Evaluating Compost Feedstock Amendments and Decomposition Dynamics with European Green Crabs

by

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I hereby dedicate this thesis to my mother, Sabina, and sister Laaron for supporting and cheering me up when I am down, no matter how far they were.

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LIST OF ABBREVIATIONS USED

AIS – Aquatic Invasive Species

ANS – Aquatic Nuisance Species

BD – Bulk Density

DOC – Dissolved Organic Carbon

DON – Dissolved Organic Nitrogen

EC – Electrical Conductivity

EPA – Environmental Protection Agency

FAO – Food and Agricultural Organisation

GC – Green Crabs

GI – Germination Index

IPCC – Intergovernmental Panel on Climate Change

MC – Moisture Content

NRAES - Natural Resource, Agriculture, and Engineering Service

OM – Organic Matter

SD – Sawdust

SW – Straw

TN – Total Nitrogen

TOC – Total Organic Carbon

WC – Water Retention Capacity

Ca – Calcium

Mg – Magnesium

K – Potassium

P – Phosphorus

Na – Sodium

S – Sulphur

ABSTRACT

The European Green Crab (*Carcinus maenas)* is an invasive species affecting the Atlantic provinces. Two studies were carried out to evaluate different feedstocks for composting with green crab (GC) biomass, including a sawdust (SD)-based carbon source with a mass ratio of 1:2 and a straw (SW)-based carbon source with a mass ratio of 1:4 while using a C: N ratio target of 25:1. Both studies were carried out using a prototype double-layered stainless steel in-vessel composter with a total capacity of 150m^3. Decomposition of carbon and nitrogen, and changes in moisture content and temperature were monitored periodically over the studies. The respiration rate of aerobic microorganisms was measured on samples at different composting stages using a respirometry test. The SD and SW based composts were combined with a potting media at different percentages (0, 10, 20, 50) and planted with Garden cress. The compost mixtures' effects on Garden Cress growth (*Lepidium sativum*), in a fully randomized greenhouse study, were monitored over several weeks. The Garden cress's height and germination index improved with the addition of SD+GC based-compost but not with SW+GC based-compost due to the crusting top layer of the potting media. The positive influence of the soil properties with the GC compost suggested that the TOC and TN availability in SD+GC compost brought a sound output on plant growth. It helped to recover the nutrient efficiency, making it a suitable method to redefine the nutrient cycles.

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CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

The invasion of marine and estuarine aquatic species had created significant impacts on the environment (Carlton 1989; Carlton and Geller, 1993). Early studies from the 1980s did not document details related to the spreading rate, transmission sources, and the frequency distribution rate of this invasion (Mooney and Drake, 1986; Drake et al., 1989). Carlton et al., (1990) inspected the adverse effects of marine invasion on the Scotian Shelf, using the long-term assessment data documented by Fisheries and Oceans, Canada, and further detected that the damages on natural habitat variations were identified due to the invasions. From the invasion data results, documented since 1990, only three predominant biological marine tunicate invasions (Violet, Golden Star, and Vase Tunicates) were listed among the high Aquatic Invasion Species (AIS), Later in the 1990s, the European Green Crabs were identified to be one among the marine species. The control ratio of the European green crabs was lower in the freshwater and land habitats (Grosholz and Ruiz, 1995) and hence listed under the AIS. Among these invasive species, European Green Crabs (*Carcinus maenas)* severely impacted all mollusc species within the range and damaging valuable habitat.

The European Green crab species are identified as one of the top hundred highly invasive species globally (Lowe et al., 2000). They are identified as voracious predators, which attack significantly smaller species like fish, oysters, crabs, and eelgrass (Klassen and Locke, 2007). The fishery and mussels' aquaculture industries have been the critical vectors for the invasion of exotic marine species from various ocean parts across the world (Shelton and Rothbard, 2006). These industries played an important role in

importing exotic species into international waters, thus initiating habitat destruction (Thomas et l., 2008). Increased connectivity within channels and cities for trading purposes, paved the way for the crabs to enter the different habitations and destroy them due to their widespread population (Carlton 1989, 1999). During the export trade of aquatic species, the Green Crabs migrated across oceans through ballast water in ships and had colonized various parts of North America (Klassen and Locke, 2007).

The spread of invasive species is a critical global issue to the environment's biodiversity (Mooney and Hobbs, 2000). Climate change influenced the rapid growth of invasive species by modifying the temperature, biogeochemistry, and salinity of the ocean, resulting in the rise of the extinction rate of native species. The broader thermal repertoire of land and ocean had a critical aspect in the rising number of new invasive species by adapting themselves to the environment over the decade (IPCC 2007).

Since the population proliferation of the green crabs has led to the increase in damages to the aquatic environment, different methodologies have been considered to minimize the effects caused by the green crabs. The green crab shells have been identified to be rich in chitin, a carbonaceous material, which could be utilized in the application of various fields, one of which being composting. The overall objective of this research is to examine the beneficial aspects of green crab in compost material.

1.2 RESEARCH OBJECTIVES

The specific objectives of this research were to:

1. Evaluate the difference in composting green crab biomass using sawdust and straw-based feedstocks during in-vessel composting.

2. Monitor the carbon and nitrogen decomposition dynamics of green crab biomass under in-vessel composting conditions with sawdust and straw-based feedstocks.
3. Determine plant responses using green crab compost developed from either sawdust or straw-based feedstocks.

1.3 THESIS STRUCTURE

This thesis contains the following five chapters to investigate these objectives:

- **Chapter 1** Introduction
- **Chapter 2** Literature review and Background
- **Chapter 3** Methods and Materials
- **Chapter 4** Results and Discussion
- **Chapter 5** Conclusion and Recommendations for future research.

CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

Marine ecosystems had significantly been affected by the invasion of green crabs because of their incredible appetite for soft-shell clams, quahogs, mussels, oysters, and crustaceans (Williams and Floyd, 2004). The green crabs had widely affected and destroyed eelgrass cultivation in the marine environment, which were the habitats to small fishes, krill, and algae (McKenzie et al., 2007). The aquatic organism trade (lobster, shrimp, etc.), being one of the highest trading areas in Nova Scotia's province, decreased the marine organisms due to the green crab invasion, affected the economic market value (Fisheries and Oceans Canada, 2019). The clam population around the National Park of Kejimkujik was also affected. The calcium carbonate from the marine organisms had decomposed, leading to water pollution, thus increasing the water's alkalinity by excessive carbonate addition (Emma 2019). Similarly, the green crabs also compete with various other crustaceans like clams, smaller crabs, and eelgrass habitats for nutrient resources and habitat (Emma 2019).

The growth of green crabs had created a significant impact only because its higher dependency on food upon the other amphibians, small size, increased from 59% to 82% between 2009 to 2013 (Hannah et al., 2016). Evidence proved that the green crabs had been affecting the other species. Hence, commercial crab fishing was introduced among the locals and was encouraged by providing a harvesting license, which was later extended on a larger scale. (Brady 2018). Brady conducted a study on crab fishing from June to September over the years of 2008 to 2016. It had shown a remarkable decline in the green crab population over the years, reducing the chances of reproduction over the

selected area (Brady 2018). The green crabs had been identified to be salinity-resistant organisms that can withstand extreme temperatures. To control the spread of these species, they were introduced into freshwater. The survival rate of green crabs was low in freshwater (Emma 2019).

In Kejimkujik National Park, these crabs, after being removed from freshwater, were dumped offshore as debris, which had been of great concern to Environmental safety (Greg and Andrea, 2007). An efficient way to control the population explosion of the green crabs in water was to utilize them for beneficial purposes, hence providing an environmental stabilization to prevent its predator capacity on smaller organisms (Ally 2019). The European green crab's shell, rich in chitin, could enrich soil fertility and manage some disease agents affecting plant growth. The chitin content was utilized for various applications; in agriculture, medicine, and cosmetics (Hirano 1996). The chitin digested by the addition of carbonaceous material in composting over a fixed period (Sébastien 1997) was added to the soil to improve the fertility and increase the plants' immunity to fight the diseases (Hirano 1996).

2.2 GREEN CRABS

The European green crab (*Carcinus maenas*), a non-native invasive species to North America, was found in the north-western Atlantic Ocean since the nineteenth century and was around the Chedabucto Bay during 1985 (Audet et al., 2003). The green crab had been widely spread in North America because of its ability to withstand harsh weather, water temperatures, salinity and to live in many types of marine habitats. The reproduction happened extensively from August to November (Klassen and Locke, 2007). The green crab also competed with other marine species for nutrient resources and habitat

(Rossong et al., 2006) and damaged the ecosystem by digging sediment in the eelgrass beds and eroding the soil region around the root system (Davis et al., 1998).

Around Atlantic provinces, the green crabs were first found in the 1950s in the eastern island of New Brunswick and extended to the southern part of Halifax in 1952. Since then, the population kept on growing, the crabs made their next migration spot to Cape Breton and further to the Gulf of St. Lawrence from 1991 to 1995. Subsequently, they had extended all over Newfoundland, and Prince Edward Island is from 2004 and 2007 (Klassen and Locke, 2007).

The Green Crabs had a life span of 4 to 7 years, growing up to a maximum carapace width of 9 to 10cms which ranges from benthic adults to planktonic larvae (Klassen and Locke, 2007). They were classified as euthermic and euryhaline in nature, where euthermic states the ability of the crabs to survive in extreme temperatures ranging between -1ºC and 35ºC and euryhaline explains the physical characteristics of crab which survives up to a depth of 6m having the salinity range of 4 to 52% in low oxygen content surfaces with very high resistance in the tidal environment (Davis et al., 1998).

2.2.1. INVASION HISTORY

2.2.1.1. Entry into the Atlantic Environment

The first migration species was discovered on the east coast of North America in Massachusetts in 1817 (Grosholz and Ruiz, 1996). Native to the European subcontinent, the crabs were found south of Virginia, and by 2007, as far north of Placentia Bay, Newfoundland, Canada (Kiley et al., 2017). First found in San Francisco Bay in 1989, the

European green crab had spread throughout the west coast extending over 1000km, reaching as far north of British Columbia, Canada (Jamieson 2000).

The rapidly increasing European Green Crab species had always been a nuisance to the aquatic environment. After various analyses, based on the statistical data collected, the Federal ANS Task Force had concluded that the species was an Aquatic Nuisance Species (ANS). The damages caused by the ANS ended up having a substantial economic depletion, requiring eelgrass replantation in the Kejimkujik National Park to compensate for the losses incurred (Sabrina 2007). Around 1998, the Washington State Government passed a law that made it illegal to transport or cultivate European Green Crabs for any purpose (Debora, H., 2001). It was declared as a prohibited species in Alaska, Oregon, and California. To control the preying activity of crabs, commercial fishing, including trapping, fishing, and caging, was encouraged further to manufacture chitin and its applications (Behrens 2001).

In 2011, highly increased species were observed and detected by Fisheries and Oceans, Canada. Based on the recent records, they were identified at least 100 miles north of Vancouver Island, within two embankments along the coastal mainland of Queen Charlotte Sound, thus increasing the population from the southern province towards the north (Canadian Science Advisory Report, 2011).

2.2.1.2. Recent Invasion History

The Kejimkujik National Park is a national historical site covering 426km^2 of the southwestern province of Nova Scotia, with inland freshwater habitat including lakes and rivers constituting approximately 404km^2. These habitats house various mammals, birds,

and amphibians but had also been widely affected by green crabs (Fisheries and Oceans Canada, 2019).

Variations in climatic change and invasions were significantly affected by European green crabs because of their incredible appetite for mussels, molluscs, and crustaceans around the Atlantic province. They also killed fishes, shrimps, mussels, and varieties of oysters in the environment (Williams and Floyd, 2004). The eelgrass cultivation had been widely affected by the crabs by uprooting them and digging holes for their habitat (Matheson 2016).

Researchers recently worked using the green crab biomass for commercial activities since the Atlantic Canadian coastlines were affected by their invasions (Figure 2.1). The researchers focused on chitin extracted from biomass to generate biodegradable polymers (Denise 2002), throughout the gathered provinces. Specialized chitin-based growing media had shown a reduction in soil pathogen levels leading to safer and improved vegetable production, which was identified under research (Denise 2002). Similarly, the extracted chitin from crabs had a wide range of applications in Biomedicine, Pharmaceuticals, Food, Agriculture, and Personal Care Products (Hirano 1996).

The European green crabs also had shells rich in Calcium that can be used to neutralize acidic soils in Atlantic Canada (Gordon 1993). This project now examines products generated from green crabs through an in-vessel composting system that plants could utilize for soil improvement, and thereby gradually reducing invasive species' effects through repeated harvest and biomass.

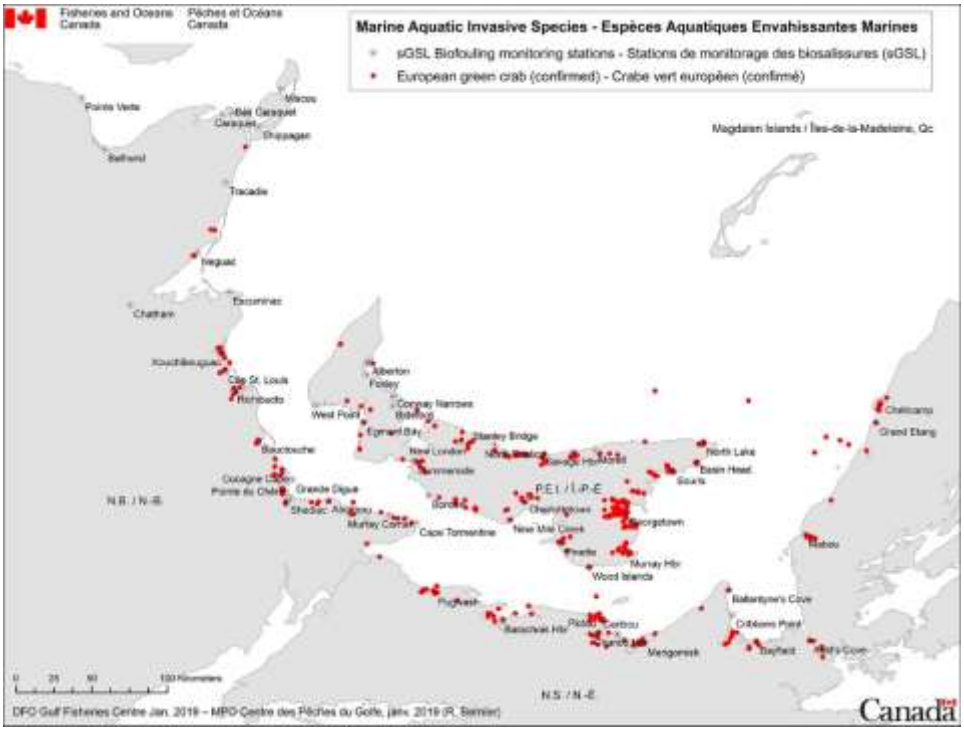

Figure 2.1: The most affected landscape due to green crab invasions based on the datum received from Fisheries and Oceans, Canada for the decade 2006 to 2017 (Fisheries and Oceans Canada, 2019)

2.2.2. EFFECTS OF INVASION

2.2.2.1. Economic Depletion due to Invasion of Green crabs

The history of invasion and the damages incurred to the marine ecosystem by the green crabs and their population explosion have affected the economy lately. Suppose the European green crab's multiplication problem goes unregulated, the local economy and the ecosystem will likely see long-term adverse effects such as loss of biodiversity and nutrients in the marine ecosystem and revenue loss in the shellfish economy (Grosholz, 2001). The total estimated loss due to the predatory activities of green crabs for reconstructing the marshland habitation ranged from $18.6 to $22.6 million per year (Fisheries Research, Monitoring, and Conservation Report, 2018). The West Coast Fisheries had been facing losses of almost $0.84 to $1.14 million annually due to this

invasive species (Lovell et al., 2007). Over the years from 2007 to 2010, the United States Government had spent approximately $315,000 on public expenditure for green crab management (Grosholz et al., 1996). The total estimated loss associated with the recreational and residential fishery user was $3.8 million per year (Hayes et al., 1992) (Table 2.1). The estimated mean annual cost to improve the shell fishing environment and maintain the safe water quality levels had ranged from $37.2 to $71.1 million annually (Hayes et al., 1992). These expenditures on green crab management comparisons raised the question of whether the control programs nullify the losses. Unfortunately, it is impossible to conclude utilizing the understanding of the crab invasions' effectiveness and the effects caused by them on the environment (EPA, 2018).

Table 2.1: Economical Losses incurring every year for the invasion disturbances caused by the green crabs (Source: Lovell, American Agricultural Economic Association Annual Report, 2007)

Departments Associated	Losses covered per year
East Coast and Eelgrass restoration facility, 2019	$18.6 to $22.6 million
West Coast and the Department of Fisheries, 2018	$0.84 to $1.14 million
US department of Coastal Development, 2018	$315,000
Welfare Loss with East Coast Recreational Users annually	$3.8 million

2.2.3. IMPACTS OF GREEN CRAB INVASION

2.2.3.1. Eel Grass Habitat Destruction

Eelgrasses serve as nursery habitats for young fish and invertebrates such as crabs, sea stars, and crustaceans. The peat marshes of the eelgrass habitats had been eroded due to the green crabs' digging activities (Joseph et al., 2012) (Figure 2.2). The eroded samples were magnified and scanned with the CT scanner, which showed that the green crabs' action had destroyed two-thirds of the eelgrass lands. Parks Canada (2018) took the

initiative to transplant the eelgrass because the recovery of the old plantation site was impossible as the uprooted eelgrass led to soil strength issues. The experimentation conducted on the sites proved that damages caused by the green crabs reduced the soil stability, so soil remediation activities were carried out before the replantation of eelgrass in the same grounds (Venitia 2018).

Figure 2.2: Wells Nature Estuarine Research Reserve showing the soil erosion due to green crab invasion (Wells Natural Estuarine Research Reserve, 20 April 2016)

2.2.3.2. Effects of Oyster Population on the Economy

Nova Scotia's province was well known for its abundance of bays filled with cold, nutrient-rich waters and a climate that allows the province to harvest over 8 million pounds of oysters every year (roughly $13 million in revenue) (Fisheries and Oceans Canada). The oyster fisheries were classified into either wild fishing or farming. The first method involved deep end fishing, collected using tongs from the deep ocean and grown under natural conditions. The second most lucrative method is farming, where they were grown in waters, under extreme conditions in the cages made up of galvanized steel,

emptied every three weeks (Connie 2015). The oysters ranging from green to grey were commercially available for exporting and regular purposes. In contrast, the green crabs act as predators and capture the biomass in the oysters and damage the shells (Figure 2.3). The damage makes it unstable for exporting or for edible purposes, making the broken shells thrown as landfills a rising environmental concern (Connie 2015).

Figure 2.3: Green Crab feeding upon a mature oyster (Science Source; 4 December 2019)

2.2.4. GREEN CRAB POPULATION ASSESSMENTS

The crabs' invasion and reproduction rate, the sampling of crabs, were carried out from 2008 to 2016. The sampling trips to Clarke Head were regularly undertaken up to 15 times (Quinn 2018) per year throughout the summer (June-September) during the day at low tides without traps and at high tides using traps. The green crabs were captured using two methods, either in bulk or individual trapping.

The intertidal crab sampling (capturing in bulk) was carried out using crates, and the crabs were trapped deep below the surface. The sampling was carried out based on the number of times in summer and showed an increase of crabs' collection during 2012. Due

to the moderate tropical climate, the migration of crabs was observed during the summer in Nova Scotia (Quinn 2018).

The secondary method adopted was subtidal capturing (bycatch or fishing), carried out around the shallow areas by regular fishing. The trips allowed for capturing the sample were higher from 2008 to 2012 (Table 2.2), showing that the crabs' trapping downs had declined along with the crab population. The sampling study results showed that the crab population could decrease when the crab fishing could be commercialized, or the crabs could be used regularly. (Daborn and Pennachetti, 1979; Westhead and Service, 2007). The green crabs had been identified to be rich in chitin, which could be used in various industrial applications, including agriculture, biomedical, cosmetics, and wastewater treatment. On the other hand, various researchers used these green crabs as a substituent for plastic as bioplastic (Audrey 2018).

Table 2.2: Sampling effort during intertidal and subtidal green crab monitoring at Clarke Head, NS, in different years and months (Source: Brady, K., 2018, The Journal of Life and Environmental Sciences)

Year	Intertidal crab sampling						Subtidal crab bycatch	
	Jun	Jul	Aug	Sept	#Quadrats sampled	# Crabs found	#Fishing trips	#Crabs caught
2008	1	2	2	1	140	394	8	35
2009	2	3	3	3	220	896	5	18
2010	1	1	1	1	80	641	10	39
2011	1	0	0	1	40	198	8	29
2012	0	2	3	2	140	1232	6	32
2013	1	5	6	3	320	86	9	1
2014	3	4	4	2	240	112	5	3
2015	1	2	1	1	80	168	4	7
2016	0	1	0	1	30	103	1	2

2.3 POTENTIAL BENEFITS TO CONTROL INVASION

The present study documented the range expansion of *Carcinus maenas* and the Atlantic province coast and their usage by carrying out short-term field and laboratory experiments to utilize the resident's *(Carcinus maenas)* invertebrate predation community by composting. The goal here is to make predictions about reducing the likely impacts created by this spreading invasion on the Atlantic province's coastal barriers into a valuable by-product (compost) to reduce the residual debris.

2.3.1. DESCRIPTION OF CHITIN

Chitin is a (1 ► 4) -linked **2-acetamido-2-deoxy-β-D-glucan,** and chitosan is N-deacetylated derivatives of chitin. Chitin and chitosan are the main structural components of crustaceans' cuticles like green crabs (Muzzarelli 1987). Uridine Diphosphate-N-acetyl-D-glucosamine is polymerized into chitin-by-chitin synthase present in the green crabs, which deacetylases into chitosan (Muzzarelli 1987). Chitinase and lysozyme catalyze chitin hydrolysis, and chitosanase catalyzes that of chitosan to afford the corresponding oligosaccharides. These enzymes are usually distributed in the tissues of plants, animals, insects, and the environment (Hirano 1996).

2.3.2. QUANTIFICATION OF CHITIN FROM REGULAR ACTIVITIES

Chitin is consumed in our daily life. In the environment, chitin is accumulated in the wastewater treatment plant from various manufacturing industries like food (100tons/year), sugar (50 tons/year), food processing (45 tons/year), health foods (80 tons/year), etc. The regularly used materials like feed for pets (60 tons/year), fabric (50

tons/year), cosmetics (40 tons/year), biomedical materials like wound dressings, suture (10 tons/year), paint, and dyes (10 tons/year) had been accounted in the mentioned concentrations in our day-to-day activities (Hirano 1996) (Table 2.3).

Table 2.3: Estimated consumption of chitin, chitosan, and their derivatives in Japanese markets in 1994 (Source: Hirano S, Applied Bioactive Polymer Materials, 1996)

Uses	Chitin Consumption (tons/year)
Food manufacturing wastewater treatment	100
Sugar manufacturing wastewater treatment	50
Food processing units	45
Health food additives manufacturing unit	80
Feed additives for pets, fishes, animals	60
Textiles and Fabrics	50
Cosmetic ingredients for hair and skincare	40
Biomedical materials	10
Paints and dyes	10

2.3.3. SIGNIFICANCE / ANTICIPATED OUTCOMES

The Department of Fisheries and Oceans Canada and Parks Canada had identified the European green crab as a highly invasive coastal species that cause significant damage to ecosystems across Atlantic Canada. The lack of commercial value for this species and the lack of commercial fishery allowed the rapid spread of the green crabs over the region. This project's outcomes were intended to provide two alternative opportunities for green crab biomass's potential commercialization. The chitin-based compost products could be used directly as a growing horticultural media to enhance soil pathogen control and significantly improve crop growth or as an extraction source for chitin/chitosan to be used for high-value applications in pharmaceuticals and the agricultural sector (Hirano 1996).

