potentially achieve similar results, as these manures contain equally high amounts of nitrogen and moisture (Rynk, 1992). This would potentially make the process of composting sargassum amenable when fish waste is not available as a feedstock. Such manures could be added in similar proportions as the fish waste to provide the additional organic matter to offset the presence of sand (Rynk, 1992). However, fish waste could prove to be a more accessible feedstock to obtain by communities along the Texas Gulf Coast, as a result of seafood processing and restaurant waste, and would also contribute to increased levels of other macronutrients such as potassium and phosphorus (Dougherty, 1999; Rynk, 1992).

Management Implications

There remains a concern for coastal ecology. While this study provided evidence that sargassum is a perfectly suitable feedstock for composting process and can be incorporated into piles at high proportions, it stresses the point that coastal flora benefits greatly from the presence of sargassum (Rice, 2015). Management practices should exercise every effort to incorporate the sargassum biomass into the beach either by building foredunes or raking in the biomass into the shore. If there is too much biomass to manage in this way, then composting can be employed to appropriately decompose the biomass in large amounts and then be used as an agricultural or horticultural product. The transportation of the sargassum biomass should be confined to local distances. Not only does this reduce transportation and fuel costs, but also creates an industry opportunity to work with coastal communities towards achieving a Zero Waste management plan.

Recommendations for Future Studies

Future studies should include a marketing analysis of the compost product as a boutique compost or soil blend and to refine the recipes to achieve the most beneficial results. A meta-analysis should be conducted to compare the other blends of compost created at Bobcat Blend. Additionally, as recommended in a previous study, a cost-benefit analysis of the removal of sargassum would be instructive for the communities impacted by sargassum. A comparison between the various disposal methods, composting, landfilling, or dune maintenance, would enhance these communities' ecological approach to beach maintenance (Sembera et al., 2018). Future studies could also strive to collect all recipe materials from the region where sargassum is collected and perhaps perform the composting process locally. This would not only eliminate many limitations for a study, but also expand the development of composting methods in the region concerned.

LITERATURE CITED

Abbott, I.A. and Dawson, E.Y. (1978). How to know the seaweeds. (2nd ed.). Dubuque, Iowa: Wm. C. Brown Co. Publishers.

Adams, C. M., Hernandez, E., and Cato, J. C. (2004). The economic significance of the Gulf of Mexico related to population, income, employment, minerals, fisheries and shipping. *Ocean And Coastal Management*, *47* (Integrated Coastal Management in the Gulf of Mexico Large Marine Ecosystem).

Biel, M. (2008). Beach maintenance at the Padre Island National Seashore. Symposium conducted at the meeting of the Sargassum Symposium, Corpus Christi, TX. http://www.sargassum.org/Proceedings2008/Proceedings.

Chennubholta, V.S.K., Kaliaperumal, N. and Kalimuthu, S. (1981). Seaweed recipes and other practical uses of seaweeds. Seafood Export Journal, 13: 9-16.

Conti, R. (2008). Sargassum Beach maintenance in Nueces County, 2007, effects on beach morphology. Symposium conducted at the meeting of the Sargassum Symposium, Corpus Christi, TX. http://www.sargassum.org/Proceedings2008/Proceedings.

Cook, C.D.K., Gut, B.J., Rix, E.M., Schneller, J. and Seitz, M. (1974). Water plants of the world: a manual for the identification of the genera of freshwater macrophytes. The Hague: Dr. W. Junk, Publishers.

Coston-Clements, L., Settle, L.R., Hoss, D. E. and Cross, F.A. (1991). Utilization of the Sargassum habitat by marine invertebrates and vertebrates - a review. National Oceanic and Atmospheric Administration (NOAA) Technical Memorandum NMFS-SEFSC-296.

Darlington, W. (2007). Compost - a guide for evaluating and using compost materials as soil amendments. Soil and Plant Laboratory, Inc.: Anaheim, CA. Form 415.

Dougherty, M. (ed). (1999). Field guide to on-farm composting. New York, NY: Natural Resource, Agriculture and Engineering Service.

Evolutionary Ecology, E. E., Vedor, M., Righton, D., Metcalfe, J., Westerberg, H., Sjoberg, N., and ... Aarestrup, K. (2016). Empirical observations of the spawning migration of European eels: The long and dangerous road to the Sargasso Sea. Science Advances, 2(10).

Eyras, M. C., Defossé, G. E., and Dellatorre, F. (2008). Seaweed Compost as an Amendment for Horticultural Soils in Patagonia, Argentina. Compost Science and Utilization, 16(2), 119-124.

Furniss, R. (2009). Evaluating the use of municipal solid waste as a feedstock for in-vessel composting.

Fritsch, F.E. (1965). The structure and reproduction of the algae, II. Cambridge: University Press.

Genthe, H. (1998). The Sargasso Sea. Smithsonian, 29(8), 82.

Illera-Vives, M., Seoane Labandeira, S., Brito, L., López-Fabal, A., and López-Mosquera, M. (2015). Evaluation of compost from seaweed and fish waste as a fertilizer for horticultural use. Scientia Horticulturae, 186101-107.

Invasive Species Specialist Group (ISSG). (2011). Global Invasive Species Database. http://www.issg.org.