2.3.4. APPLICATIONS

2.3.4.1. Agricultural Applications

Crabs and shrimp shells are composed of chitin, carbonate, and proteins. The shells were removed from the crabs, and chitin was manufactured using the crab shells, whereas the other parts were employed in the manufacturing of fertilizers. In addition to the high chitin content, the crustaceans' exoskeletons had been utilized in the farming industry. There was no accurate data on the global crustacean farming, so the Food and Agricultural Organization of the United Nations estimated that 35% to 45% of the crab had been discarded as waste, about 5.9 Mt (FAO 2003). The chitin, chitosan, and other protein forms obtained from crustaceans had all been experimented on the crops cultivated to discuss the agronomical responses incurred due to the pests on the crops. Chitin and chitosan were made into powders, flacks, or solutions and used as fertilizer into farming soils or as liquid culture media (Hirano 1996). The federal and state government rules implemented the usage of organic fertilizers (EPA 2017). Like initially soaking the plant seeds in chitosan, several solutions, by sprinkling chitosan over the leaves, were adopted to initiate plants' diseases. Plant seeds' surface was coated with a thin membrane of chitin or chitosan or their fine powders (Tsugita 1995).

2.3.4.1.1. Crustacean Waste as Fertilizers

Chitin is enzymatically degraded to endo-chitinases and exo-chitinases and then to the monomers by influencing bacterium Monomers, further decomposing the ammonium nitrates, which would substitute the usage of direct nitrogen uptake by plants (Chernin and Chet, 2002). The monomers or the oligomers initiate plant defence mechanisms, thereby activating the antibacterial effect (Velasquez and Pirela, 2016). The antibacterial

effect of chitin brought out the biocidal action by inducing the plant defence mechanisms where the chitin acts as elicitors to induce plants' immune system (Okada et al., 2002). The biocidal activity depends on chitin's molecular weight acting upon the polymer chain (Egusa et al., 2015).

In reaction to the fertilizer effect of chitin or chitosan caused by the polymer's biodegradation in the soil to ammonia-derived compounds, the decomposition was caused by the growth of selected microorganisms (Dahiya et al., 2006). Similarly, the decomposition of chitin in the soil was achieved by the action of bacterial chitinases. (Enzymes that degrade chitin and mix them into the soil), Many existing chitinases decompose in the optimum temperature range of 30 to 60ºC and the pH range of 4.0-9.0. Here the chitinolytic enzymes were divided into endochitinases, exochitinases, and glycosaminidases. Endochitinases catalyze the hydrolysis of random bonds over the whole polymer chitin, which produces soluble oligomers that were further degraded.

Similarly, the exochitinases released diacetylchitobiose units and glycosamides, resulting in GlcNAc monomers from oligomers (Velasquez and Pirela, 2006). At the end of the cycle, the chitin starts decomposing [the action of bacterial chitinases to ammonia and nitrates], which the plants can consume. The diseases affecting the crops could be identified by the chitin decomposition in the soil (Kaplan et al., 2016).

2.3.4.1.2. Crustacean Compost as Direct-Growth Regulator

The crustacean composts were used in the nitrogen fixation making the nitrogen available directly to the plants when added to the roots. The pathogens and microorganisms present in the crustaceans led to the degradation of the pathogens' cell walls using the chitinases by composting. (Maximov et al., 2011). The bio-stimulants in the compost precisely

formulate multi-component products, resulting in the module's specific action by testing the specific pathogen acting in the medium (Yakhin et al., 2017).

2.3.4.1.3. Crustacean Compost as an Anti-transpirant

When added to the soil for plant growth, the chitin content present in the crustacean forms a barrier that minimizes transpiration of water from the leaf tissues and prevents the pathogens from invading the healthy plant tissues (Hirano et al., 1996). The length of the chitin's activity depends upon the oligomer's activity; the chitin oligomers had not displayed any noticeable pathogen activity, but the chitosan enzymes encountered the pathogen remediation occurred due to the oligomeric activity.

These oligomers present in the wastes altered the seed treatments that expressed antifungal, antiviral, and antibacterial properties, promoting germination and plant growth (Yu et al., 2008).

2.3.4.2. Other Applications of Chitin

Chitosan acetate salt (Kikuchi 1975; Shinoda et al., 1975) was used as a cationic flocculating agent to recycle wastewater (Sato 1990). The wounds can be treated with the pastes of chitin and chitosan, where the cell proliferation in wound tissue is simulated hence enhancing the prevention of bacterial infections (Kobayashi et al., 1994).

The organic acid salts of low molecular weight chitosan soluble in aqueous ethanol were used as an ingredient for hair-setting lotions (Hirano et al.,1990) and the protecting function of mechanical hair damages (Chikamatsu 1995). The green crabs are rich in chitin; hence rich chitinous waste-based composts have been previously used in pest management activities and biological control of crop disease, especially in the crops like

Capsicum annuum (Dong et al., 2006). Pure chitin has been used as a soil amendment to control fungal diseases and parasitic root nematodes (Gooday 1990). Chitin and its derivatives (such as chitosan) have become the objects of intense study over the last 15 to 20 years

2.4 COMPOSTING

As the organic fraction of crab waste kept increasing, composting was adopted relating the waste management system. As far as large-scale composting was concerned, many composting plants with different capacities had been arranged based on disposal capabilities. The composting completes decomposition by returning the organic matter to plants that can be broken down and utilized for the soil's nutrients. Under the right living conditions, the decomposers thrive in the compost and monitor the conditions when implemented as a soil amendment (Raviv 2005). As a part of the waste management practice, composting had been widely involved in treating various waste materials, including animal waste (Adler and Sikora, 2005). The complex organic matter in these materials was decomposed and humidified by adding some bulking agents to improve the composting performance like absorbing odor, maintaining the moisture content, enhancing the porosity, aeration, etc. (Laos et al., 2002). The quantity of carbon bulking material and the waste material could be adjusted by the CN ratio based on the lignocellulose-rich by-product (Alburquerque et al., 2006). The composting performance associated with the organic matter monitors the temperature profiles, effect of high salinity, and the nutrient losses, thus evaluating the potential for plant growth (Hu et al., 2009).

2.4.1. IMPROVING AERATION AND WATER RETENTION OF SOIL USING COMPOSTS

The use of chemical fertilizers killed the soil decomposers like bacterium or any other microorganisms and limited the renewing of organic matter. If the soil is likely to show any form of erosion due to inorganic fertilizers, composts improved the soil's water retention capacity. The size of the carbonaceous material improved the aeration inside the compost. The compost also acts as a binding material between the sandy soils to hold them together, thus providing the water retention capacity by the aggregate formation, increasing the soil's tensile strength by the action of organic matter. The aggregate soil holds equal parts of air and water and formed the plants' vital source throughout growth (Lewis 1980).

Proper moisture was vital for the health of the microorganisms that help in the composting process. Moisture content between 40 and 60 percent provided enough dampness to prevent the microorganisms from becoming dormant, but enough oxygen is forced out of the pile if they remain inactive. The amount of oxygen within the compost pile was also vital as oxygen deficit leads to anaerobic microorganisms taking over, leading to a stinky compost pile. Oxygen can be added to the compost pile by stirring or turning over the pile (Lewis 1980).

2.5 DECOMPOSITION

The metabolic degradation of organic matter (e.g., plant residues, animal tissues, and microbial material) into simple organic and inorganic compounds is by decomposition (Wang et al., 2013). Decomposition and subsequent mineralization were indispensable for

sustaining life on Earth, as they were the only process enabling massive recycling of chemical elements in the biosphere. The conversion of nutrients from an organically bound form to a water-soluble inorganic form is by the process of mineralization (Wang et al., 2013).

Decomposition and mineralization are near related processes: mineralization was often considered a subset of decomposition, while decomposition does not always lead to mineralization (Wang et al., 2013). The available carbon cycle had involved decomposition, whereas mineralization contributes to the nutrient cycle. Three general processes were involved in terrestrial decomposition: leaching, fragmentation, and chemical alteration (Wang et al., 2013). Fragmentation is a physical process through which new organic matter is broken down into shreds. Some chemical compounds like carbon dioxide, ammonia, phosphate, and sulfur were broken down during this process. The study involves microbial colonization, which leads to further decomposition. Fragmentation techniques act as a direct product of feeding tiny organisms like protozoans, pot worms, and earthworms, which led to further fragmentation in the form of litters (Wang et al., 2013). Leaching is a physical process through which ions (such as potassium, magnesium, and calcium) and small water-soluble organic compounds (like amino acids and sugar) dissolve in water and move out of the decomposed organic material. The final decomposition process involved the chemical alteration through which the fragments were further broken down into simple organic and inorganic compounds (Wang et al., 2013).

2.6 DECOMPOSITION DYNAMICS OF COMPOSTING

The dynamics of composting picture a strong C-N bond, where the N atoms were strongly bonded to the organic matter's carbon skeletons, which provide nutrients for plant growth. N is generally released from the bond as dissolved organic nitrogen (DON) during the C-N skeletons breakdown, which utilized decomposition, fragmentation, or chemical alteration (DON) (Brian 2018). N-mineralization starts with the release of Dissolved Organic Nitrogen associated with decomposition (Wang et al., 2013). N-mineralization is the process where the mycorrhizal fungus associated with the roots of the plants and the microbes present in the soil take up dissolved organic nitrogen (Wang et al., 2013). Although in most cases, the DON uptake by the microbes occurs frequently. Once the microbes' need is met, the microbes break down the remaining DON, and the energy released would be used in the breaking up of the C-N bond and secrete Ammonia into the surroundings (Brian 2018). Immobilization is the condition that occurs when the DON intake is insufficient by the microbes (Rosa et al., 2006). They start absorbing additional N from the inorganic nitrogen pool (e.g., NH_4, NO_3) in the compost mixture. Immobilization also includes removing inorganic N from the soil solution by chemical fixation (Rosa et al., 2006). The composition of chitin present in green crabs' shells and muscles is not easily extractable. So, regular chemical extraction follows the procedure of breaking down solid organic matter. Here, breaking down solid organic matter, which is presumably high in nitrogen, has been adopted by adding sufficient carbonaceous material (Brian 2018).

2.7 DECOMPOSERS

Fungi play a vital role because of their ability to decompose somewhat resistant organic material. Fungi can contribute to about 60 to 90% of the microbial biomass in grassland soils (Wang 2013). They also had extensive hyphae networks, which allowed them to collect carbon and nutrients from the mineral medium. The chitin is a strong chained carbon, which had an unbreakable bond. The rapid movement of the rafts and the microorganisms present in the compost break down the complex material into structural compounds like lignin and keratin, which were inaccessible to other decomposers initially. (Felimon et al., 2019)

Bacteria among the influential decomposers were ubiquitous in air, water, both dead and living organic matter, based on the available conditions. A wide range of soil bacteria gradually degrades cellulose, hemicellulose, lignin, and even fiber walls (Huisman and Passarge, 2008). Due to their large volume, bacteria rapidly absorb soluble substrates and reproduce quickly in substrate-rich conditions. Bacterial decomposition also happens in regions where the fungal stress is resistant.

2.8 CONTROLLING FACTORS

Biotic and abiotic factors often control decomposition rates. The biotic factors focus on the quantity and quality of nutrient content available in the microbial community. Similarly, abiotic factors include temperature, moisture, pH, which determined the soil and environmental conditions.

2.8.1. BIOTIC FACTORS

The quality of compost was determined by some general characteristics, namely, the type of chemical bonds present in the organic compounds, the amount of energy released by the microorganisms for their decay, and the size and structure of these compounds and their nutrient content. The C/N ratio in the microorganism was generally confined to more Nitrogen with less carbon limited. A lower C/N ratio usually led to a higher decomposition rate. Litters and soil organic matters follow the microbial decomposition rates. The average C/N ratio maintained would be 25:1 for organic matter. Still, when the value exceeded N immobilization (microbes hold back nitrogen instead of releasing it), it occurred instead of net mineralization (Dickson et al., 1991).

2.8.2. ABIOTIC FACTORS

2.8.2.1. Temperature

The temperature of the compost could affect carbon decomposition both directly and indirectly. The temperature change may be associated with the temperature generated by the microbial activity and the ambient temperature related to the environment. Higher temperatures (Mesophilic and Thermophilic phases) denote the higher rate of microbial activity. On the other hand, the composter temperature played a direct role in the microbial community's activities. The composter temperature associated with the ambient condition determined a low decomposition rate if the compost was dry. This quick compost drying occurred mainly during colder weather, which generated a higher decomposition rate, which ended up in N-mineralization within the subsequent regions.

2.8.2.2. Soil Moisture

The influence of temperature on the compost medium winds up in dehydration, which reduced the dimension of the water film coating the compost particles. Low moisture content limited the provision of a substrate by diffusion through the medium. The optimal environmental conditions for microbial activity eventually developed within the environment were warmth with moist and aerated soil. There would be low aeration under wet conditions, which led to a consequent limitation in the quantity of oxygen, which degraded decomposition speed. The placement determined the speed of decomposition. Also, soil moisture fluctuation ends up in differences within the decomposition rates and mineralization, supported by soil nutrients' supply after removing its nutrients.

2.8.3. COMMON DECOMPOSITION STUDY METHODS

2.8.3.1. Rotating Batch Unit Composting

The easiest way to get quick hot compost was by throwing the wastes in a rotating composter. The commercial model of the composter involved a composting unit of volume 170L. A drum-shaped composter had an axle in the middle and rotated in the center attached by rafts acting perpendicular to the axle. Units with the axel and rafts were suitable for breaking up the clumps in the compost. The compost should be filled to three-quarters with mixed greens or brown waste and should be rotated based on the composition frequently. The moisture content was maintained throughout the process of composting to prevent the loss of compounds.

The rotating composter was a batch system where a large quantity of prepared waste was made before starting. The rotating composter does not support the continuous addition of

raw materials, and the next batch was added only when the earlier batch was completed. A rotary composting batch will not compost uniform if we keep adding wastes all the time. Turning and mixing the pile changes its bioavailability. The composter unit must be rotated continuously to avoid trouble with clumping and sliding to avoid a rough mix. These rotating composters had small air holes to avoid anaerobic conditions and prevent the unit's loss and exchange of matter.

2.8.3.2. Pile composting

The pile composting, also called hot composting, allowed the appropriate mix of feedstock and water in the available ratio sufficiently enough for a large pile and mixed them regularly. The pile usually needs to be about $1.2m^3$ in size to insulate the hot core of the pile. The batch was built in the appropriate size using nitrogen and carbonaceous materials. Turning the pile allowed the air to get in, ensuring aerobic decomposers' distribution throughout the pile and also provided the anaerobic wastes to break off any lumps and getting the air into the spaces allowing faster decomposition.

The first set of decomposers in the middle of the pile will be heated as they consume the available feedstock; once the decomposers run out of food, the pile would cool down. Turning piles at this point access the decomposers towards the undigested feedstock from the edges of the piles. A compost thermometer was used for monitoring the heat exchange occurring in the piles. The pile can be turned once every four days, then again once every 7 to 10 days after that. The weights of the compost will slowly compact over time, pushing out the air. The bacteria will die, and new bacterium will grow because of watering the compost repeatedly. Turning piles and digging holes would also reintroduce air into the pile to keep them aerated and maintain uniform decomposition throughout.

2.8.4. CHARACTERISTICS OF COMPOST

Bio-solid composts, manures, peat, and manufacturing plant waste have all been necessary to immobilize heavy metals like Lead, Cadmium, and Zinc (Basta et al., 2001). All composts, especially compost-containing biomass, reduce the soil's heavy metals (Merrington and Smernik, 2004). Currently, different materials and technologies employed in composting variables like organic matter, nitrogen, dissolved organic carbon (DOC), nitrate and soluble sugar concentration, pH, and electrical conductivity (EC) can vary significantly in support with time (Zmor et al., 2007). Therefore, it was challenging to predict compost behaviour with relevance in the mobility of heavy metals. Organic matter refers to the soil may increase the DOC, encouraging heavy metals' mobility (Antoniadis and Alloway, 2002).

2.8.4.1. Essential Carbon to Nitrogen Ratio

The microorganisms in the composting pile thrive on two essential nutrients to survive: nitrogen and carbon. Nitrogen is the basic building block for microorganisms to grow and reproduce. Depending upon the total nitrogen, the higher the nitrogen concentration, the greater the number of decomposers present in the compost. Similarly, carbon is the primary food for decomposers. Composting experiments were carried out by balancing the carbon and nitrogen ratio, limiting the microorganisms that could quickly decompose the organic matter. The ideal carbon to nitrogen ratio is 30:1; however, the carbon and nitrogen ratio is adjusted between the ranges 20:1 to 40:1. The carbon-nitrogen ratio calculated might not be exact but does not accommodate bioavailability, density, or moisture levels, which were also significant components in a healthy compost pile.

2.8.4.2. Balancing Material Size

The size of the carbon material plays a vital role in the rate of decomposition. The compost's porosity was decreased by the carbonaceous material's size, thus increasing the decomposition rate. The raw material size should be maintained [coarse sized] to adjust the decomposition rate of composts. If the carbonaceous material was very fine or powdery, the quantity was adjusted to avoid physical loss of the compost material by air in the surroundings. For extra-fine materials, the regular turning and alteration of moisture content provide proper aeration to prevent clumping. The compost matting due to the particle size could be avoided by adding crumpled paper or wet paper coated with shredded compost dirt.

2.8.4.3. Moisture Content

Water is necessary for a pile because microorganisms require moisture to survive. However, when the compost's air spaces were filled with water, the microorganisms start dying in the surroundings due to the inability to breathe. A thin coating of water over the decaying matter in a pile would ensure the decaying rate of microorganisms. The rapid turning of composts could allow the water to evaporate and ensure the compost's microorganisms decay. The pile temperature also changes when the moisture content varies, so holes were poked with an aeration device, and water was added by hose into these holes. If proper measures were adopted for composting, a pipeline would be installed through the compost's center to distribute water throughout the compost. If the pile dries out quickly, the compost was moved to a shady location or loosely covered with a lid or water-proof fabric to trap the evaporation.

2.8.4.4. Compost Activators

Mineral Activators are not activators at all – they are soil amendments that could be used to initiate the process of composting. Some examples of activators include limestone, rock powders, sulfur, and gypsum. These minerals are not very necessary in composting piles, and they would adversely affect the pile's microbial life. The compost's pH affects soil microorganisms' action if the finished compost was completely acidic; calcium hydroxide was added to neutralize the pH to 7.0. The number of mineral additives must be measured simultaneously concerning the pH so that the additives do not negatively affect the soil's chemistry.

The nitrogen activators were the only ones that truly work to get a struggling pile of work. Suppose the pile was not hot enough and moist enough but had the described quantity of carbon and nitrogen material. The compost was adjusted to continue composting by adding nitrogen activators to initiate the heating. These activators were composed of high nitrogen feedstock, such as poultry manure, blood meal, alfalfa pellets. The organic nitrogen activators were preferred over the chemical nitrogen activators as they kill the microorganisms and prevent the decomposition in composting.

2.8.5. FEEDSTOCK SOURCES FOR COMPOSTING

2.8.5.1. Sawdust

The sawdust, which is extremely high in carbon content, decomposes when mixed with a high nitrogen feedstock, such as marine organisms. The sawdust preferred to be used was collected and not taken from treated or particleboard wood. The sawdust was evenly mixed with the raw materials to prevent matting. Sawdust can also be used as a mulch

through the soil, which would help organic fertilizers prevent sawdust from drawing nitrogen away from the soil. The sawdust, rich in carbon, was quite tricky to break down directly when a varying quantity of organic material was added. When heaped around for a year, the sawdust starts losing colour and softens when added on a heap. The larger the particle size of the carbonaceous material, the more prominent the porosity and the aeration inside the pile. The sawdust was tested before the composting treatment to avoid any chemicals in the raw materials.

2.8.5.2. Straw

The straw rich in nitrogen requires a high nitrogen material to initiate composting. The straw's particle size was maintained as a coarse size to allow the aeration and sustain the composting medium's moisture contents retention capacity. The shafts provide proper aeration in the composter, thus altering the drying of the compost simultaneously. Straw could be purchased from garden centres and used as a high carbon material for the compost pile. The pH without the addition of organic material had been tested to be 6.5 to 7.0. The moisture content monitoring plays a dominant role in using the straw as a carbonaceous material.

2.9 ASSESSMENT OF COMPOST STABILITY

The compost's stability or maturity was essential for composts in agricultural and horticultural production (Inbar et al., 1990). Stability was used to define the bioavailability of organic matter, where the high level of microbial activity record denotes the nature of the compost (Mathur et al., 1993). So, the compost collected determines the material sustainability for plant growth associated with the degree of compost

humidification (Hue and Liu, 1995). Compost researchers used plants to analyze nutrients using feed stocks that would mature the soil suitable for plant growth. The duration of composting also played a vital role in the plant growth support, showing that time was definable for the entire plant growth study (Mathur et al., 1993).

2.9.1. PLANT GROWTH STUDY

Plants were observed to be in a stationary medium, and they stay in a constant place, gaining light, space, water, and nutrients. The reception of light and various other changes led to morphological and growth-related plants' changes (Pinho 2008; Yeh and Chung, 2009). Plants could detect even minor variations in growth due to light spectrum changes, intensity, and direction. Light receptors could be used in plant growth regulation. The light receptors had been classified into various types, UV-A, blue light (Cashmore et al., 1999), and phototropic (Briggs and Huala, 1999), functioning as plant growth promoters under controlled conditions, for a stabilized plant growth study.

2.9.2. PARAMETER VARIATIONS OBSERVED

The most common parameters associated with composting include compost temperature, nutrient availability, total C, C: N ratio, pH, and soluble salts (Fauci et al., 1999). The parameters associated with composting had an inverse relationship with compost stability. The compost parameters were detrimental to the plant growth study during the earlier stages of composting, and they decreased along with the experiment when the compost matures. In various other studies, the compost's humic and fulvic acids act as the compost's bio-maturity indicators, where the measures tend to increase as soon as the compost matures (Adani et al., 1995; Erhart and Burian, 1997). Various studies used

germination tests or plant growth bioassays to indicate compost maturity. Still, specific parameters could not be accounted for related plant growth's compost maturity (Eklind et al., 1998).

In the current research, we analyzed the stability of two different types of green crab compost with different carbonaceous materials, sawdust (GC+SD in the ratio 1:2) and straw (GC+SW in the ratio 1:4) by growing Garden Cress (*Lepidium sativum*), as well as a compost maturity test. We also studied the compost properties related to the garden cress growth and nitrogen uptake to determine nutrient availability from the growing media treatments.

CHAPTER 3 MATERIALS AND METHODS

3.1 RAW MATERIALS

Green crabs (GCs) ranging from 35mm to 70mm carapace width were collected in association with Parks Canada in bait cage traps (Figure 3.1) in Kejimkujik National Park, Nova Scotia, on July 25, 2019. The samples were transported in the cage bait traps to the research facility at the Bio- Environmental Engineering Centre, Bible Hill, Nova Scotia. The bulk crab biomass was weighed using a top-loaded Digital Balance (Salter Brecknell, Max 75kg with the dimensions of 1200x1200mm with a precision of 0.001kg).

The other significant materials for this research included carbonaceous feedstocks for the composting studies; sawdust (SD) for the first study, and straw (SW) for the second study. The sawdust (SD), having a diameter of approximately 0.5cm to 1cm, was purchased from Nova Tree Inc., Glenhome, Nova Scotia, Canada and consisted of a mixture of Spruce-Pine-Fir, Eastern hemlock, and tamarack larch. The straw (SW) was obtained from Dalhousie University's Research Farm unit in Bible Hill, Nova Scotia. The straw was collected from barley *(Hordeum vulgare)* shredded to a diameter of approximately 0.5cm to 1cm using a stainless-steel shredder. The shredding chamber used was 32″ X 32″ X 44″ deep, with a bottom cone discharge of 12″. The inside chamber had (2) shafts with blunt rotary knives. Each side wall also had stationary knives, which were 1-1/2″ thick. The sawdust and straw size allowed good aeration throughout the process, and mixing materials was done under regulated conditions for decomposition.

Figure 3.1: Green crabs collected from the Kejimkujik National Park.

3.2 IN-VESSEL COMPOSTING

A double-walled stainless steel in-vessel compost reactor was utilized for the composting studies. The in-vessel composter was originally constructed for small pilot-scale research applications and had a capacity of 150m^3. The interior chambers were trapezoidal with an open-top through which the raw materials were added (Figure 3.2). The top opening was covered with a wooden lid, connected to a variable speed fan to retain some of the metabolic heat generated and provide regulated airflow through the system. A hollow shaft running vertically at the centre of the composter contained six thermocouples spaced at 5cm intervals and connected to a Campbell Scientific CRX100 data logger (Campbell Scientific, Edmonton, AB). The thermocouples measured changes in the internal temperature of the composter and were logged at hourly intervals over the entire study period. A thermocouple at the top of the hollow shaft was used to collect changes in the

ambient temperature. The in-vessel composter also consisted of a central shaft with adjustable paddles and connected to a variable speed motor and PLC controller (Model Company). The rotational shaft was kept on at the lowest speed setting of 60rpm throughout the study periods to ensure adequate mixing of the feedstocks. The study was carried out in a clear polyethylene plastic-covered greenhouse with a large fan to help regulate environmental conditions within the space. Using green crab and sawdust (GC+SD), the first composting study was conducted from July to September 2019. Using green crab and straw (GC+SW), the second composting study was conducted from the end of February to April 2020.

Figure 3.2: Top View of the in-vessel composter chamber, with two mixing paddles on stainless steel.

3.3 COMPOSTING RECIPE

A composting recipe calculator (i.e., an Excel spreadsheet) was used to determine the quantity of feedstocks added to the composter. The weight ratio of 1:2 of GC and SD

were added in the composter based on the calculated values of total carbon and nitrogen for the crustaceans and sawdust (NRAES Compost Manual, 1992). After continuing the experiment with the pre-determined values from the compost manual, the raw materials were tested for total carbon, total nitrogen, and moisture content, and quantities by mass of dry feedstocks and a C: N ratio of 25:1 was achieved with the composting calculator. To achieve a similar C: N ratio for the second composting study, the quantity of green crab (GC) to straw (SW) was added to the in-vessel composter in the ratio of 1:4 (Figure 3.3). The ratios achieved based on the C: N ratio and the volume of material in the in-vessel composter at or below 75% capacity were maintained. The physical and chemical properties of the feedstocks are provided in Table 3.1. The feedstocks' total carbon and nitrogen were analyzed using a LECO-CN 2000 (LECO Corp., St. Joseph, MI).

Figure 3.3: Straw &Green crab (SW+GC) [top] and Sawdust & Green Crab (SD+GC) [bottom] based composting studies in the composter, at the ratios of 1:4 and 1:2.

Table 3.1: Physical and chemical properties of the raw composting feedstocks

Parameters	Raw materials		
	SD	SW	GC
Moisture Content (%)	46.85	8.82	66.02
Total C (%)	46.3	38.51	27.80
Total N (%)	0.07	0.99	6.54
Bulk Density (kg dry m^{-3})	462	533	888

3.4 SAWDUST COMPOSTING

The green crabs and sawdust were analyzed for carbon-nitrogen and combined in the ratio of 1:2 on a mass basis. A total of 149kg of compost mixture was introduced into the composter, consisting of 49.5kg of crabs and 99.5kg of sawdust. A C: N target of 25:1 was achieved using the moisture content, total carbon, and total nitrogen analyses of the individual feedstock weights. The compost was subsampled (Figure 3.4) at the times shown in Table 3.2 from the in-vessel system by collecting material from various locations in the chamber.

Figure 3.4: Composts generated over the 60-day period for the SD+GC study. Numbers under each photo represent lapsed compost time. Note that the compost started drying off without moisture during Day 5 to Day 27 (change in colour can be seen from left to right) and were later supplemented with water from Day 28 onwards.

Throughout the studies, the reactor temperature was monitored as a proxy for microbial metabolic activity leading to heat release during decomposition of organic matter. The ambient temperature was compared to the composter temperature from which composting phases (mesophilic (20 to 40ºC), thermophilic (>40ºC) and maturation (20 to 25ºC)) of the compost cycle was determined. Moisture loss from the composter evaluated from samples was also correlated to temperature fluctuations in the composting system. The sub-sampling regime over the composting study ranged from Day 0 to 125, with a composite sample of approximately 200g collected from various locations within the in-vessel system at each sampling period (Table 3.2).

Table 3.2: Compost sub-sampling dates for the Sawdust & Green crab composting (SD+GC) over a period of 125 days

Sampling days	Date		Sampling days	Date
0	25-07-2019		31	25-08-2019
1	26-07-2019		32	26-08-2019
2	27-07-2019		33	27-08-2019
3	28-07-2019		34	28-08-2019
5	30-07-2019		35	29-08-2019
7	01-08-2019		36	30-08-2019
10	04-08-2019		37	31-08-2019
12	06-08-2019		39	02-09-2019
14	08-08-2019		41	04-09-2019
18	12-08-2019		43	06-09-2019
22	16-08-2019		46	09-09-2019
27	21-08-2019		49	12-09-2019
28	22-08-2019		53	16-09-2019
29	23-08-2019		57	20-09-2019
30	24-08-2019		125	07-11-2019

3.5 STRAW COMPOSTING

A second in-vessel straw composting study was conducted from the end of February 2020 to April 2020. The straw was reduced in particle size by shredding them in the feedstock shredder (Figure 3.5). The particle size of straw initially ranged from 5mm to 10 mm after shredding, and then they were added to the green crabs and into the composter for the process of composting at a ratio of 1:4 by mass. A 59kg compost mixture was introduced into the composter, consisting of 12kg of crabs and 47kg of barley straw. The weights were adjusted to determine an equivalent C: N ratio of 25:1 using the total carbon and total nitrogen content of the individual feedstocks, similar to Study 1. The supply of green crabs was limited due to the COVID restrictions over Winter 2020. The compost composition was derived from the carbon-nitrogen values calculated separately for the raw materials.

Figure 3.5: Preparation of straw to reduce the particle size to be added to the in-vessel composter together with green crabs to initiate study 2 in the ratio of 1:4.

The SW+GC study had an initial moisture content of 55%, which was attempted to be maintained throughout the 54-day study. Sample times are provided in Table 3.3.

Initially, the straw was longer and kept binding to the shafts and stopped the composter continuously; hence the straw was reduced in size ranging between 5mm and 10mm in length using a feedstock shredder and sub-sampled periodically similar to Study 1.

Table 3.3: Compost sub-sampling dates for the Straw & Green crab composting (SW+GC) over the 54-day period

Sampling days	Date
0	26-02-2020
2	28-02-2020
3	29-02-2020
5	02-03-2020
7	04-03-2020
10	07-03-2020
12	09-03-2020
16	13-03-2020
20	17-03-2020
23	20-03-2020
26	23-03-2020
29	26-03-2020
37	03-04-2020
43	09-04-2020
49	15-04-2020
54	20-04-2020

3.6 SAMPLE PREPARATION FOR ANALYSES

3.6.1. MOISTURE CONTENT

Subsamples collected from the composter were immediately frozen to reduce microorganism activity for analyses at a later date. The gravimetric analysis of moisture content was determined by drying the samples in an oven at 75ºC for up to 72 hours, or until they reached a constant weight (Figure 3.6).

Figure 3.6: Oven-drying of composts for the determination of moisture content.

3.6.2. GRINDING OF SAMPLES

The oven-dried compost samples were ground using a pestle and mortar (Figure 3.7) to reduce particle size and further ground to a fine powder using a coffee grinder (Black + Decker Smart-Grind Stainless Steel Coffee Grinder) for total C and N analysis.

Total Carbon and Nitrogen were then determined for the samples using a LECO – CN 2000 analyzer (LECO Corp., St. Joseph, MI), as well as organic matter (or volatile solids) and ash contents using a Loss-on-Ignition (TMECC Method 05.07A) method in a muffle furnace **(**Fisher Scientific Isotemp Programmable Muffle Furnace 650-14)**.**

Figure 3.7: Oven-dried samples at 75ºC processed in a ceramic pestle mortar and transferred to a coffee grinder to receive finely ground compost material.

3.7 ANALYSES

3.7.1. ELEMENTAL AND CHICAL ANALYSES

3.7.1.1. Total Carbon and Total Nitrogen

The pH of the compost samples was determined by dissolving the compost samples in distilled water in a ratio of 1:2.5 (Guitian-Ojea & Carballas, 1976). The electrical conductivity (EC) was measured in the ratio 1:1, composed of the extracted compost and distilled water, which was measured using an EC meter (Thermo Scientific Colour Touch Screen Cyber Scan pH 6000 - pH/pH FET/mV RS232, USB, IRDA Meter with pH electrode EC620130, ATC probe, electrode holder).

The total carbon and nitrogen were determined from the finely ground collected compost samples (Figure 3.8) using dry combustion analysis in a LECO – CN 2000 elemental analyzer. The equipment was initially calibrated with known standards of EDTA and

Alfalfa, where this method required less than 1g of the compost sample (Figure 3.9), which had been dried and made free of moisture at 1250ºC.

Figure 3.8: Finely ground oven dried SD+GC samples for CN Analysis.

Figure 3.9: Samples weighed on ceramic boats before being loaded into the LECO for CN analysis

3.7.1.2. Organic Matter Content

The compost samples were rich in carbonates from the crab feedstock in the mixtures. To avoid consideration of this inorganic carbon source organic matter determination in the sample, 0.5mL of 0.05N of Hydrochloric Acid was added to 10g of sample. The sample was then oven-dried at 75ºC and maintained for 48 hours or until the sample reached a constant weight. The samples were then placed in ceramic containers into a muffle furnace programmed at 550ºC (Figure 3.10) for 8 hours, and after they were entirely combusted, the temperature was reduced to 200ºC and maintained for 2 hours. Then the ash from the crucibles was weighed for the determination of the organic matter content.

Figure 3.10: Muffle Furnace set up for 550ºC using Loss on Ignition method.

3.7.1.3. Respirometry Study

A respiration study was carried out on compost samples in both studies. The C: N ratio is a general index of change during the composting process, but respirometry can measure the potential accessibility of the available carbon in the substrate. The incubation study was intended to provide additional insight into the microbial respiration rates associated with compost samples at different time intervals over the composting studies. Samples (100g) were collected from the composting studies at Days 1, 5, 14, 29, 39, 46, 57, and 125 and placed in 1L glass mason jars and incubated in a controlled environment chamber at 30±1ºC. The samples were tested in triplicates and maintained at a gravimetric moisture content of 65%.

The samples were established in triplicate for each period from both studies and arranged in a completely randomized design within the chamber (Figure 3.11). Each mason jar also had a vial with 30ml of 0.5M potassium hydroxide traps to trap carbon dioxide evolved during the decomposition of the organic matter. The potassium hydroxide traps set in the mason jars absorb the carbon dioxide respired by the micro-organisms, where they combine to form potassium bicarbonate (TMECC, Method 05.08-B). The traps were replaced with a new trap of potassium hydroxide after 0 to 4, 4 to 8, 8 to 24, 24 to 48, 48 to 72, and 72 to 96 hours, after aerating the compost by mixing the material thoroughly using a glass rod to maximize microbial access to carbon, and then sealing the vessel with a lid.

The treatment mixtures were maintained at 65% gravimetric moisture content throughout the incubation study of 96 hours (4 days) by adjusting the moisture loss with the appropriate volume of distilled water at every sampling, by adding water based on weight

loss. The EC of each alkaline trap solution was measured, and the carbon dioxide content was calculated relative to a reference potassium bicarbonate solution. Cumulative carbon dioxide trapped in the vials was measured in the sealed vessels after 4 hours for the first two time periods (4 and 8 hr), 16hrs (8 to 24 hr) and 24 hrs for each subsequent time period (48, 72, and 96 hrs)

The total carbon dioxide evolved during each time interval in the sealed jars was used to calculate the proportion of carbon from the source material over the incubation study as shown in the equation below.

$$\frac{(\text{ECraw} - \text{ECsample})}{(\text{ECraw} - \text{ECsat})} \text{ x (trap capacity}_{mg}) = \text{Amount of Evolved } CO_2 \ldots\ldots\ldots\ldots\ldots\text{Equation 3.1}$$

(Method 05.08-B)

where:

$ECraw$ = electrical conductivity of pure 0.5 M KOH

$ECsat$ = electrical conductivity of 0.25 M K_2CO_3

$ECsample$ = electrical conductivity of the trap associated with a particular sample

Figure 3.11: Experimental Setup in the controlled environment incubation chamber for the Respiration experiment.

3.7.1.4. Bulk Density

The bulk density of the compost samples reflects the potential ability for roots to grow in the compost media and also the potential movement of air and water through the compost. The transmission and storage of composts also affect the bulk density. The bulk density was measured based on an as-is weight basis. The bulk density was calculated by weighing a certain quantity of compost by filling them to one-third of a 500ml container. The compost was lightly compacted by tapping the bottom of the container on a firm flat surface ten times. This methodology was done in layers until the material reached a volume of 450cm^3. The compacted sample inside the container was used in the determination of bulk density using the following formula,

$$BD = \frac{(B-C)}{(D)} \quad \text{.....Equation 3.2}$$

(ASTM D 2980-71, 1990)

where:

B = mass of the compost-filled pail, (kg),

C = mass of the empty pail, (kg), and

D = volume of the water-filled pail, (m^3)

3.7.1.5. Water Retention Capacity

The water holding capacity is the percentage of water-filled pore volume relative to the total volume of water-saturated compost, % w/w. The compacted sample was added with the measured quantity of water. The volume of the water required to fill the compacted compost was measured by filling tap water until the container's brim, for which the mass was recorded. The sample rests for three hours to allow the compost samples to absorb

the moisture. The mouth of the container was covered with a cloth that served as a filter. The container was inverted to drain the water from the saturated material for 24 hours. The combined mass of the water-saturated composts and the mass of the container were measured after saturation.

$$WC = \frac{[(B-C)-(D-C)xE]}{[(D-C)xE]} \quad \text{.....Equation 3.3}$$

(ASTM D 2980-71, 1990)

where:

WC = water-holding capacity, (kg kg^{-1}), %,

B = mass of the water-saturated compost-filled pail, (kg),

C = mass of empty pail, (kg),

D = mass of the compost-filled pail, (kg), and

E = total solids ratio, unitless

3.7.1.6. Chitin Extraction from Composts

The green crab shells have been observed to be rich in chitin, a carbonaceous material extracted using the green fermentation method. The process of composting breaks the chitin down, and releases chitinase into the matrix. To extract chitin from compost, the 10g of samples by weight were mixed with 0.5mL of 2M hydrochloric acid and constantly stirred for approximately 24 hours at 70ºC and weighed. The residue then collected and washed using distilled water and neutralized by 1M sodium hydroxide solution and weighed. The demineralized samples were filtered using the vacuum filtration method, and pH was neutralized by washing the samples using distilled water. The samples were oven-dried, and the residue was collected and weighed as the extracted chitin.

% Yield of chitin = $\frac{Weight\ of\ extracted\ chitin}{Weight\ of\ the\ compost}$ x 100……....Equation 3.3

3.8 PLANT GROWTH DYNAMICS

3.8.1. PLANT RESPONSE STUDY

To evaluate the potential of the two green crab composts as a growing medium, a plant response study was conducted. Compost samples from the end of each study, (i.e., SD+GC compost, and SW+GC compost) were mixed with a commercial potting media (Coconut Fibre Potting Mix, Canna COCO). The most commonly used criteria to evaluate phytotoxicity symptoms in plants, especially when using compost amendments, are germination rate, stem length, color changes, and deformation of organs (i.e., stem, leaf). The chemical composition of the media (potting mix + compost) was also compared to the control groups (potting mix) (Table 3.5).

Lepidium sativum (also called Garden Cress) was used as the test species in this germination study since the seeds have a relatively fast 3-to-5-day germination rate (Delgado et al., 2010). Garden cress is a cool-season salad green, which requires light to medium fertility and relatively moist soil-type growing medium, maintained at a pH of 6.0 to 7.5.

Pre-germination tests were performed by transferring seeds to the Petri dishes with a wet paper towel by maintaining them at a germination temperature of 15 to 25ºC. The seeds were examined and individuals that were not decoloured, damaged, or abnormally low growth during the pre-germination phase selected. The seeds were then maintained under dark for 24 hours and then transferred to the daylight for 24 hours to initiate the germination study. The seeds took approximately 2 to 7 days to germinate. The cress

seeds were planted in the late winter, 10 to 15 seeds per foot of row and 0.6cm deep. The leaves were harvested when they were 3.5 to 7.5 cm deep.

Once the shoots emerged from the seeds, they were transferred into separate pots based on treatment ratio of the composts and potting mix previously determined from the scientific literature (Pavel et al., 2013). With the selected seeds, four replicates of each compost treatment were established. The compost media ratio was established as treatments using both, SD+GC and SW+GC compost at percentages, 10%, 20%, and 50%, relative to the commercial potting media, and arranged in a completely randomized design (Table 3.4).

Surface crusting of SW+GC and commercial potting media at the 50% ratio caused issues with plant emergence and therefore this ratio was subsequently reduced to 35%.. The 50% SW+GC treatment only was replaced with 35% since the 10% and 20% of straw had moderate plant growth due to the crusting of the surface.

Four replicates of commercial potting soil only were also maintained as controls. Plants were grown in a controlled environment modular vertical farm system developed by the Innovative Waste Management Research Program located in the Faculty of Agriculture, Dalhousie University, Bible Hill, Nova Scotia. The germination study plants were maintained at 18ºC under LED lighting (FastBack Spectra Blade, Intravision Group Inc., Oslo, Norway) maintained for 24 hours for all 20 days (Figure 3.12).

The media in which the plants grew were maintained at a moisture content of 80% based on the w/w ratio since this species required higher water content. They were planted less than 0.65cm apart to allow a faster harvesting rate. The harvesting period for these plants ranged between 15 and 20 days of the entire composting study.

After 20 days, when they reached a height of 5cm, the whole plants were harvested, including the roots. The media was separated from the plants and each analyzed individually for minerals and moisture content.

Table 3.4: Treatment design of the plant growth study with a commercial potting media and green crab compost made with either sawdust (SD) or barley straw (SW)

Treatments	Percentages	Compost as - is weight (g)	Potting Soil as – is weight (g)
control	0%	0	250
sd 10	10%	25	225
sd 20	20%	50	200
sd 50	50%	125	125
sw 10	10%	25	225
sw 20	20%	50	200
sw 35	35%	87.5	162.5

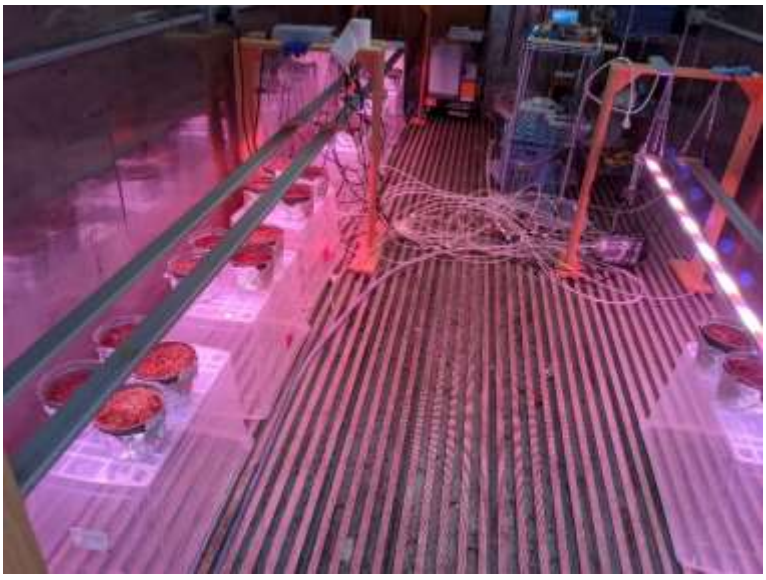

Figure 3.12: The initial experimental set-up of the plant growth study based on *Lepidium sativum* under controlled temperature.

3.8.2. PLANT NUTRIENT ANALYSIS

The gravimetric moisture content of the harvested plant biomass and growing media was obtained by drying them in the oven at 50ºC for up to 72 hours, or until a constant weight

was reached. A nitric acid microwave-assisted digestion of the samples was carried out using 0.25g of plant or growing media sample in a digestion vessel with 10ml of acid. The samples were digested at 200ºC in a microwave digester (CEM Mars 230/60 PN 907501 230v Microwave Accelerated Reaction System) (Figure 3.13).To digest the samples, they were centrifuged at 2000 – 3000 rpm for 20 minutes. The digested samples were diluted to a 1:100 concentration using deionized water and then filtered using a Q8 filter paper to avoid the opaque or translucent solution. The digested solution was analyzed following US EPA Methods 7470A (SW-846 method for metals like Calcium, magnesium, Potassium, Phosphorus, Potassium, Sulphur, Sodium, Aluminium) by ICP-AES at the Nova Scotia Department of Agriculture Analytical Laboratory, Bible Hill, Nova Scotia.

Figure 3.13: Microwave digestion of Garden cress (*Lepidium sativum*), SD+GC and SW+GC compost with potting soil after harvesting.

3.9 STATISTICAL ANALYSIS

Statistical analyses were performed using the analysis of variance (ANOVA), where each parameter was analyzed. The mean values of the carbon decomposition, nitrogen, moisture content, and organic matter were modelled linearly and non-linearly based on the nature of the data. The corresponding equation and slope are computed to determine the statistical significance independently. The equation modelling was carried out using the MiniTab 19 software package, MiniTab LLC, Pennsylvania. A completely randomized design was used for the plant growth for the sawdust- and straw-based media experiments. Each treatment was replicated four times. All data were subjected to a one-way analysis of variance (ANOVA), and the main effects of treatments were partitioned into orthogonal contrasts. Two-way analysis of variance was performed to determine any significant difference among the parameters analyzed from the harvested plants. One-way ANOVA was done to determine any significant and insignificant differences between both the composting medium using JMP 16 from SAS. Means comparison was done using the Tukey's method at a significance level of 5%. The significant differences were computed based on the error probability value (p-value < 0.05). The graphing was performed using the MS Excel 2016, Microsoft Corporation, Washington, US.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 STUDY 1 – SAWDUST AND GREEN CRAB

4.1.1. GENERAL ANALYSIS OF COMPOST PARAMETERS

The SD+GC study included a mix of green crab and straw were taken in the ratio 1:2, where the physical parameters dealing with the mechanical stability and chemical parameters used in monitoring the microbiological activity are provided in Table 4.1. The sawdust-based compost towards the end of the collection of composts had a moisture content of 34.95% after 125 days of composting, which was found towards the end of maturation phase and organic matter of 77.5% was also found (Table 4.1). The total carbon in SD+GC composting study with 32.96%, similarly, total nitrogen was 1.17% in SD+GC study. The bulk density was lower in SD+GC composting study (450 kg dry m^{-3}). On the contrary, the water holding capacity was higher along the SD+GC composting study (20.81%) (Table 4.1). The moisture content and water holding capacity was higher in SD+GC composting study based on the final data in comparison with the range.