Klock-Moore, K.A. (2000). Comparison of salvia growth in seaweed compost and biosolids compost. Compost Science and Utilization: 6: 24-28.

Koschnick, T. J., W. T. Haller and A. W. Chen. 2004. Carfentrazone-ethyl pond dissipation and efficacy of floating plants. Journal of Plant Aquatic Management 42:103-108.

Lowenfels, J., and Lewis, W. (2010). *Teaming with microbes : the organic gardener's guide to the soil food web / Jeff Lowenfels and Wayne Lewis; foreword by Elaine Ingham*. Portland, Or. : Timber Press, 2010.

Lyndon B. Johnson School of Public Affairs. Natural Heritage Policy Research, P. (1978). Preserving Texas' natural heritage: a report / by the Natural Heritage Policy Research Project, Lyndon B. Johnson School of Public Affairs, the University of Texas at Austin. In, Lyndon B. Johnson School of Public Affairs policy research project report; no. 31 [Austin] : The School, 1978.

Martin, D. L., Gershuny, G., and Minnich, J. (1992). *The Rodale book of composting / Deborah L. Martin and Grace Gershuny, editors*. Emmaus, Pa. : Rodale Press ; [New York] : St. Martin's Press [distributor], c1992.

Martin, E. A., and Hine, R. (2008). *A dictionary of biology*. Oxford ; New York : Oxford University Press, 2008.

Martin, R. (2012). *A History of the Seafood Industry*. Wiley-Blackwell.

Mohamed, A. H., Holechek, J. L., Bailey, D. W., Campbell, C. L., and DeMers, M. N. (n.d). Mesquite encroachment impact on southern New Mexico rangelands: remote sensing and geographic information systems approach. *Journal Of Applied Remote Sensing*, *5*.

NOAA. (1997). Exotic, invasive, alien, nonindigenous, or nuisance species: no matter what you call them, they're a growing problem. http://www.glerl.noaa.gov/pubs/brochures/invasive/ansprimer.pdf.

Pennsylvania State University. (2016). Compost analysis: sampling and mailing procedure. University Park, PA: Pennsylvania State Agricultural Analytical Services Laboratory.

Pound, K., Nowlin, W., Huffman, D., and Bonner, T. (2011). Trophic ecology of a nonnative population of suckermouth catfish (Hypostomus plecostomus) in a central Texas spring-fed stream. Environmental Biology Of Fishes, 90(3), 277-285.

Rice, H. (2015). Galveston may be spared from unsightly seaweed this season. Houston Chronicle. http://www.houstonchronicle.com/news/houston-texas/houston/article/Gulf-Coast-may-be-spared-from-unsightly-seaweed-6174685.php.

Rynk, R. (1992). On-farm composting handbook / editor: Robert Rynk ; by Robert Rynk ... [et al.]. In Ithaca, N.Y. : Northeast Regional Agricultural Engineering Service, 1992.

Rogers, K. (Ed.). (2011). Fungi, algae and protists. New York, NY: Britannica Educational Publishing.

Round, F.E. (1981). The ecology of algae. New York, NY: Cambridge University Press.

Sembera, J., Meier, E., and Waliczek, T. (2018). Composting as an alternative management strategy for sargassum drifts on coastlines. *Horttechnology*, *28*(1), 80-84.

Soanes, C. (Ed.). (2002). Oxford's English dictionary. New York, NY: Oxford University Press.

Stoffella, P.J. and B.A. Kahn. (2001). Compost Utilization in Horticultural Cropping Systems. Lewis Publishers, Florida.

TMECC. 2002. Test Methods for the Examination of Composting and Composts. Composting Council Research and Education Foundation. Holbrook, New York. CDROM Only.

Wang, S., Jiang, X.M., Han, X.X., and Liu, J.G. (2009). Combustion characteristics of seaweed biomass. 1. combustion characteristics of Enteromorpha clathrata and Sargassum natans. Energy Fuels, 23: 5173-5178.

Walker, P., Waliczek, T., and Williams, D. (2006). An analysis of the horticulture industry as a potential value-added market for compost. Compost Science and Utilization, 14(1), 23-31.

Watson, R. (2008). Good and bad beach maintenance on an eroding shoreline. Symposium conducted at the meeting of the Sargassum Symposium, Corpus Christi, TX. http://www.sargassum.org/Proceedings2008/Proceedings.

Weis, J.S. (1968). Fauna associated with pelagic Sargassum in the Gulf Stream. American Midland Naturalist, 80(2): 554-558.

Weise, B.R. and White, W.A. (1980). Padre Island National Seashore: a guide to the geology, natural environments, and history of a Texas barrier island. Austin, TX: Bureau of Economic Geology, University of Texas at Austin.

Williams, A., and Feagin, R. (2010). Sargassum as a natural solution to enhance dune plant growth. Environmental Management, 46(5), 738-747.

Williams, A. M. (2010). Environmental Processes, Social Perspectives and Economic Valuations of the Coast (Doctoral dissertation, Texas A&M University).

Win, L.L. and Saing, K.M. (2008). Effectiveness of Myanmar brown seaweed (Sargassum spp.) extract as organic fertilizer in pot trial of rice. GMSARN International Conference on Sustainable Development: Issues and Prospects for the GMS: 1-4.