Table 4.1: Final compost physical and chemical parameters observed in the SD+GC compost (n=3)

Parameters (n = 3)	Final Compost Characteristics (mean ± SD)
	SD+GC Study
Moisture Content (%)	34.95 ± 10.5
Loss on Ignition (%)	77.50 ± 2
Total C (%)	32.96 ± 2.8
Total N (%)	1.17 ± 0.3
C: N Ratio	28.17 ± 1.6
Bulk Density (kg dry m^{-3})	450 ± 0.01
Water Holding Capacity (%)	20.81 ± 0.2

Sawdust-based composts are generally lower in total nitrogen concentration than in other co-composts with different carbonaceous materials (Kuo 1995). Similarly, the total

nitrogen concentration was lower in the SD+GC composting study, irrespective of the marine raw material (GC), than in the SW+GC compost. These stabilized composts had generated a minimal release of odours and leachate. Similarly, the SD based composting study associated with green crabs have shown rapid carbon degradation, as shown in Figure 4.5. The loose structure allowed for efficient aeration based on bulk density (Table 4.1), which was slightly lower than the ideal bulk density range (420 to 655 kg dry m^{-3}) (Khafer, 2015).

The main objective of the overall composting study was associated with the production of composts with sawdust and straw-based feedstocks mixed with a chitinous raw material, i.e., green crab, and the potential application for plant production. The goal was also to stabilize organic nitrogen from green crabs through the decomposition process with sawdust carbon.

4.1.1.1. Comparison of the Compost Recipe and Analyzed Composts

The values from the NRAES composting manual yielded an overall dry carbon weight of 31.7kg and overall dry nitrogen weight of 1.1kg, which were theoretically generated values. But the values generated from LECO – CNS 2000 after analysis was found to be 29.16kg of dry carbon and 1.2kg of dry nitrogen. The theoretically calculated C:N value was found to be 29.5:1 which was higher than the analyzed C:N value 25.7:1. But both were observed to be in the ideal composting range. The moisture content varied between both the studies varied widely since, the values from the theoretically generated raw materials were standardized with an overall moisture content of 41.7% and the analyzed oven dried samples had a moisture content of 53.2%, thus indicating a change in the dry

weight between both the values. The theoretically generated dry weight was observed to be 86.9kg and the analyzed proper overall dry weight was observed to be 69.7kg, which was relatively low. The moisture content varied but the compost calculated recipe and analyzed recipe was similar by the dry carbon and nitrogen weights. The final compost had approximately 28.17:1 C: N ratio from the composting study, when tested externally with the help of Harlow Institute, Dalhousie University Campus, Truro, Nova Scotia.

4.1.2. ANALYSIS OF PHYSICAL PARAMETERS

4.1.2.1. Bulk Density of Compost

The compost degradation is generally affected by particle size, bulk density, water retention capacity, and porosity (Iqbal et al., 2010). In the SD+GC-based composting study, the initial compost had a bulk density of 379 ± 0.3 kg dry $m^{-3,}$ and the final compost had a bulk density of 450 ± 0.1 kg dry m^{-3}. This was due to a reduction in both mass and volume, which was prominent during the composting process.

The bulk density of the final compost increased by 15.78% by the end of 125 days of composting. This bulk density increase resulted in a decreased water holding capacity during the process of composting and increased heat, assisting in the thermophilic phase of composting.

4.1.2.2. Water Retention Capacity of Compost

The water retention capacity of the final compost was observed to be 2.81±0.2 kg dry kg^{-1} (Table 4.1), which determined the higher decomposition rate compared to the other compost materials like the water retention capacity of cow dung compost in the range 1.2 to 1.3±0.2 kg dry kg^{-1} (Vengadarama, 2012).

The water retention capacity was simultaneously reduced as the action of composting by the shafts and the rapid microbial decomposition in the composter. Thus, the lower the bulk density, the higher the water retention capacity during the composting process (Table 4.1).

4.1.3. COMPOST TEMPERATURE PROFILE IN COMPOSTING STUDIES

The compost's overall mean temperature for SD+GC study (Figure 4.9) was observed to be on an average of 38.5ºC, and the ambient temperature was recorded to be on average of 23.7ºC (August 2019). Typically, the heat evolved in the system rapidly increased when the composting mixture was first established inside the system due to rapid microbial decomposition. It was observed that temperature reached its thermophilic phase (>45ºC) in less than 24 hours. The quick increase in temperature was observed early in the SD+GC study, maintaining a thermophilic phase until Day 10. Since the compost had decreasing moisture content and higher carbon content, the composting process rate decreased, increasing the heat in the system.

An addition source of heat relates to the green crabs which are rich in calcium. The calcium reacts with carbon dioxide to form $CaCO_3$, which follows an exothermic reaction to expel heat resulting in moisture reduction during the overall composting process (Denise & Brian, 2002). Heat generation and loss was typically due to microbial activity in the composter. The compost temperatures show a declining trend after the initial thermophilic period, which resulted in a rapid moisture loss in the system. The loss in moisture content paused the microorganism activity in the composter. During the first

seven days, the microbial consortia were very active, decomposing the substrates in the in-vessel composter, thus radiating heat, and increasing temperatures in the vessel.

The thermocouple had been measuring the temperature in five regions inside the composter hourly and their average per day was recorded in the graph. The average of temperature 1, 2, 3, 4, and 5 indicated the regions on the thermocouple in the centre of the composter (Figure 4.1). The average recorded over each day was used in identifying the change in rapid, slow and steady phases of composting, based on mesophilic and thermophilic temperature range.

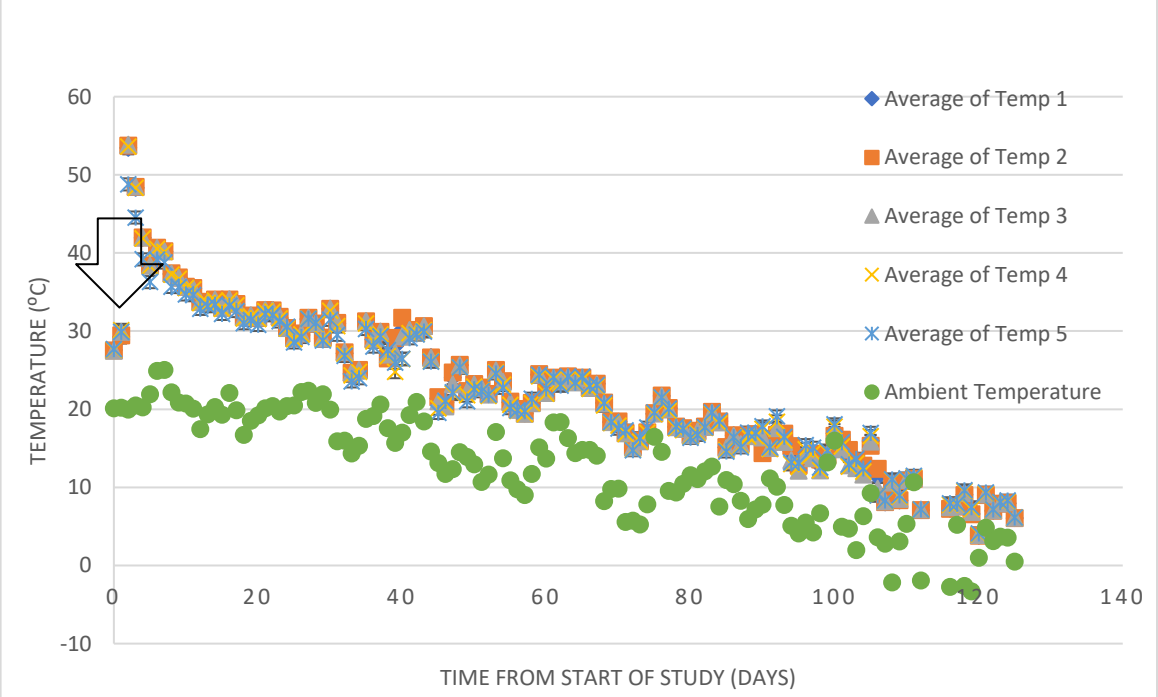

Figure 4.1: Compost temperature profile of the SD+GC composting study over 125 days (n=24) Note: Arrow indicates the beginning of composting study.

After the thermophilic phase of composting, the temperatures decreased, suggesting a reduced level of microbial activity leading into the secondary curing phase, where the drying of compost occurred until Day 27 when water was added. The mesophilic phase of composting and the ambient temperature after Day 30 from the SD+GC study (Figure

4.9) followed the same parallel decrease in temperature along the curve. The microbes in the compost medium degrade the organic matter gradually over the curing period, regulated partly by consistent airflow (oxygen supply) and access to water.

The temperature drops along the study indicated the minimal microorganism growth in the composter. After reaching the maturity phase from both the composting studies, the final compost had a low odour and finer particle size.

4.1.4. MASS CHANGE OF COMPOST OVER TIME

During aerobic decomposition, one part of carbon and nitrogen present in the raw material is utilized by microbes, and one part of the carbon is evolved as carbon dioxide (Meena et al., 2020). As a result, the carbon content and hence mass of the compost decreased throughout the process when the acceptable moisture content (55%) was maintained over the composting periods. Over the duration of the study, the compost's mass decreased non-linearly due to physical loss from the composter and microbial activity (Figure 4.10). After the entire composting process of 125 days, the initial compost mass was decreased by 40.3% for the SD+GC study. Due to the drying out of the composter during the initial days of composting, a physical loss of compost material in the form of dust on Day 27 was observed but could not be quantified. After Day 28 as the moisture content was maintained, the mass loss was attributed to microbial decomposition. Three mass loss phases associated with composting were rapid, slow, and stable phases (Figure 4.2). The maximum mass loss was the slow phase of composting, approximately 25.44%, and the least mass loss was observed during the stable and matured composting phase of 0.67% (Table 4.2).

Table 4.2: Mass loss observed as a result of the subsampling and physical loss during the composting phases during SD+GC Study

Mass loss phase	Duration (Days)	Mass loss over SD+GC Study (%)
Rapid	0 to 27	14.12%
Slow	28 to 57	25.44%
Stable	57 to 125	0.67%

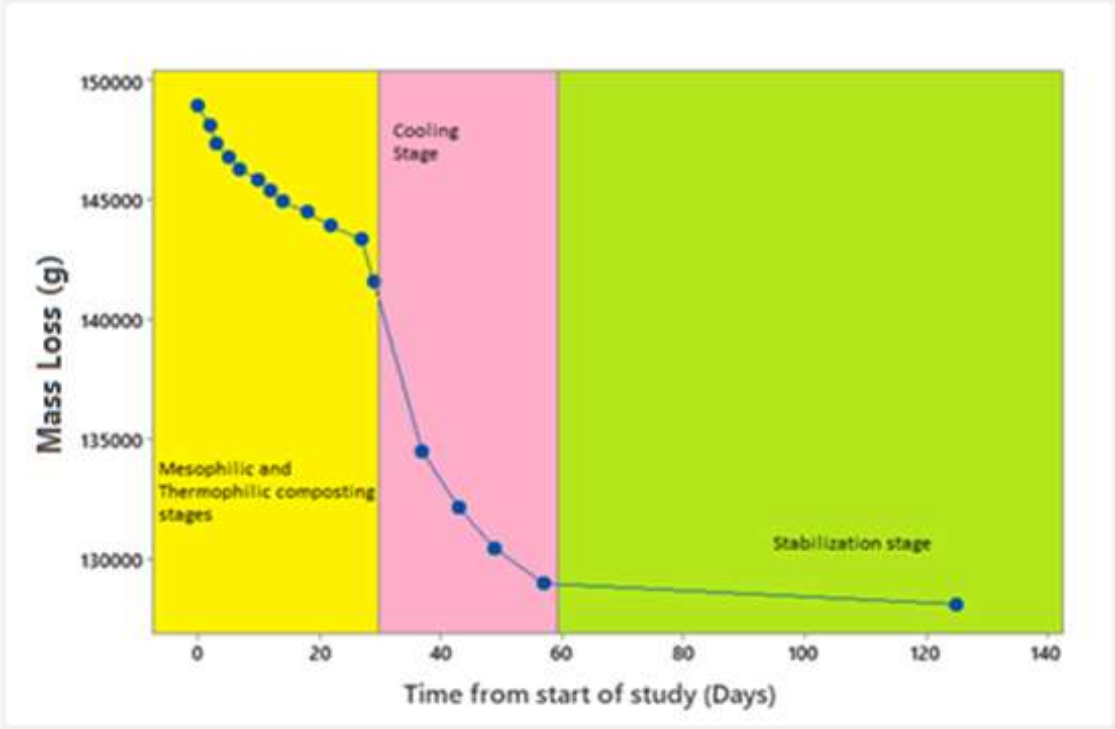

Figure 4.2: Variation of mass observed over the SD+GC based composting study over the composting period of 125 days.

4.1.5. ANALYSIS OF CHEMICAL PARAMETERS

4.1.5.1. Moisture Content Changes in Composting Studies

The moisture content during composting provides some perspective on whether moisture might be a limiting factor for microbiological activity (Huerta-Pujol et al., 2010). The raw materials' initial moisture content in green crab and sawdust was 66.02% and 46.85%. The raw materials had a high enough initial moisture content to meet the composting

target of 53% (ideal range: 50 to 55%). When the study was initiated, subsamples were collected regularly but subsequently stored in the freezer for analysis later.

It was analyzed from the sub-samples, that the compost material would dry out slowly (Figure 4.3). However, a change in the ambient conditions, i.e., the greenhouse started heating up rapidly over the first part of the study, and an increase in temperature in the composter led to rapid loss of moisture. Increasing temperature in the composter was recorded (indicated the microbial activity), together with the ambient temperature led to the moisture loss until Day 27 in the SD+GC Study. The extreme loss of moisture from the compost samples was not determined until Day 27, when a physical loss of materials from the composter, as a fine dust was observed.

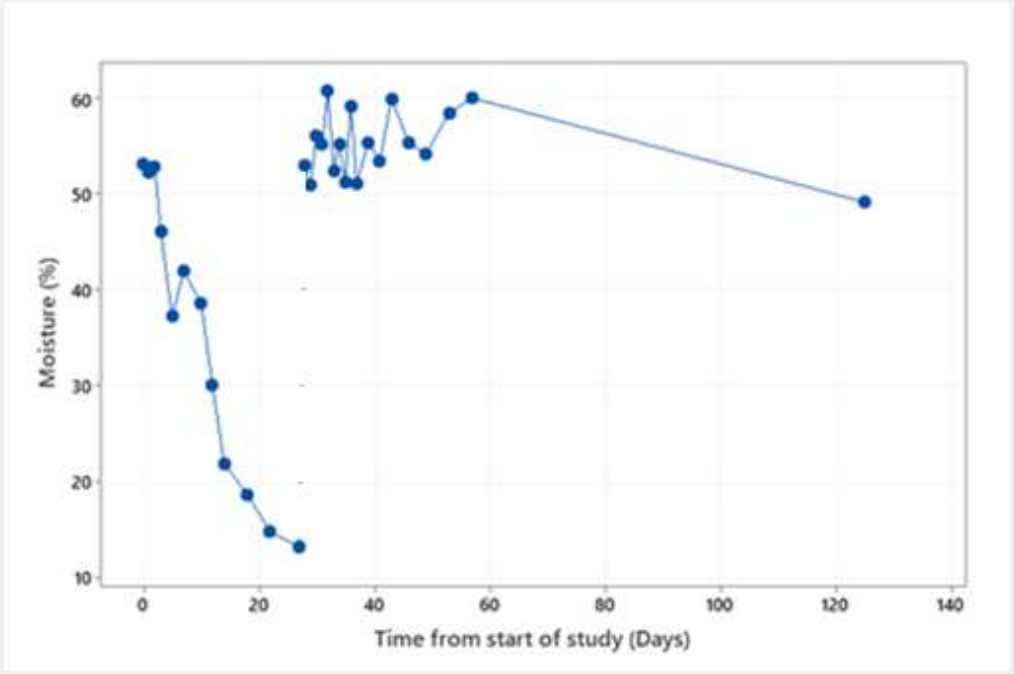

Figure 4.3: The moisture content variation for the 125 days period over the SD+GC in the in-vessel composter.

At this point, it was determined that the compost needed very regular water supplementation. From Day 27 onward, samples were tested for moisture content

regularly, and water was added to ensure that the compost moisture content was maintained approximately at 55%. On Day 27, 15 litres of water were added into the composter. Based on the calculated moisture content and the added water, water loss was computed from the initial moisture content determined. The moisture loss was high during the initial composting stages. The green crabs' rich in calcium, reacts with carbon dioxide to form $CaCO_3$, forming an exothermic reaction, which expels heat, thus also drying the compost in the in-vessel composter. The samples collected from day 28 to day 125 tend to have no significant differences because the moisture content is maintained at 55%.

4.1.5.2. Total Carbon – Total Nitrogen Dynamics

Various elements are involved in the microbial decomposition of composts, carbon and nitrogen being essential ones. The change in total carbon and nitrogen reflected the decomposition of organic matter and stabilization during the SD+GC composting study. The decomposition brought out by the microorganisms utilizes carbon as the source of energy and nitrogen as a building material for cell structure (Kalamdhad et al., 2010). The total carbon associated with the SD+GC study showed decreases over the study (Figure 4.4). The heterogenous chemical nature of the substrate was the critical factor in determining the rate of the process. During the composting study, the C: N ratio was measured after three months of composting, which was lower than the final C: N ratio. An essential aspect of compost is the total carbon and total nitrogen. The general optimum C:N ratio of the fish wastes-based compost was observed to be in the range of 25:1 to 30:1 (Pace et al., 1995). The rate of decomposition occurred at a slower rate at the initial composting stages based on the total carbon content (%). Since the moisture content kept

dropping from 55% (Figure 4.3), the lower moisture content deprived the microbes of water needed for the metabolism and inhibited their activity resulting in slower composting. The enough moisture content allowed dampness to prevent the microorganisms from becoming dormant. After the addition of water, the microbial activity rate increased again and then started decaying carbon at an increased rate under more ideal moisture conditions as shown in Figure 4.3.

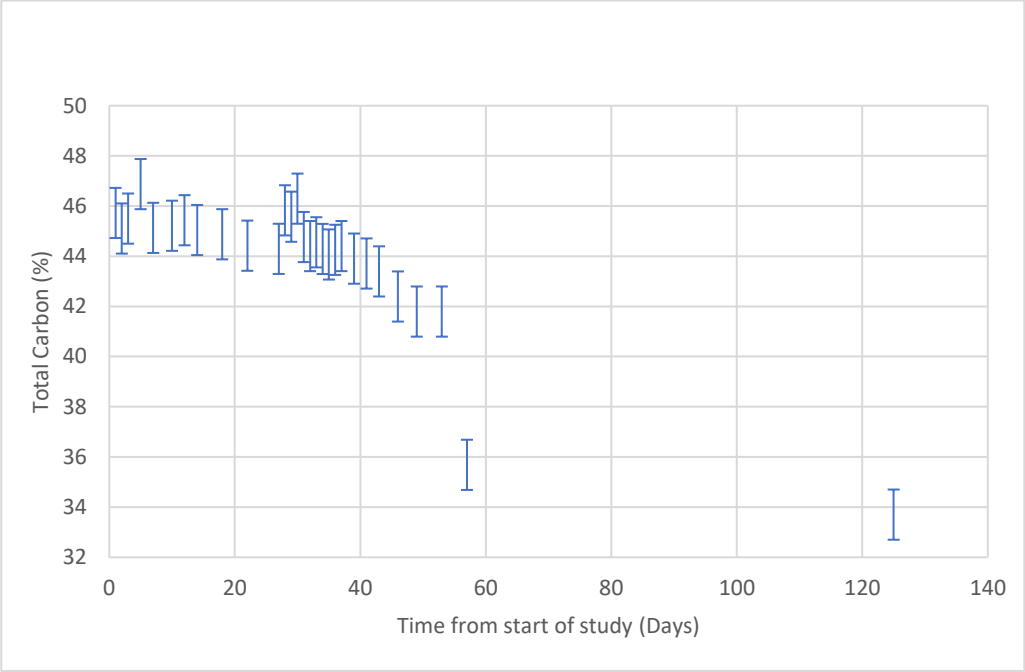

Figure 4.4: Total carbon change observed with respect to the sampling period in the SD+GC study for an overall period of 125days.

As the composting proceeded, the total carbon gradually decreased from the beginning. Sawdust has a smaller particle size than many other carbonaceous feedstocks, i.e., a greater surface area, that may allow for higher microbial growth.

The initial carbon content was measured as 45.84% at the beginning of study and as the composting proceeded, the total carbon gradually decreased from this initial value. The decomposition continued through the thermophilic phase of composting, where the

carbon content almost remained 45.46% since there was water loss encountered (Figure 4.4). After the thermophilic phase of composting, as the moisture content from Day 12 to 27 was not maintained, the carbon content decreased from 45.18% to 44.27%, indicating a decline in the microbial population. At 28 days when the moisture content was increased led to further decomposition to 35.14% during the mesophilic phase of composting. After day 57, the compost started reaching the maturation stage of composting, and water was not externally added to maintain moisture content. But after the maturation phase, the compost reached a total carbon content of 34.96% by Day 125 (Figure 4.4).

The decomposition rate of organic matter depends upon both the properties of the substance and the accessibility to microorganisms and their enzymes (Ekschmitt et al., 2008; Lutzow et al., 2006; Brodowski et al., 2006). The compost released carbon throughout the experiment (Figure 4.5); the amount of carbon present at the end of the composting study was calculated to be 25500 g dry C d^{-1}, which is roughly half the value of the estimated initial value of 41059 g dry C d^{-1}(Figure 4.5). The results of the respiration study (Figure 4.6a & b) showed that the decomposition rate tends to peak during the initial days of composting, then gradually decreased along with Day 28 to Day 57 of composting (Figure 4.5) and stabilized along with the maturation phase of composting.

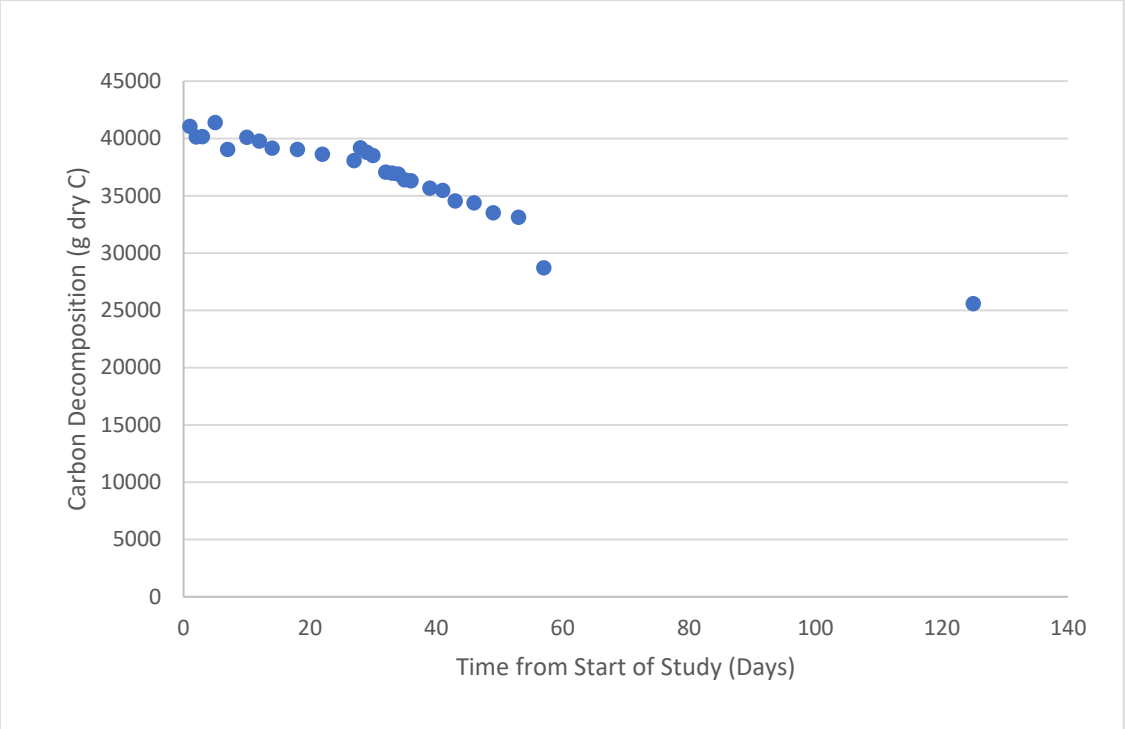

Figure 4.5: Decomposition of carbon (mass basis) in the in-vessel composter during the SD+GC study conducted over a period of 125 days.

As shown in Figure 4.6, the total nitrogen concentrations slowly increased over the 125 days of composting. Marine organisms are rich in nitrogen and as they decompose will release ammonia, nitrate, and soluble organic nitrogen, whereby some of the soluble organic nitrogen can be converted into microbial biomass. The composter maintained a uniform increase after Day 2 of composting from 2.65% to 4.18% (Figure 4.6) on Day 12 during the thermophilic phase of composting. The mesophilic phase of composting had a consistent percentage of nitrogen of 3.95 ± 2%, from Day 28 to Day 57, with a maintained moisture content of 55% (Figure 4.3). The maturation phase of composting yielded the final nitrogen value, which represented the starting value for further plant growth studies. The microorganisms die when the moisture content drops, hence after Day 27 when the moisture is raised back to 55%, the new microorganisms develop in the

compost. The old microorganisms decompose along the composting study and the nitrogen concentration changes slightly increases to 4.18%.

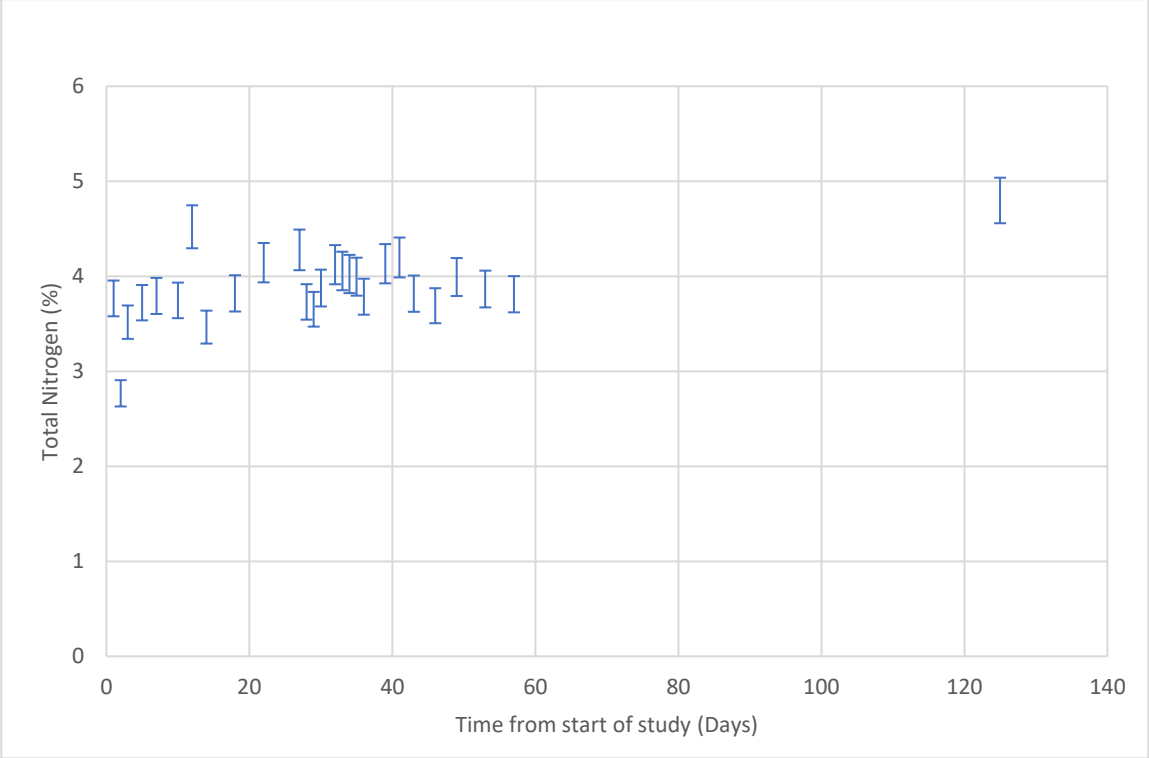

Figure 4.6: Change in Total nitrogen concentration observed with respect to the sampling period in the SD+GC study for an overall period of 125days.

When the total nitrogen was plotted against the sampling period, the relationship was observed to be statistically significant ($p<0.05$). The average of the total nitrogen content increases along the sampling days, the standard deviation is higher throughout the distribution. When the total nitrogen replicates are higher than the other replicate, the SD has been observed to be higher due to the insufficient number of replicates analyzed. The nitrogen content (%) on Day 125 was observed to be 4.66% in a similar curve; the point was observed to be the result of the total nitrogen (%) after the maturation phase of composting.

The initial concentration of total nitrogen in the raw materials at the beginning of the composting studies was 3374 g dry. As a result of composting, the large amount of available nitrogen present in the raw materials started mineralizing and were likely taken up again into organic forms. The nitrogen content continuously increased over time and continued to rise along the sub-sampling days. The nitrogen stabilized towards the end of the study to 3782 g dry (Figure 4.7). The nitrogen mineralization occurred along the initial stages from Day 2 to 12 along with the thermophilic phase of composting (Figure 4.7), following a 30% drop from the initial raw material study, which had been observed to be the highest decline in nitrogen content. After Day 27, water was added to the composter, hence initiating the microorganism growth again; thus, a slight decline of 12.1% was observed and started increasing after Day 28 (3107 g dry N d^{-1}) till Day 125 (3782 g dry N d^{-1}), when the maturation was reached.

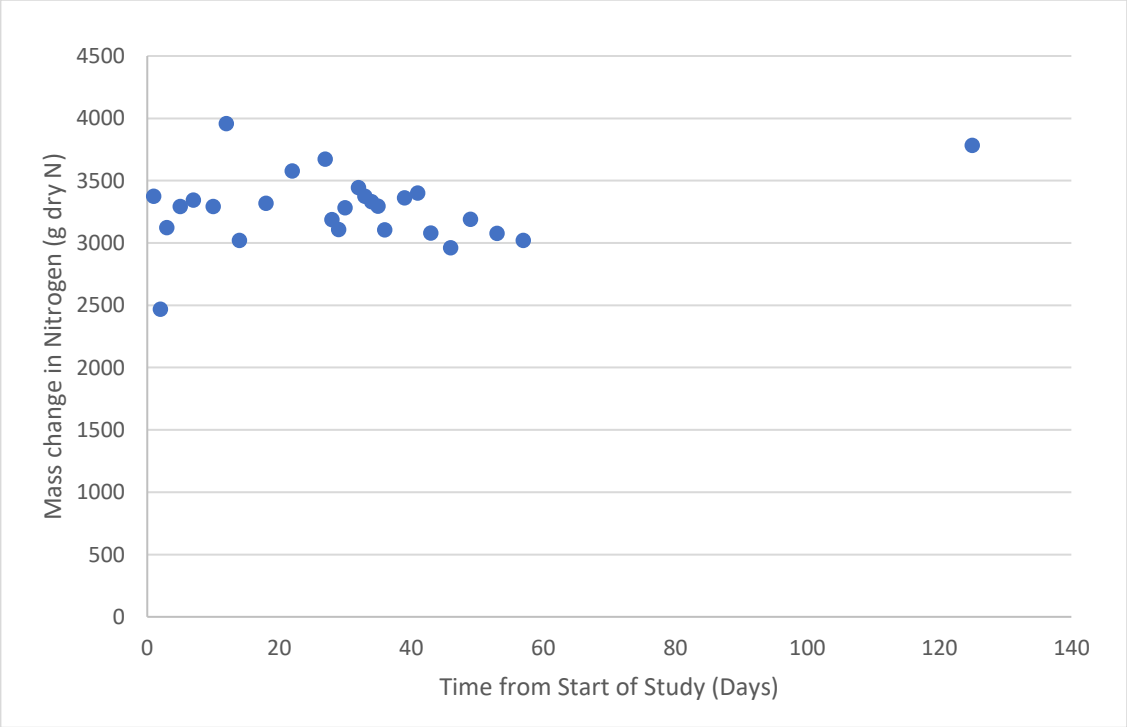

Figure 4.7: Change in mass based on Nitrogen in the in-vessel composter during the SD+GC study conducted over a period of 125 days.

4.1.5.3. Changes in Organic Matter Content in the Composting Studies

The change in the organic matter content in the compost material varied based on the heterogeneity of the samples over the composting period, particularly over the initial sampling times. The decomposition of compost throughout the study is affected by the OM content but during the initial stages of composting was more influenced by the moisture content. Sullivan et al., (2018) stated that lower the moisture content, higher the amount of organic matter per ton of the compost, similarly, the moisture loss during the initial stages of the SD+GC composting study, the moisture content declined up to Day 27, which further indicated the organic matter increase. Initially, the OM was observed to be 0.88 ± 0.5 on Day 1, increasing to 0.93 ± 0.03 (Figure 4.8) until Day 14, indicated that the composts have not been thoroughly composted (Sullivan et al., 2018), which indicated the increase. The rapid moisture loss (< 11%) indicated high organic matter in the compost sub-samples collected. The composts with high organic matter resulted in low bulk density and high-water retention capacity (USDA, 1996), similarly, the high organic matter in the SD+GC composts, resulted in lower bulk density and higher water retention capacity (Table 4.1). The increase in organic matter during the initial stages of composting resulted in heterogeneous sub-samples since the raw materials have not been completely composted during the initial composting days in the absence of moisture. The organic matter on Day 125 was observed to be 0.84 ± 0.01%. The samples were quite heterogenous in nature resulting in an increase along the initial days of composting.

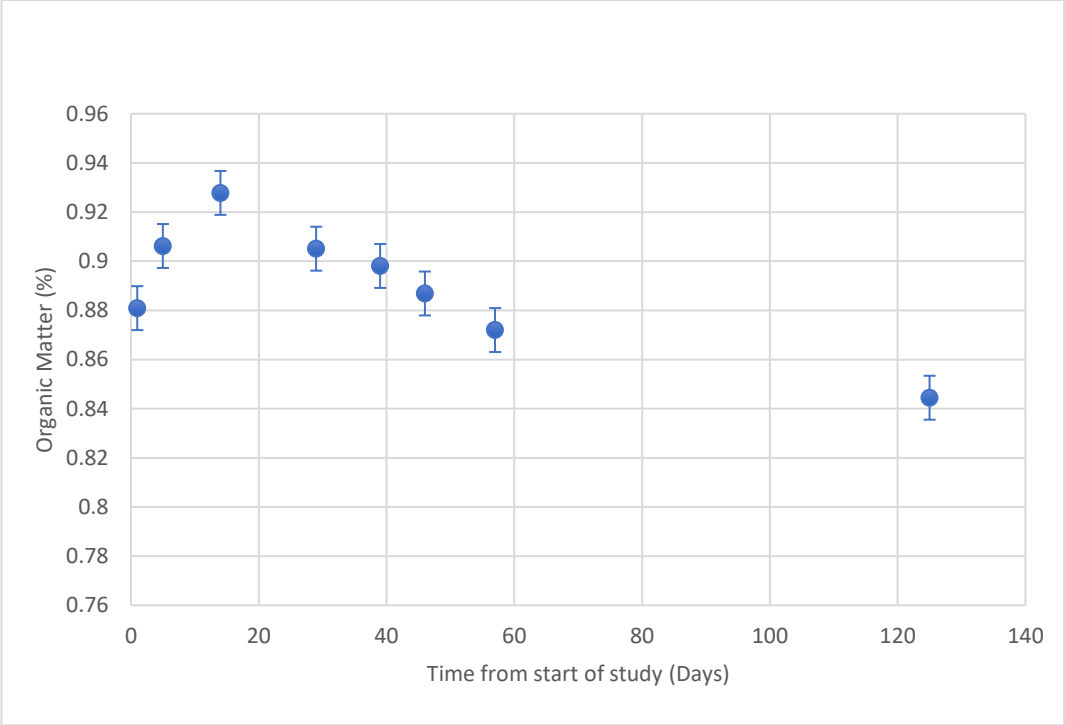

Figure 4.8: Organic matter determined as per the TMECC method by burning in the muffle furnace at 550ºC (n=3).

The difference between the highest point and where the curve plateau suggests that decomposition of organic matter likely to have occurred through the composting process. The organic matter increases from 88% to 93%, is associated with the initial days of drying of compost, which involves manual errors associated with the measurements related to sub-sampling periods, whereas the Day 28 to 125 had shown a decline in the organic matter content similar to the total carbon content measured in samples along the same time period.

4.1.5.4. Carbon Dioxide Evolution Rate

The carbon dioxide evolution rate is useful as a measure of the stability of the compost because it measures the carbon derived directly from the decomposition of the organic matter. The respiration study is relatively used as a mechanism to determine the quantity

of easily available carbon in the composter, which is utilized by the microorganisms, by quantifying the amount of carbon dioxide evolved. When the raw materials are physically agitated in the composter using rafts by providing adequate air, the microbes utilize the environmental conditions and break down the carbon and decomposition occurs along a rapid scale. The optimum aerobic environment is estimated to differ in the length of time over sealing through the samples collected over the composting period based on the maintained temperature of 30±0.5ºC. In the first 27 days of the SD+GC composting study, the microorganisms could not consume oxygen to break down the carbon in the compost material in the process of cellular respiration, due to the increase in temperature and drying of compost. During the initial 27 days of composting, the decline in the carbon dioxide rate, (Figure 4.9) was observed due to the insufficient quantity of water and oxygen for the microorganisms for the decomposition. The respiration rates kept increasing during the first 57 days of the SD+GC composting. As shown in Figure 4.6a & b, the highest respiration rate was observed during the first 8 hours and then decreased thereafter. The carbon dioxide evolution rate at each sample point over the 0 to 4, 4 to 8, 8 to 24, 24 to 48, 48 to 72, and 72 to 96-hour periods (Figure 4.9). The carbon dioxide evolution rate over the incubation sampling period for Day 1 samples was calculated to be 1.79, 3.05, 1.5, 0.71, 0.81, 0.70 mg g^{-1} CO_2 – C hr^{-1} (Figure 4.9). On Day 125 samples of the composting study, the evolution rates were calculated to be 1.54, 2.48, 1.5, 0.32, 0.37, 0.28 mg g^{-1} CO_2 – C hr^{-1}. The respiration rates of carbon dioxide rate decreased along the incubated times. The decline in the respiration rate after 8 hours was due to the longer duration that the incubation vessels remaining sealed. When the incubation vessels were sealed for a longer period of time i.e., greater than 4 hours (16 hours and 24 hours),

microbial activity declined possibly due to the lack of oxygen in the sealed containers and not necessarily due to a lack of carbon. Respiration is a sensitive indicator of compost stability and directly correlates with the state of aerobic biological activity in the organic matter (Jokova et al., 1997). A standard carbon dioxide evolution rate for a fully matured compost has been determined to be 4mg of CO_2 – C /g of OM/day (Canadian Council of Ministers of the Environment (CCME), 1996).

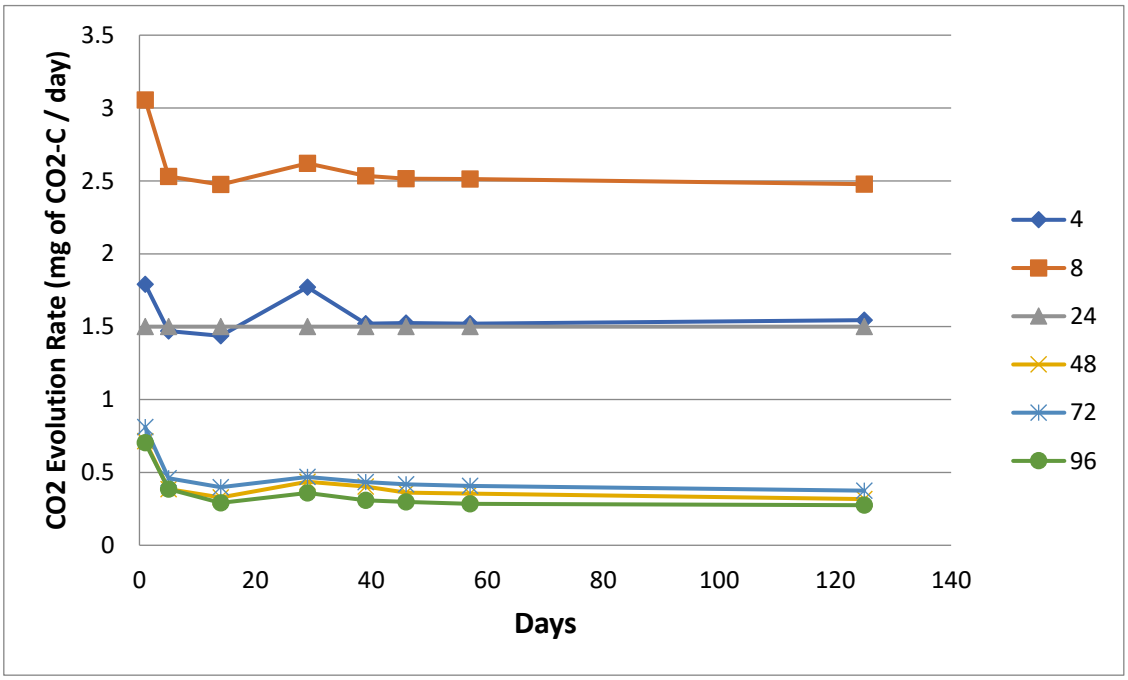

Figure 4.9: Carbon dioxide evolution rates for SD+GC compost samples collected over a 125-day study and incubated for different amount of time over a 4-day period highlighting per day.

There was a decline in the rate observed from Day 1 to Day 27 due to the loss of moisture which made the environment unsuitable for microorganisms to survive upon during the initial composting study. The lower final values of CO_2 evolution rate provided a more stable and quality compost during the in-vessel composting technique. After the compost entered the maturation phase, the CO_2 rates started decreasing due to the lack of available carbon, which suggested a more mature organic material.

The cumulative respiration rate showed a maximum CO_2 release through the composting study (Figure 4.10). The rate constant for cumulative carbon dioxide evolved was calculated based on the 8th hour readings from the incubation test (b = 0.0296), which showed that the microorganism activity had been more active during the initial days of composting. The equation used was y=a*(1-exp(-bx)) since the data remained an increasing curve. The response curve plotted for the SD+GC showed higher carbon dioxide evolution rate early during the composting study plateauing later in the study, which denoted lesser microorganism activity (Figure 4.10).

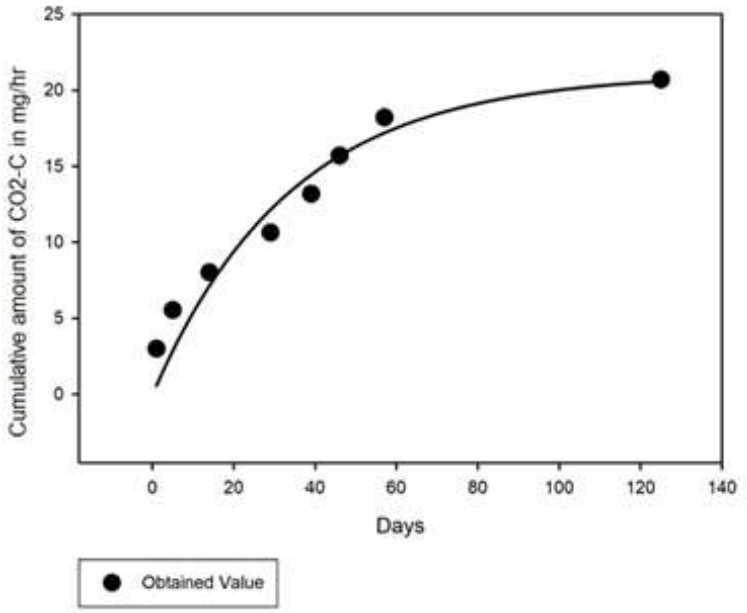

Figure 4.10: Final first order non-linear response recorded with respect to the cumulative CO_2 – C observed in the SD+GC Study (rate constant=0.0296).

The carbon dioxide evolution rate from Day 1 and Day 29 are statistically different from each other, which indicated the drying out of compost due to moisture loss which led to less carbon consumption by microorganisms, hence a declining trend is observed between Day 1 and Day 27 of the composting. Similarly, Day 39 is statistically different from Day 1 and Day 39 depending upon the carbon dioxide consumption and the temperature based

on the microorganism activity in the composter (Figure 4.1). Similarly, the organic matter, total carbon and the carbon dioxide evolution rate helps in establishing the maturity of the compost (Figure 4.4, 4.8 and 4.11) indicates that the maturity of composts occurs after Day 29 and stabilizes along Day 57.

Table 4.3: Analysis of Variance generated among the sub-sampled days over the entire composting study based on the optimum carbon dioxide evolution rate

Source	DF	Seq MS	F-Value	P-Value
Days	7	0.7868	144.5497	0.0001

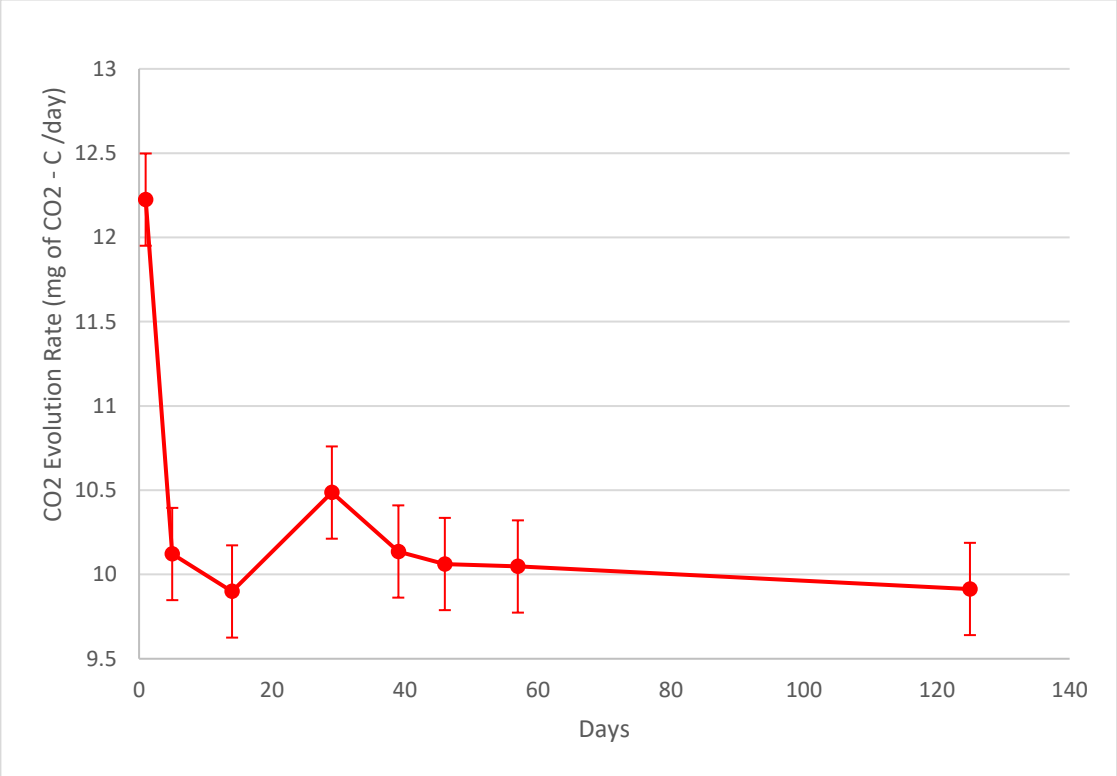

Figure 4.11: Least square means plot of hourly rate of carbon dioxide generation differentiating the 8-hour sampling from others over the 4-day period.

4.1.5.5. Extraction of Chitin from Compost

Table 4.5 lists the yields of chitin obtained from various sub-samples collected throughout the SD+GC composting process. The table shows the chitin content varied between 24% to 32% (on a dry weight basis) (Table 4.4). The highest percentage of chitin percentage

was recorded on Day 125 of composting study. These results are consistent with when the composting study reached the maturation phase of composting. From other studies in the literature, the chitin yields from other crustaceans such as lobsters, crayfish, and squills were observed to be 23.2 – 23.8% (Acosta et al., 1996), and the European green crabs were 12.6 – 14.5% (Naczk et al., 2004). In contrast, the chitin concentration obtained from the GC compost after composting was observed to be higher compared to the raw crab shells through the matured composting phase (32%).

Table 4.4: Composition of chitin yield after the demineralization and deproteination of crab shells in the SD+GC composting study

Time from Start of Study (Days)	% Recovery after demineralization	%Recovery of chitin from crab compost
1	39	24.75
53	36	27.86
125	44	32.01

4.2 STUDY 2 – STRAW AND GREEN CRAB

4.2.1. GENERAL ANALYSIS OF PARAMETERS

A mix of green crab and straw were taken in the ratio 1:4, where the physical and chemical parameters are entered in the Table 4.5. The straw-based compost towards the end of the collection of composts had a moisture content of 0.25% and organic matter of 81.8% which was observed to be higher than the SD+GC compost study (77.5%) (Table 4.1). The total carbon was higher in SW+GC composting study with 44.8% and SD+GC compost with 32.9%, similarly, total nitrogen was 1.6% in SW+GC composting study and 1.2% in SD+GC study. The bulk density was higher in SW+GC composting study (650 kg dry m^{-3}). On the contrary, the water holding capacity was higher along the SD+GC composting study (20.81%) (Table 4.1). This further indicated that the SW+GC

composting study was precisely higher than the SD+GC composting study in parameters like Total Carbon, Total Nitrogen, Bulk Density and Moisture content. The moisture content and water holding capacity was higher in SD+GC composting study based on the final data observed.

Table 4.5: Final compost physical and chemical parameters observed in the SW+GC compost (n=3)

Parameters	Final Compost Characteristics (mean ± SD)
	SW+GC Study
Moisture Content (%)	0.25 ± 18.6
Loss on Ignition (%)	81.18 ± 2
Total C (%)	44.80 ± 1.8
Total N (%)	1.63 ± 0.6
C: N Ratio	27.49 ± 2.3
Bulk Density (kg dry m^{-3})	650 ± 0.1
Water Holding Capacity (%)	12.21 ± 0.4

The plant-based composting study was utilized to see the composting properties associated with the green crabs, which typically include cellulose, hemicelluloses, lignin, lipids, proteins, simple sugars, starch, water, hydrocarbon, ash, and other compounds (Jenkins 1998), since the straw based raw materials had higher carbohydrate materials, the required frequent monitoring of moisture content. The straw-based compost was tested for pH and estimated to be quite alkaline in nature (8.0 – 11.0). This straw contains 38% cellulose, 25% hemicellulose, and 12% lignin (Japan Institute of Energy 2002). Compared to the wood-based materials, the straw contains low cellulose and lignin, but it is higher in hemicellulose content (Barmina et al., 2013).

4.2.1.1. Comparison of The Calculated Value and The Analyzed Value

The total carbon and nitrogen of green crabs were already calculated during the Study 1, hence the difference between the compost recipe and analyzed value were quite similar. For the study 2, the straw values were taken from the NRAES composting manual which yielded an overall dry carbon weight of 23.1kg but the LECO – CNS 2000 yielded a dry carbon weight of 16.5kg, which showed a difference of approximately 7kg, but the nitrogen weight was similar in both the theoretical and analyzed values (0.4kg). The moisture was higher in the general straw data collected from the manual (12%), similarly the collected data indicated that the analyzed moisture content was lower, which further resulted in the compost recipe C:N ratio of 38.9:1, but the analyzed data yielded the C:N of 25.5:1.

4.2.2. ANALYSIS OF PHYSICAL PARAMETERS

4.2.2.1. Bulk Density of Compost

Bulk density is dependent on the particle size and the texture of the compost. The compost with straw has a smaller particle size is less porous; on the other hand, finer-textured composts result in high bulk density. The bulk density is also used to determine the quality of the compost and growth assessment of the crops in the medium. The bulk density of the final compost was found to be 650 ± 0.01 kg dry m^{-3} (Table 4.5) from the initial raw materials straw and green crabs having a bulk density of 530 ± 0.12 kg dry m^{-3} and 890 ± 0.1 kg dry m^{-3} (Table 3.1). As the bulk density increases, the particle size associated with final compost is minimal.

4.2.2.2. Water Retention Capacity of Compost

The compost's magnitude of water retention capacity was determined by particle size and porosity of the compost. The straw had a capacity of crusting easily when accumulated and not agitated over the composting period. The water retention capacity was comparatively lower in straw since the particle size was minimal and compacted easily when added to any growth medium. The water retention capacity of the compost was 12.21 ± 0.4%.

Thus, the bulk density was higher along with the SW+GC composting study (650 ± 0.01 kg dry m^{-3}) and lower in the SD+GC composting study (450 ± 0.01 kg dry m^{-3}), which had lesser water retention capacity and lesser carbon decomposition along with the study.

4.2.3. COMPOST TEMPERATURE PROFILE IN COMPOSTING STUDIES

As shown in Figure 4.21, the temperature profile associated with the SW+GC composting study began to rise slowly after establishing the composting conditions by incorporating raw materials in the composter. As expected, the temperature increased for all the composters during Winter 2020. The compost never reached the thermophilic phase for the following reasons: (i) The ambient temperature in this study was very low, which affected the temperature during composting, thus resulting in lower temperature. Due to the winter weather, the fan was drawing in more dry air, resulting in the drying of compost more quickly. The maximum temperature recorded in the composter was 28.5 ± 1.5ºC (Figure 4.12), so this composting study never reached the thermophilic phase of composting. The ambient temperature was recorded up to -5.7 ± 0.5ºC, which affected the composting temperature. (ii) Initial stages of composting were associated with the high-

temperature range, whereas the composter temperature was high, but it had not reached a peak temperature. The number of green crabs added was relatively low; hence the temperature was also not affected by the exothermic reaction of the green crabs. The temperature showed an increase along the thermophilic phase of composting but decreased after Day 30 since the ambient temperature was relatively low throughout the process of composting. The temperature variation occurred at a higher rate depending upon the quantity of green crabs added to the medium. But to maintain a C: N ratio of 25:1, the strawweight had to be increased to the ratio of 1:4 (w/w).

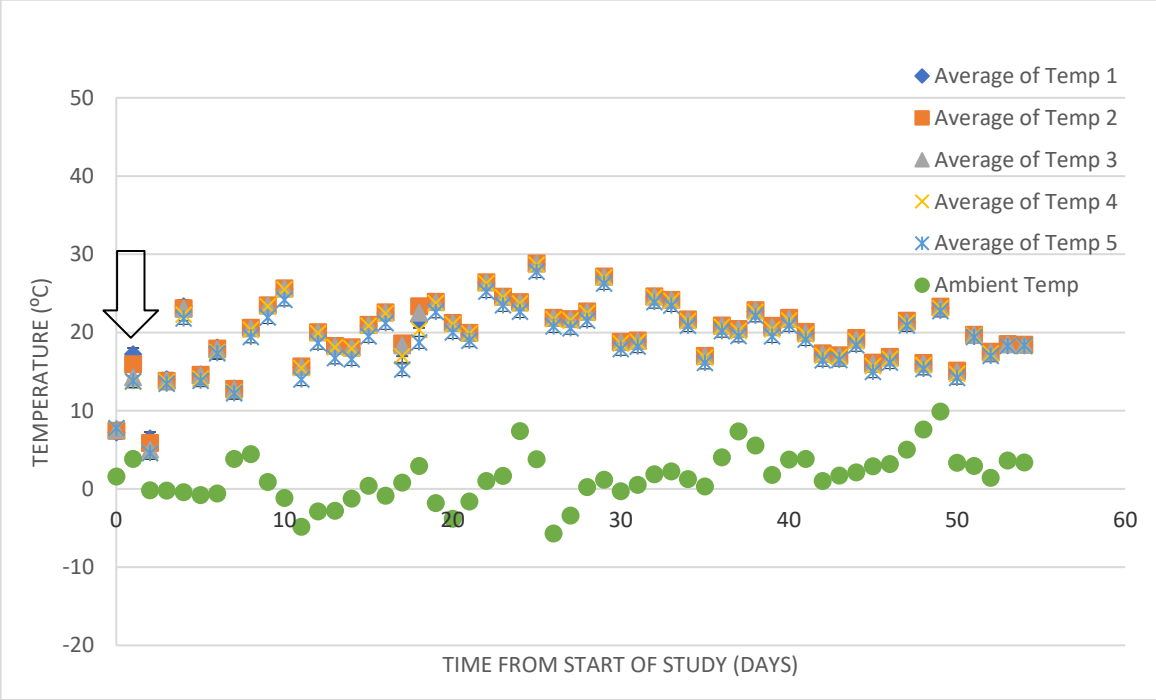

Figure 4.12: Compost temperature profile of the SW+GC composting study over 54 days Note: Arrow indicates the beginning of composting study.

The ambient and composter temperature associated with SD+GC composting study was very high, which resulted in quicker moisture loss and drying of compost. Despite the higher temperature, the water loss was lower in the SW+GC study; thus, the rate of

carbon decomposition was also lower. The SD+GC composting study consumed more water compared to the SW+GC composting study.

4.2.4. MASS CHANGE OF COMPOSTS OVER TIME

The initial weight of raw materials determined from the composting recipe sheet; the sub-samples were collected with a sub-sampling average of approximately four days. A final mass was determined at the end of the study. With the provided duration, the temperature, and the microbial activity in the composter and hence the compost's mass decreased non-linearly over the duration of the test. After the entire composting process of 54 days, relative to initial residue, the mass decreased by 21.81% for the SW+GC study. The composter had an initial moisture content maintained in the range of 40 to 55%. After Day 37, the composter remained unattended until Day 54, which led to a loss of moisture content, thus rapidly slowing the decomposition rate. The three mass loss phases associated with composting were rapid and slow phases (Figure 4.13), where the maximum mass loss was along with the slow phase of composting approximately 9.45%, a minor mass loss was observed during the stable and matured composting phase 0.67% (Table 4.6).

Table 4.6: Mass loss observed as a result of the subsampling and physical loss during the composting phases during SW+GC Study

Mass loss phase	Duration (Days)	Mass loss over SW+GC Study (%)
Rapid	0 to 27	9.97%
Slow	28 to 54	11.84%
Stable	NA	NA

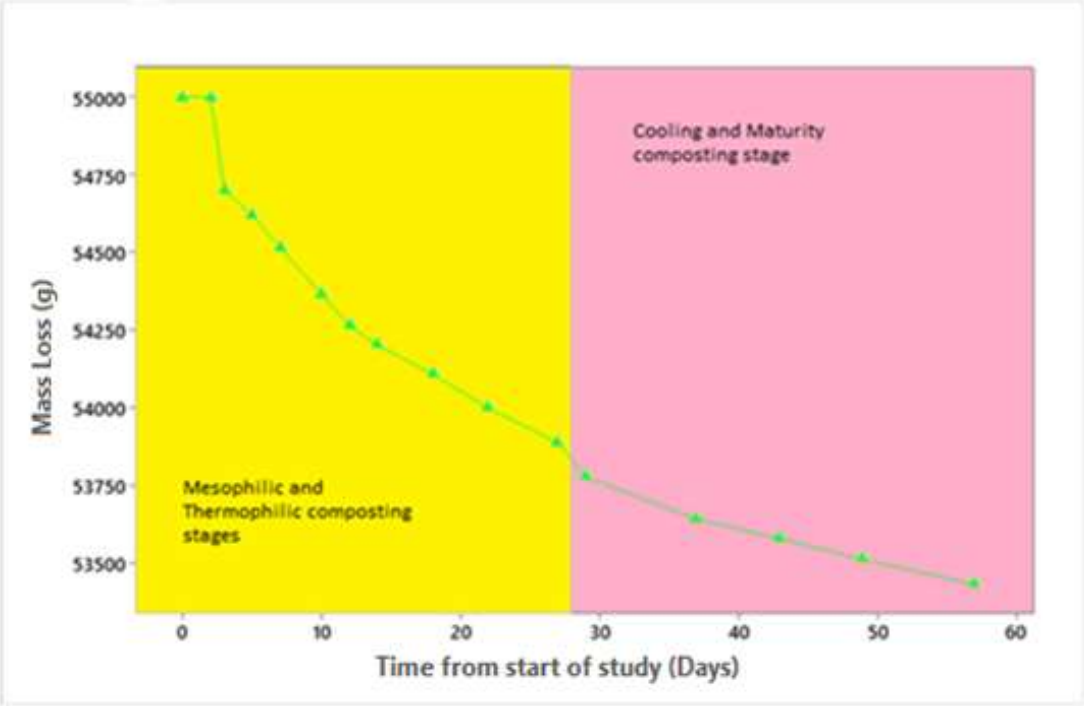

Figure 4.13: Variation of mass observed over the SW+GC based composting study over the composting period of 54 days.

4.2.5. ANALYSIS OF CHEMICAL PARAMETERS

4.2.5.1. Moisture Content Changes in Composting Studies

Unlike the SD+GC study, in the SW+GC study, the moisture content was monitored throughout the compost study and adjusted to 40 to 55% by adding water for the first 43 days. The turning of composts throughout the composting study altered the moisture content as heating increased during the earlier stages of composting. The moisture loss was occurring as a result of the ambient conditions and the temperature associated with composting. Due to the winter weather during February 2020, the fan was drawing in more dry air, resulting in the drying of compost quickly. Hence water was added to the composter.

Figure 4.14 shows the moisture content of the compost throughout the study period. Low moisture contents of the composting materials affect the availability of oxygen for

microbial processes and therefore, the moisture loss was compensated by adding water to maintain the moisture content. The ambient temperature played a prominent role in the moisture loss. The average water lost from Day 1 to Day 37 was 1.7±0.3L.

In contrast, towards the end of the composting, the composter was left unmonitored from Day 43 to 57 due to the pandemic, resulting in the loss of moisture. The loose structure resulting from lack of moisture allowed for efficient aeration based on bulk density results (Table 4.5), This aeration also functions as a heat conductor for the maturation of composts. The straw showed valuable addition to the composting system since the straw-based composting had moisture loss periodically in a sustainable manner (Figure 4.14). The straw stood as an effective conductor of heat, with significantly less water retention capacity, which thus resulted in the final compost with lesser water retention capacity (Table 4.5).

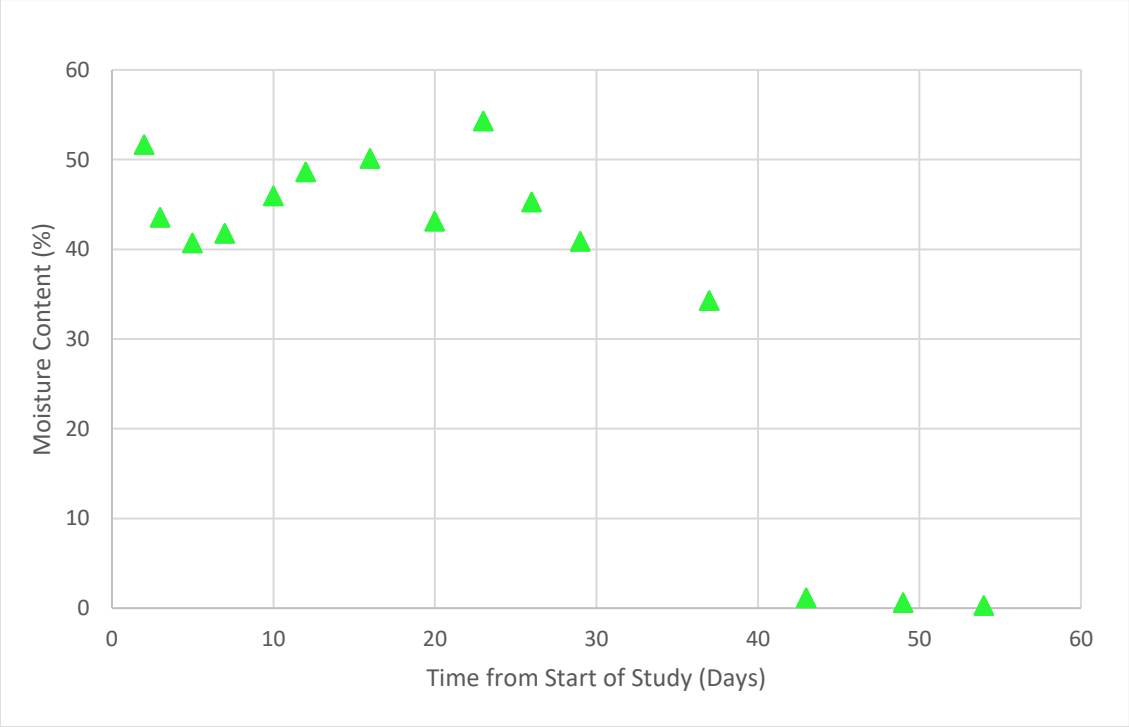

Figure 4.14: The moisture content variation for the 54 days period over the SW+GC in the in-vessel composter.

These sub-sampling points were observed to be rapidly decreasing towards the end of composting but initially the moisture content was mostly monitored within the range. The data when compared against SD+GC composting study, there was no rapid drop in moisture content, but the final stages were not properly maintained.

4.2.5.2. Total Carbon – Nitrogen Dynamics

The C: N ratio of the residue to be composted was one of the most critical factors that affected the composting period. A higher composting ratio over the initial stages of composting led to the more extended composting periods, based on the initial C: N ratio, which began very low since the green crabs were not ground and added to the composter. The total carbon concentration generated in the composting process decreased throughout the composting process (Figure 4.15). The straw used in composting initially had lower carbon content (Table 3.1). Hence the green crab quantity was added to maximize the carbon quantity in the ratio 1:4 (Figure 4.15).

According to the carbon decomposition data associated with the composting, the microbial activity was also influenced by the moisture content, which dropped along with Day 43, 49, and 54, which led to an increase in carbon decomposition, due to unmonitored period. During the initial stage of composting, the carbon content was 44.94% (Figure 4.15), which stayed relatively constant by maintaining the moisture content. The final carbon content on day 37 was observed to be 38.52%. Meanwhile, from Day 23 to Day 26, there was an increase in the carbon content from 41.92% to 42.41%, influenced by the sampling errors associated with them since the compost was not evenly distributed inside the composter (Figure 4.15). Hence the sub-sampling rates had been influencing the carbon decomposition due to the microbial activity.

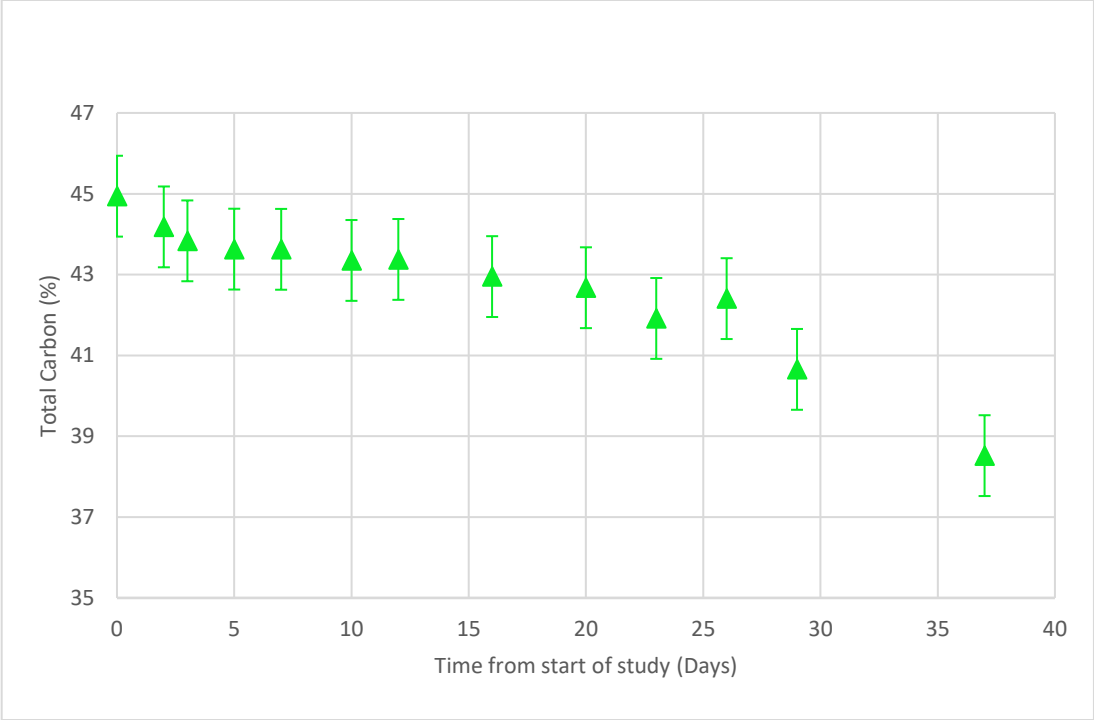

Figure 4.15: Carbon decomposition observed with respect to the sampling period in the SW+GC study for an overall period of 54days.

The relationship between the carbon content and the sub-sampled days was calculated to be statistically significant, but the points were not very uniformly decreasing due to the number of replicates used and the sub-sampling carried out quite uneven. The microorganism activity had not entirely ceased since the temperature, and the composter's breaking down inside the composter were continuing inside the composter after Day 37 since the shaft rotation continued. The carbon decomposition was rapid along the SD+GC composting study compared to the SW+GC composting study.

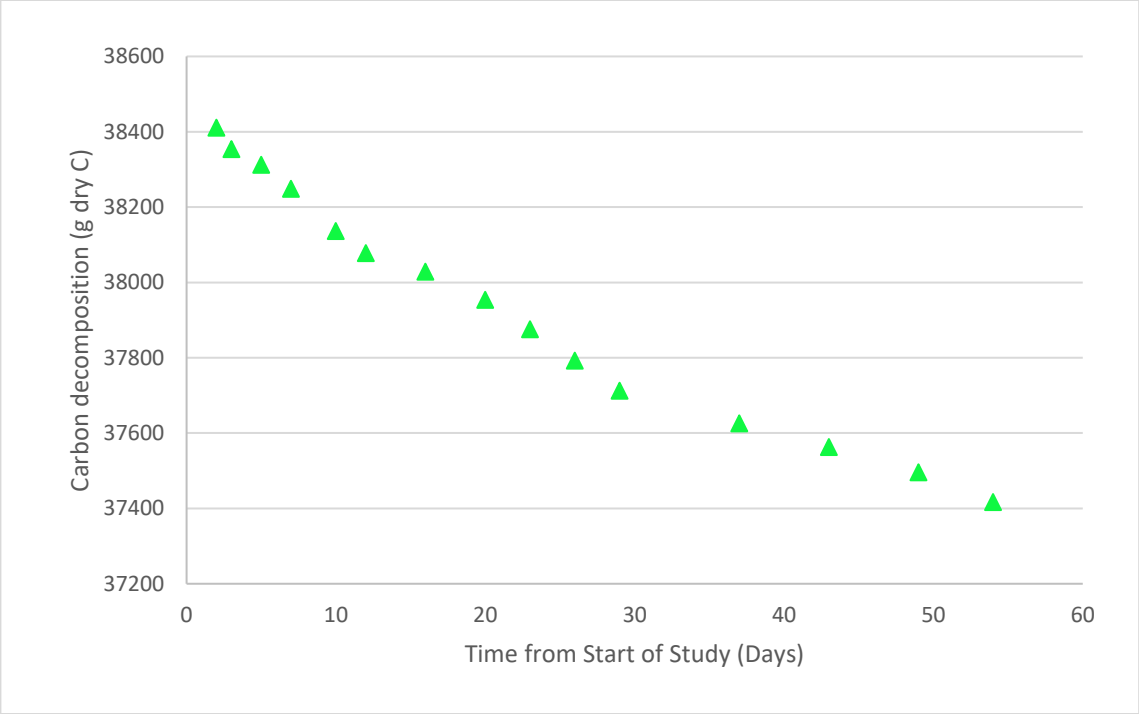

Figure 4.16: Decomposition of carbon (mass basis) in the in-vessel composter during the SW+GC study conducted over a period of 54 days.

The compost released carbon throughout the experiment (Figure 4.15). The amount of carbon calculated at the end of the composting study was 12112g dry C d^{-1}, roughly half the value of the initial value 16942 g dry C d^{-1} (Figure 4.16). The final matured samples collected from the composter also released carbon with the SD+GC compost treatment. The respiration study and the SW+GC study showed that the carbon dioxide evolution rate decreased after Day 29 of the composting study and further decreased along with Day 54 of the study (Figure 4.20). Contradictorily, the cumulative carbon dioxide was still at an increasing rate because the microbial activity never ceased, even if the moisture content reduced over the study (Figure 4.20).

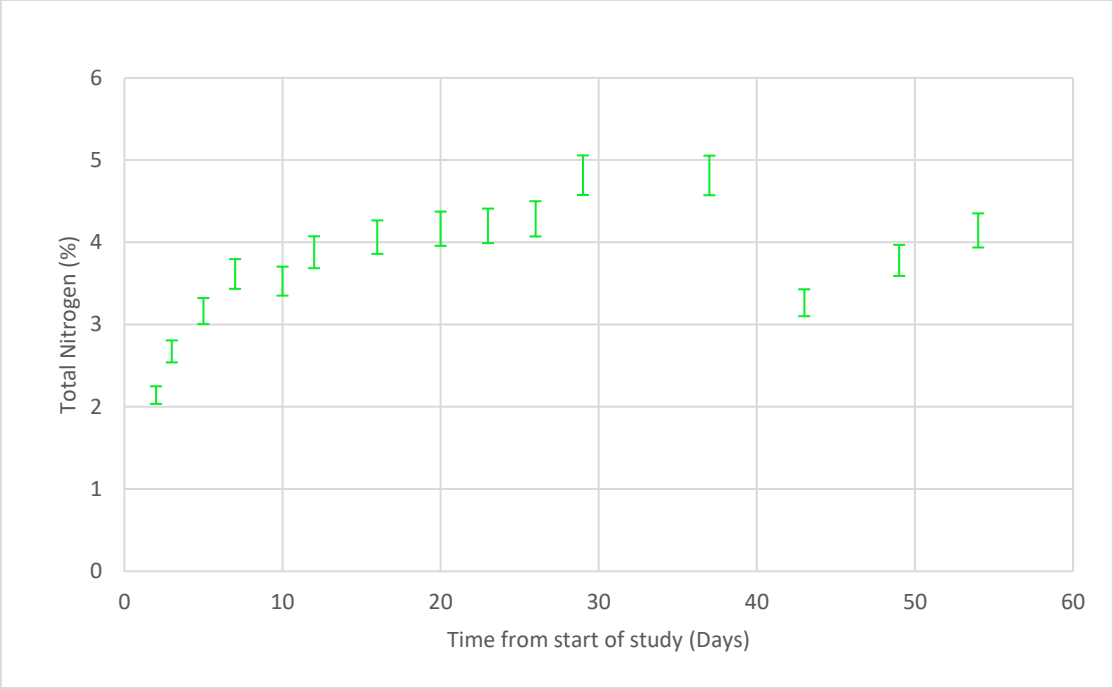

Figure 4.17: Nitrogen change observed with respect to the sampling period in the SW+GC study for an overall period of 54days (n=2; ±SD).

As shown in Figure 4.17, the straw-based compost had a higher nitrogen content compared to the SW+GC compost feedstock in study 1. Between 10 to 50 percent of the nitrogen concentration of raw materials occurred within the first 12 days of composting (Figure 4.17). The total nitrogen concentration release began on Day 2 as 2.2% and proceeded to mineralize up to 4.82% until Day 37 of the composting since the moisture content was maintained stable through Day 2 to Day 37. The composting study after Day 37 had a very minimal moisture content of an average of 1.5 ± 0.01% (Figure 4.14), which minimized the nitrogen content to 3.35% on Day 43 from 4.82% on Day 37. The moisture content could not be maintained due to the COVID restriction in place with limited access to the research sites. This nitrogen increase showed the microbial activity growth decrease along with the study.

The elemental analysis of total carbon and total nitrogen was carried out for the SD+GC composting study to determine the decomposition data, but due to the uneven moisture content, there were manual errors related to the carbon and nitrogen data. To reduce errors related to the moisture content, the oven drying of compost samples were carried out, until the weight remained uniform.

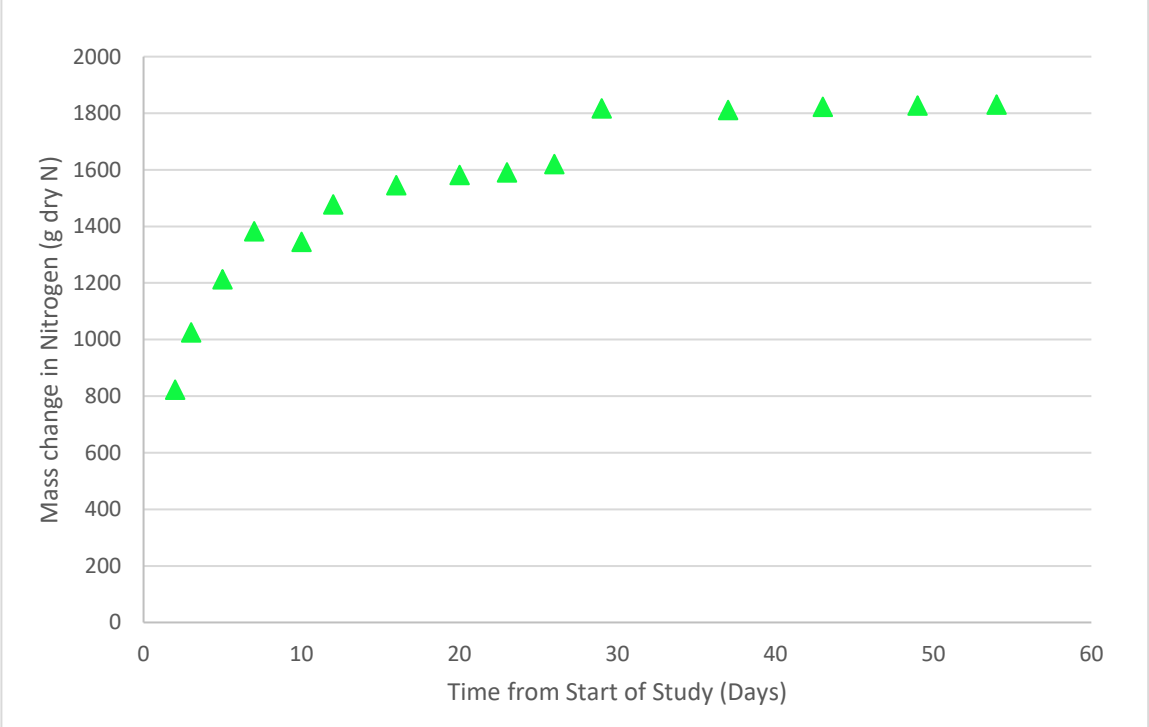

Figure 4.18: Change in Nitrogen mass in the in-vessel composter during the SW+GC study conducted over a period of 54 days.

The initial concentration of total nitrogen in the green crabs at the beginning of the composting studies was 6.54%. As a result of composting, the large amount of available nitrogen present in the raw materials started mineralizing, generating a high nitrogen content in the composts. The nitrogen content continuously increased over time and continued to rise along the sub-sampling days. The nitrogen continued to remain stabilized towards the end of the study as 1851 g dry N d^{-1}, which initially began at 823 g dry N d^{-1} (Figure 4.18). After Day 37, water was added to the composter, hence initiating

the microorganism growth again. Thus, a slight decline of 12.1% was observed and started increasing after Day 37 (1811 g dry N d^{-1}) until Day 54 (1850 g dry N d^{-1}) when the composting study was completed.

Based on the carbon and nitrogen content calculated, the estimated carbon and nitrogen deterioration on a mass basis were collected, the decomposition of carbon and mineralization of the nitrogen was recorded, but the carbon decomposition rate along the SD+GC composting study was also accounted as a result of the lost compost during the entire composting process, due to the drop in temperature from Day 1 to Day 27. Still, the mineralization of nitrogen was on an increasing scale, thus indicating the nitrogen weights are slightly increasing but not on a more significant percentage. Still, the increase denoted microorganism activity which was then identified with the respiration study carried out under controlled conditions.

For Study 1, a final carbon value of 32.96±2.8% and nitrogen of 1.17±0.3% was obtained. In contrast, the study 2 had carbon and nitrogen values of 44.80±1.8% and 1.63±0.6%, respectively. The total nitrogen concentration was higher along the SW+GC composting study, since the straw had a high total nitrogen concentration compared to the sawdust. The sawdust had a high total carbon concentration compared to straw, but the decomposition rate occurred to be higher along the SD+GC composting study, despite having a higher total carbon initial concentration.

4.2.5.3. Changes in Organic Matter Content in The Composting Studies

The ash content mass generated from the study was used in the estimation of the total organic carbon, since the ash content and organic carbon / organic matter are inversely

proportional to each other. The organic matter was initially in the range of 0.92±0.01 (%) whereas the final range of organic matter was observed to be 0.85±0.02 (%). In a fully matured compost, the relatively fair amount of organic matter was observed in the range of 0.7 to 1.0% (Margaret & Labunme, 2013). The low ash from the compost after high temperature, resulted in a relatively higher proportion of organic matter. During the earlier stages of composting, the organic matter was on a rising curve, based on which the organic matter increased from 0.88 ± 0.02 % to 0.93 ± 0.07% (Figure 4.19). The increase in the organic matter content was observed as a result of addition of extra carbonaceous material (straw) to adjust the initial C:N ratio to 25:1. Still, there was no increase in the thermophilic range of composting. The composter remained in the average range of 35ºC, the weather was dry and moist free, and the fan in the greenhouse let the composter stay in the low-temperature range, which resulted in the organic matter decrease over the composting days.

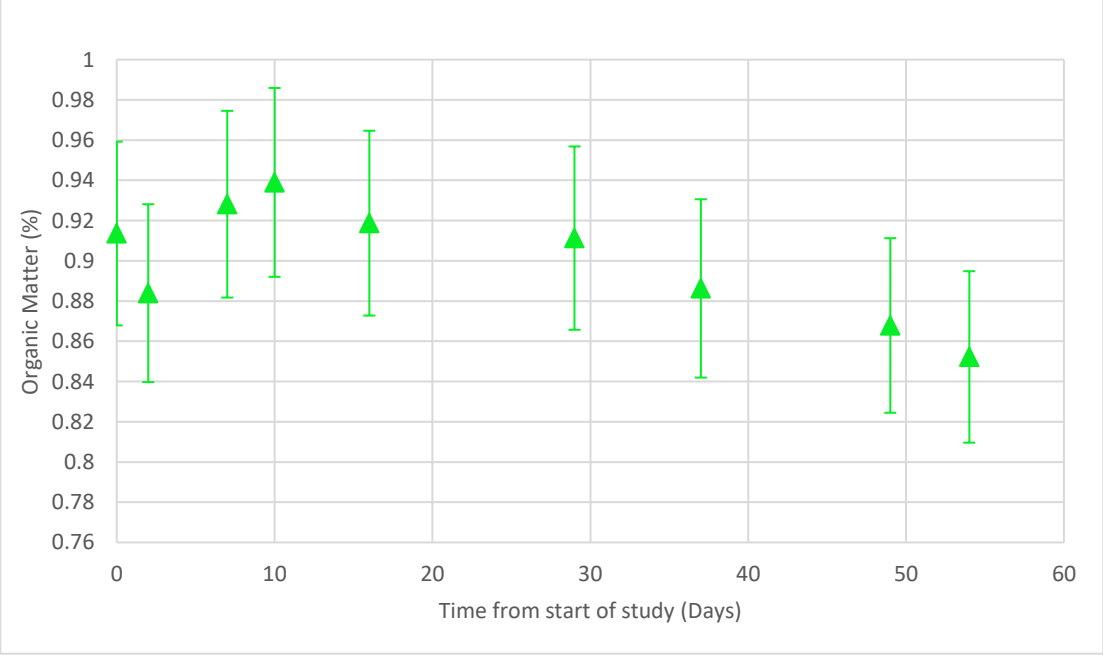

Figure 4.19: Organic matter determined as per the TMECC method by burning in the muffle furnace at 550ºC (n=3; ±SD).

The temperature was used as an indicator to provide the organic matter loss and the total carbon decomposition in the medium. The loss of organic matter occurred at a higher rate when a large quantity of green crabs was added. But the quantity of green crabs for Study 2 was 1 part of GC to 4 parts of SW, hence the decomposition was lower due to the reduced quantity of mineral decomposition. In order to maintain a C: N ratio of 25:1, the straw weight had to be increased to the ratio of 1:4 (w/w), thus providing an equal organic matter of 0.85%. These values can compute the organic matter (y) utilizing the sub-sampling days along the horizontal axis. The total organic matter decreased with the composting and further stabilized along with the curing phase of the composting study.

The SD+GC composting study had a higher organic matter percentage compared to the SW+GC composting study. But the variation over the last days of composting was not directly encountered in the ignition at 550ºC. The SW+GC composting study had a final organic content of 0.85%, whereas the SD+GC composting study had 0.84%. Hence a higher organic content was observed in the SW+GC composting study since it is associated with the plant-based composting study.

4.2.5.4. Carbon Dioxide Evolution Rate

Carbon dioxide evolution rate is one of the most direct techniques used in measuring the stability of the compost. The carbon dioxide evolution directly correlates with the microorganism activity in the compost. After 54 days of composting, the carbon dioxide evolution in a controlled environment was highly optimized during the 8^{th} hour of composting (Figure 4.20).

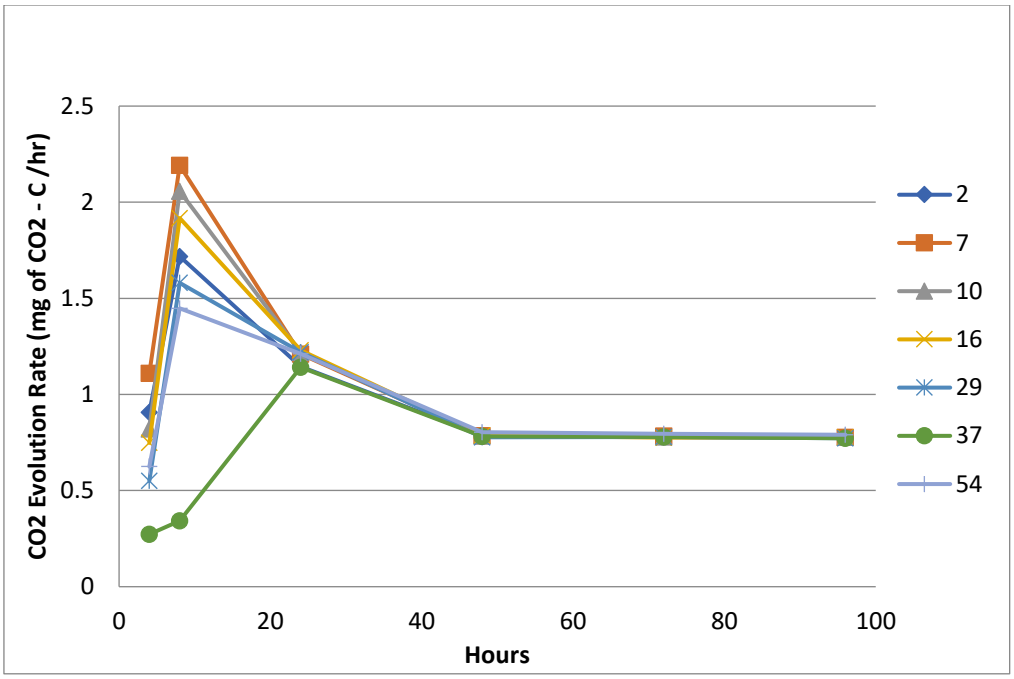

Figure 4.20: Carbon dioxide evolution rates for SW+GC compost samples collected over a 54-day study and incubated for different amount of time over a 4-day period highlighting per hour.

The 8th hour of the respiration study utilized the higher microorganism activity, but Day 37 had a drop in the amount of carbon dioxide evolution rate. The carbon dioxide evolution rate for Day 2, 7, 10, 16, 29, 37, 54 throughout 4-hour, 8-hour, 24-hour, 48-hour, 72-hour, and 92-hour was calculated. The carbon dioxide evolution rate over the 8th hour of the composting study was calculated to be 0.85, 1.09, 1.03, 0.96, 0.79, 0.17, and 0.72 mg g^{-1} CO_2 – C hr^{-1}, where Day 37 had a low carbon dioxide evolution rate compared to the 8th hour of composting study (Figure 4.20).

The carbon dioxide evolution rate along Day 37 of composting was recorded to be 0.27 mg g^{-1} CO_2 – C hr^{-1}, 0.17 mg g^{-1} CO_2 – C $hr^{-1,}$ and 0.76 mg g^{-1} CO_2 – C hr^{-1} along the 4-hour, 8-hour, and 24hour composting study, respectively. But the evolution rate along the 8-hour were observed to be along with the declining rate as 0.34 mg g^{-1} CO_2 – C hr^{-1}, during Day 37 of composting. Day 37 was the last day when the moisture content was maintained, and hence the organic matter also declined, thus indicating the decomposition

occurring in the composter. The cumulative values of carbon dioxide (Figure 4.19) showed a maximum CO_2 release through both the composting studies. Hence a first-order non-linear exponential increase curve was plotted to observe the variation in rate over the timeframe based of the composting study. The first order non-linear dynamics were plotted using the 8th hour of the SD+GC study (Figure 4.21), where the rate constant was the highest (b=0.0979), showed that the microorganism activity had been more active during the preliminary days of composting and remained uniform through the 24th, 48th, 72nd, and 96th hours of composting study.

The equation used was y=a*(1-exp(-bx)) since the data remained an increasing curve. A higher rate of microbial activity was observed in the SW+GC composting study compared to the SD+GC composting study. The rate constant remained higher through the 8th hour of composting study a rate constant b = 0.0979 (Figure 4.21). The rate constant started declining after the 8th hour of composting study, and the variation was recorded before the 24th hour of composting.

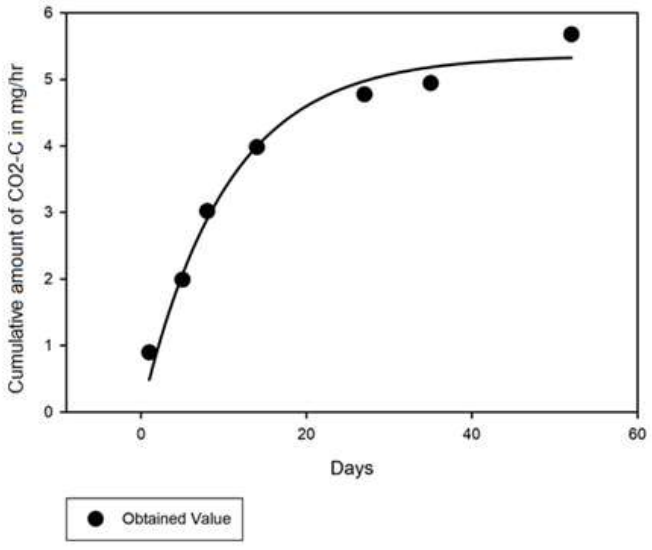

Figure 4.21: Final first order non-linear response recorded with respect to the cumulative quantitative CO_2 – C observed in the SW+GC Study (rate constant=0.0979).

The optimum key incubation point observed over the difference in the length of time over the sealed environment under controlled temperature, and restricted oxygen supply was around the 8th hour of the controlled conditions. The compost stabilized earlier than the expected time frame; the low water retention capacity is also observed. The SW+GC compost had a lesser microorganism activity since it stabilized as the compost, which resulted in more water addition over the initial stages of composting to maintain the moisture content in the in-vessel composter. Compared with the SD+GC composting study, the quantity of water lost while sub-sampling was lesser, indicating the microorganism growth over the study. Thus, the high optimum aerobic environment was favourable in the SW+GC composting study, where the stabilization phase occurred in an earlier time.

Every sub-sample collected during the SW+GC composting study, where the days were significantly different from each other. The carbon dioxide evolved as the result of the composting study has been on a decreasing rate due to the microorganism activity. The similar trend is observed in the carbon data (Figure 4.15) and organic matter (Figure 4.19).

The day 54, had encountered a carbon dioxide level in between Day 29 and 37, which indicates an error due to the other external factors like temperature and moisture loss. The uncontrolled factors led to increase the microorganism activity from Day 37. Initially around Day 2 due to shredding of feedstocks and other components the carbon dioxide evolution rate was very low but increased after Day 7 the carbon dioxide evolution rate decreased due to the lack of available carbon based on the microorganism activity.

Similarly, Day 37 is statistically different from Day 1 and Day 54 depending upon the carbon dioxide consumption and the temperature based on the microorganism activity in the composter based on the 8th hour composting (Figure 4.20). Similarly, the organic matter, total carbon and the carbon dioxide evolution rate helps in establishing the maturity of the compost (Figure 4.15, 4.19 and 4.22) indicates that the maturity of composts occurs after Day 29 and stabilizes along Day 54.

Table 4.7: Analysis of variance generated among the sub-sampled days over the entire composting study based on the optimum carbon dioxide evolution rate

Source	DF	Seq MS	F-Value	P-Value
Days	6	6.8383	1714.024	< 0.0001

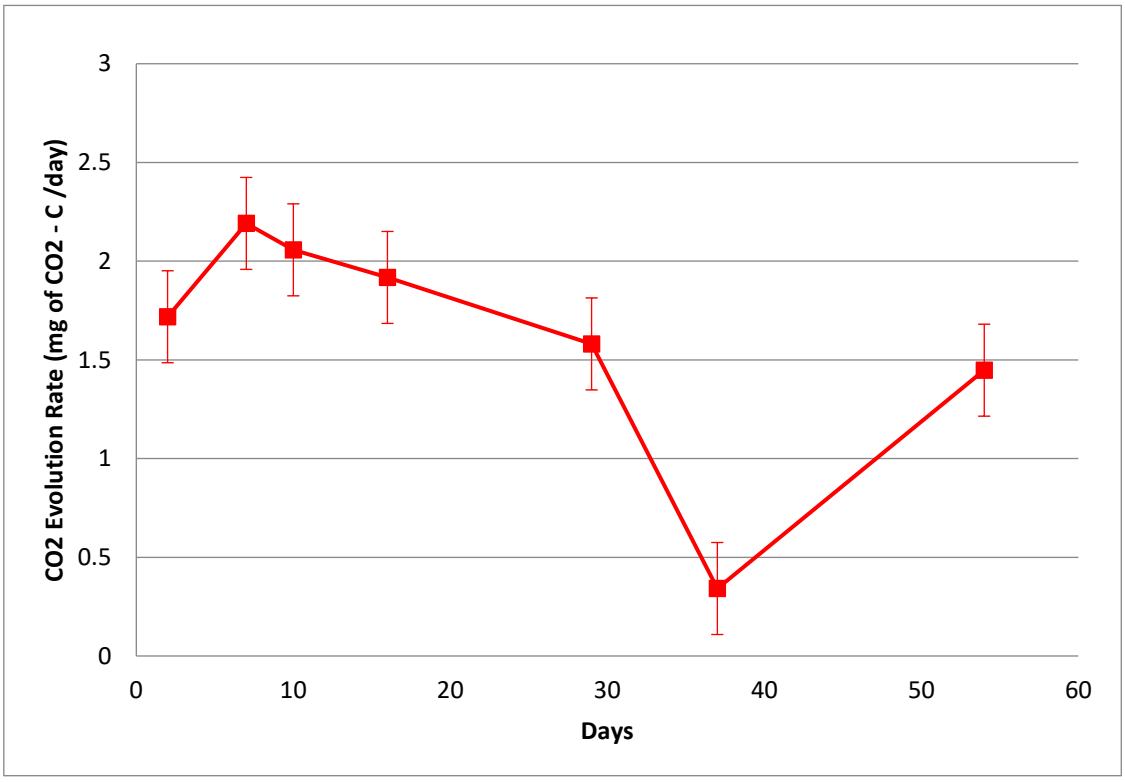

Figure 4.22: Least square means plot of hourly rate of carbon dioxide generation differentiating the 8-hour sampling from others over the 4-day period.

4.3 PLANT RESPONSE AND NURSERY MEDIA EVALUATION WITH THE GREEN CRAB BASED COMPOST

4.3.1. INTRODUCTION – GENERAL PROPERTIES

The plants' physical and chemical properties and compost-based media varied based on the feedstock composition since the harvested yield generated source of nutrients in different ratios available to the plants (Inbar et al., 2010). Composts were utilized in the growth media for nursery production systems to be stable, consistent support that promotes uniform plant growth. The pH, salinity, and heavy metal concentration were determined prior to adding composts to the growth media since they could affect the properties of the *Lepidium sativum,* reducing the germination capacity, since they required neutral pH and moisture content of 65% (Ajdanian et al., 2019).

The pH of the final SD+GC compost was found to be 6.8±0.2, and SW+GC compost was found to be 9.4±0.3 (Table 4.8). The plant species were chosen based on high germination rate of 85% (Pavel V L et al., 2013), water requirements of 80% (Doke S 2018), and temperature requirements <20ºC (Sattari H, 2020). Paula et al., (2017) estimated that the pH had been adversely affected by the chitin content; initial sawdust was discovered to have a pH in the range of 7.9 – 7.98, but after the addition of raw chitin to the sawdust the pH was in the range of 7.05 – 8.99.

Hence the chitin had minimal effects on the SD+GC compost since the chitin content in the raw sawdust was measured to below the detectable range (Niaounakis M 2014). The chitin content in straw was measured as 5.2% (Tshinyangu K 1996) and also the quantity of chitin measured from green crabs was observed to be 23.2 – 23.8% (Acosta et al., 1996), which states that both the raw materials (straw and green crabs) contain chitin

content, which is a highly basic polysaccharide (Niaounakis M 2014), thus increased the alkalinity of the overall compost system (Table 4.8). The alkalinity also increased further along the addition of the higher concentration of SW+GC compost.

Table 4.8: Initial chemical characteristics of sawdust- and straw-based media amended with 0, 10, 20, 35, or 50% compost (n=3 per treatment; ±SD)

Compost (% by weight)	pH	Moisture (%)	Carbon (%)	Nitrogen (%)	C/N Ratio
Sawdust					
Control	7.1	83.45±0.50	46.26±0.01	1.12±0.005	41.15
SD10	7.2	81.55±0.53	43.90±0.02	1.67±0.003	26.27
SD20	6.8	78.43±0.44	43.92±0.01	1.84±0.011	23.88
SD50	6.7	75.22±0.26	48.07±0.01	2.09±0.015	22.98
Straw					
Control	7.1	83.45±0.50	46.26±0.01	1.12±0.005	41.15
SW10	9.3	82.97±0.45	45.13±0.01	1.59±0.005	28.31
SW20	8.9	83.44±0.35	46.97±0.02	1.81±0.006	26.01
SW35	10.5	81.63±0.52	42.24±0.01	1.77±0.001	23.90

4.3.2. ANALYSIS OF COMPOST GROWTH MEDIA SAMPLES

4.4.2.1. Chemical Characteristics of The Medium

Composts had an initial pH in the range of 6.0 to 7.5. Initial pH values of the SW+GC compost increased with the higher concentration of the compost with the planting medium (Table 4.9). The moisture content of 80% was initially added to the media with sawdust- and straw-based compost (Table 4.6). As the SD+GC compost content increased, the moisture content decreased towards the final composting stage due to the higher water retention capacity of the SD+GC compost mixtures.

It was found that the moisture content in the straw-based compost with the media was less than the sawdust-based compost with the media. As the compost percentage with the media increased, the percentage of nitrogen increased (Table 4.9). The decrease in the C:

N ratio from the initial and final composts (Table 4.8 & 4.9) indicated that the compost was stable and mature towards the composting.

Table 4.9: Final chemical characteristics of sawdust- and straw-based media amended with 0, 10, 20, 35, or 50% compost (n=3 per treatment; ±SD)

Compost (% by weight)	pH	Moisture (%)	Carbon (%)	Nitrogen (%)	C/N Ratio
Sawdust					
Control	6.9	76.65±0.25	46.91±0.03	2.34±0.001	20.08
SD10	7.1	83.44±0.31	47.19±0.01	2.33±0.001	20.27
SD20	6.8	80.16±0.55	46.36±0.13	2.72±0.002	17.06
SD50	6.9	78.48±0.63	46.12±0.10	2.81±0.001	16.42
Straw					
Control	6.9	76.65±0.25	46.91±0.03	2.34±0.001	20.08
SW10	9.2	79.57±1.26	46.60±0.01	2.14±0.005	21.76
SW20	8.4	78.77±1.19	45.31±0.03	2.22±0.001	20.42
SW35	10.7	76.53±0.49	45.94±0.12	1.82±0.003	25.24

The addition of compost decreased the C: N ratio for the SD+GC compared to the SW+GC compost and media (Table 4.9). The C: N ratio of the compost composition of 35% was observed to be within the range along with the study, whereas when combined with control media, the pH affected the plant growth.

4.4.2.2. Nutrient Composition of The Growing Medium

In this study, the media was analysed from the 28 potting locations with four replicates on each concentration of compost (10%, 20% and 50%) with the potting media. Table 4.10 lists the number of samples associated with each potting media. The initial and final composition of nutrients in the growing medium was analyzed for Ca, Mg, K, P, Na, S, Al, and Fe (Table 4.10). The six different compost and media mixtures underwent a microwave assisted acid digestion and analyzed by ICP-AES for plant available nutrients. The variation of nutrient concentration between the composting media (initial and final) was statistically analysed to assess the differences in the concentrations in the potting

media and plants used in them. The *Lepidium sativum* seeds require 0.81mg/g of calcium, 0.38mg/g of magnesium, 0.76mg/g of phosphorus and 6.06mg/g of potassium (Shail D et al., 2016) to provide the media the nutrient requirements to support the plant growth, but the media lacked K and P content.

Table 4.10: Initial properties of the growing media used in the experiment (n = 4 per treatment; ±SD)

Compost (% by weight)	Ca	Mg	K	P	Na	S
	mg / g of treatment					
Sawdust						
Control	2.26± 0.01	0.21± 0.01	0.34± 0.01	0.05± 0.01	ND	0.47± 0.01
SD10	3.36± 0.01	0.23± 0.01	0.76± 0.01	0.21± 0.01	0.27± 0.01	0.56± 0.01
SD20	2.92± 0.01	0.28± 0.01	0.92± 0.01	0.22± 0.01	0.29± 0.01	0.62± 0.01
SD50	2.18± 0.01	0.33± 0.01	0.92± 0.01	0.29± 0.01	0.33± 0.01	0.78± 0.01
Straw						
Control	2.26± 0.01	0.21± 0.01	0.34± 0.01	0.05± 0.01	ND	0.47± 0.01
SW10	4.62± 0.01	0.24± 0.01	0.28± 0.01	0.21± 0.01	0.24± 0.01	0.52± 0.01
SW20	4.47± 0.01	0.28± 0.01	0.28± 0.01	0.27± 0.01	0.27± 0.01	0.68± 0.01
SW35	4.02± 0.01	0.31± 0.01	0.36± 0.01	0.36± 0.01	0.41± 0.01	0.72± 0.01

Nutrients such as Na, and S increased as the percentage of SD+GC compost increased in the medium as shown in Table 4.10. When comparing initial (Table 4.10) to final (Table 4.11), the final concentration of Ca and K were lower at the end of the study harvesting the yields. These contents were observed to be on an increasing trend along 20% and 35% SW media treatments (Table 4.11), with the exception of K. This nutrient composition indicated that the nutrient uptake was higher with the sawdust-based composting medium since the nutrient intake after harvesting was lower.

Table 4.11: Final properties of the growing media used in the experiment (n = 4 per treatment; ±SD)

Compost (% by weight)	Ca	Mg	K	P	Na	S
	mg / g of treatment					
Sawdust						
Control	1.69±0.03	0.15±0.01	0.24±0.01	0.04±0.01	0.12±0.01	0.38±0.01
SD10	2.66±0.03	0.21±0.01	0.65±0.01	0.17±0.01	0.26±0.01	0.47±0.01
SD20	2.08±0.07	0.19±0.01	0.66±0.01	0.18±0.01	0.26±0.01	0.47±0.01
SD50	1.96±0.04	0.26±0.01	0.67±0.02	0.20±0.01	0.27±0.01	0.61±0.01
Straw						
Control	1.69±0.03	0.15±0.01	0.24±0.01	0.04±0.01	0.12±0.01	0.38±0.01
SW10	3.76±0.06	0.16±0.01	0.26±0.01	0.11±0.01	0.19±0.01	0.39±0.01
SW20	3.65±0.16	0.24±0.01	0.30±0.01	0.19±0.02	0.32±0.01	0.62±0.01
SW35	2.14±0.14	0.26±0.01	0.31±0.01	0.34±0.02	0.35±0.02	0.67±0.04

Two-way analysis of variance was employed to determine what, if any, effect the compost mixture had on the observed nutrient concentration levels. The comparison tests between different compost concentration were performed on the paired difference data for all six nutrients (Ca, Mg, K, P, Na, S); these test results are shown in Table 4.12 & 4.13. The initial concentrations of the six nutrients produced a p-value < 0.05. The concentrations of Ca, Mg, K, P, Na, and S concentration when compared against the controls for one-way ANOVA along the SD+GC compost (Table 4.12) and SW+GC compost (Table 4.13) were statistically significant. The nutrients were higher in concentration along the 50% of SD+GC compost and 50% of potting media where the levels are statistically different between the lowest and the highest concentrations of SD+GC compost.

The SD+GC composting study when controlled against the standards, the SD+GC media 50% were significantly different along potassium, phosphorus, sodium, and sulphur concentrations over the other minerals. Hence along the SD+GC media, the higher

concentration stayed significantly different from the other concentrations along the same medium.

Table 4.12: Analysis of Variance between different concentrations of media within the compost group levels during SD+GC study

Source	DF	Sum of Squares	F-Value	P-Value
Calcium	3	1.5198	9.9165	0.0014
Magnesium	3	0.0022	8.8798	0.0023
Potassium	3	0.0049	7.5699	0.0042
Phosphorus	3	0.0173	3.8526	0.0384
Sodium	3	0.0212	6.4854	0.0074
Sulphur	3	0.0317	5.2824	0.0149

Table 4.13: Analysis of Variance between different concentrations of media within the compost group levels during SW+GC study

Source	DF	Sum of Squares	F-Value	P-Value
Calcium	3	1.2262	54.3174	0.0001
Magnesium	3	0.0132	108.5259	0.0001
Potassium	3	0.3118	134.2652	0.0001
Phosphorus	3	0.0365	184.5198	0.0001
Sodium	3	0.0438	49.9502	0.0001
Sulphur	3	0.0706	83.7092	0.0001

In addition, the paired comparison tests were performed on the six nutrients against both the studies for which the media nutrients were symmetrically increasing along the concentration. These test results are shown in Table 4.14. The 35% SW+GC compost-based media had higher concentration of Ca, Mg, K, P, Na and S in comparison with the lower concentration levels (10 and 20%). But media and levels interactions between Mg and K had been statistically significant. Only two of the six concentrations produced a p-value below 0.05 (Mg: p=0.0446; K: p=0.0095). These results, which agree with the paired comparison results imply that the mean nutrient concentration levels were the same within the four replicates collected from the varied concentrations.

In addition to the mean comparison tests, SD+GC media versus SW+GC media comparison ANOVA stated that the six nutrients were statistically significant and associated p-values are shown in Table 4.14. The media nutrients concentrations of potassium, phosphorus and magnesium when compared against each other, the SD+GC media 50% had been significantly different. The SW+GC media was higher along the pH as seen in table 4.9, hence the calcium and sodium concentrations were statistically different along SW+GC media 50%, hence the higher concentration of both media had higher nutrient concentrations.

Table 4.14: Analysis of Variance between different concentrations of media between the compost group levels during SD+GC and SW+GC study

Source	DF	Sum of Squares	F-Value	P-Value
Calcium	2	0.6337	8.3034	0.0028
Magnesium	2	0.0012	7.4366	0.0046
Potassium	2	0.0029	26.0891	0.0001
Phosphorus	2	0.0139	6.7029	0.0067
Sodium	2	0.0129	7.1355	0.0052
Sulphur	2	0.0269	9.3647	0.0016

4.3.3. ANALYSIS OF PLANT SAMPLES

4.4.3.1. Physical Characteristics of Plants

Most of the shoot characteristics calculated (number of leaves, length of the stem, and number of plants germinated), decreased linearly as the % of compost content in the media increased, except SD 20 and SD 50 (Table 4.15). A reduction of the shoot variables occurred with the plants in higher (20 and 35%) straw-based compost amended media compared to the sawdust amended media. The number of leaves was higher along with the SD+GC compost amended media compared to the SW+GC compost-based media.

However, irrespective of all compost treatments and media base, the quality of the plants could be compared by subjective observations.

4.4.3.2. Germination Rate of Seeds in The Compost Media

Additional conventional compost maturity and testing were performed via biological methods such as germination tests. Each experimental unit included 55 seeds of garden cress (*Lepidium sativum)* distributed first over paper towels on Petri dishes, where the composts of different concentrations were added to the seeds to verify the growth rate. The germination rate of the seeds was calculated to be 80.5% with distilled water of pH 6.0 – 6.5, under light. Petri dishes were covered with lids and then left in a dark room for 12 hours to start the process of germination, which showed an initial germination rate of 90% (Figure 4.23).

Later the seedlings were transferred to the pots carefully to continue planting plant growth after the shoot had emerged from the seeds to avoid the drying of seeds inside the experimental units, but the pots had varying pH which led to various germination ratios (Figure 4.23).

Figure 4.23: Petri Dishes containing seeds of *Lepidium sativum* germinated over the pre-germination study.

This indicated that lower the concentration of compost, generated higher yield along the study. The seed germination percentage was determined to estimate the plantlet emergence above the surface. Counting was carried out on an everyday basis until day 14 after no additional germination was observed. The Germination Index (GI) was calculated for the germinated seeds by counting the number of seeds germinated. Their growth length was compared with the control (100% potting media) with no compost added. As shown in Figure 4.33, the 50% concentration of straw showed no growth, and the seeds remained hidden under the crusted layer of straw, leading to the sprouted seeds drying. The ratio of SW+GC compost was then reduced to 35%, which showed a good germination index of 37.4% (Figure 4.24).

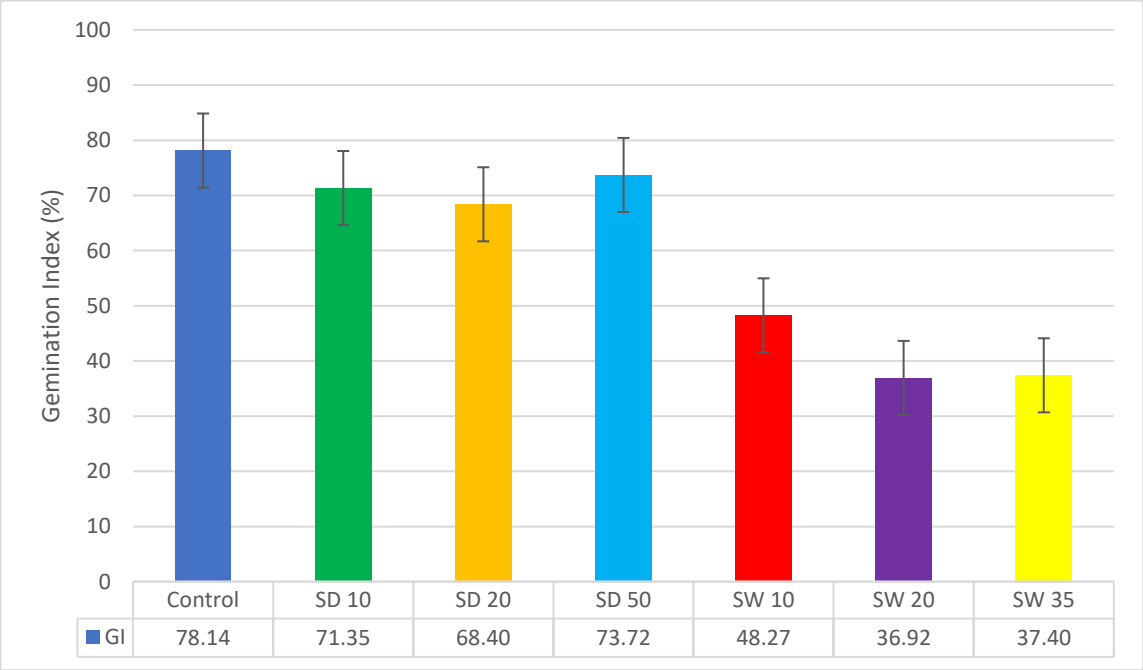

Figure 4.24: Germination index of the treatments, Control 0%, Sawdust + Green Crab with the potting mix in the composition percentage (10, 20 and 50%) and Straw + Green Crab with the potting mix in the composition percentage (10, 20, 35%).

The dry yields from each composting medium were compared based on the levels of composition in the media (10, 20, and 50%). In the SD+GC-based composting medium,

the yield was higher along with the 10% compared to the other compositions of media and straw. The dry yields at 10% increased relative to control but 20 and 50% decreased relative to controls. The dry yields along the concentrations of SD+GC compost media and SW+GC compost media, when compared against each other were weakly significant with p=0.0776 having a weak positive correlation between each other (Table 4.16).

When analysed, against the controls, the yield was statistically significant at p=0.0270 for SW+GC compost media where the SW+GC media 10% is statistically different from other compost concentrations and p=0.0081 for SD+GC compost media within the media when compared against the controls, where the concentrations of SD+GC compost media 20% was statistically different from the other concentrations. The compost when added in different compositions were analyzed for yield variations along the study. The SD+GC based media had a higher yield of 0.72±0.11, whereas the yield received from other studies remained lower along the study in comparison with the controls.

The SD+GC and SW+GC yield were not statistically different from each other, since the Tukey's HSD test (Table 4.16) showed that the levels of comparison were similar along the different concentrations, since the concentrations were connected by a similar letter.

Table 4.15: Stem length, number of leaves and dry weight of *Lepidium sativum* plants grown in sawdust- and straw-based compost amended media in the composition 0, 10, 20, 35 and 50% (n = 4 per treatment, ±SD)

Compost (% by weight)	Length of the stem (cm)	No of leaves	Dry weight of plants (g)
Sawdust			
Control	1.44±0.02	6.5±0.50	0.61±0.01
SD10	1.34±0.02	7±0.57	0.72±0.11
SD20	1.40±0.00	7.5±0.50	0.61±0.15
SD50	1.36±0.04	7±0.57	0.45±0.16
Straw			
Control	1.44±0.02	6.5±0.50	0.61±0.02
SW10	1.33±0.03	6.5±0.50	0.63±0.01

SW20	1.36±0.04	7.5±0.50	0.39±0.21
SW35	1.30±0.0	6±0.00	0.37±0.25

Table 4.16: Comparison of the Least Square mean value of dry yields generated from SD+GC and SW+GC composting medium

Compost (% by weight)		Dry yield of harvested plants (g)	Compost (% by weight)		Dry yield of harvested plants (g)
Control	A	0.61±0.01	Control	A	0.61±0.02
SD10	A	0.72±0.11	SW10	A	0.63±0.01
SD20	A	0.61±0.15	SW20	A	0.39±0.21
SD50	A	0.45±0.16	SW35	A	0.37±0.25

The plant growth after 20 days was observed. The biomass was not sufficient for a plant digestion procedure; hence another 25 pregerminated seeds were added to each pot, and the 30 seeds were already planted in them. This yielded a higher fresh weight for the harvested plants (Figure 4.25), in which the fresh yield was higher along the SD+GC 10%, similarly the harvested fresh yields when dried in the oven (Figure 4.26) generated a moisture content of 85±2.5%, which also provided a higher dry yield along SD+GC 10%.

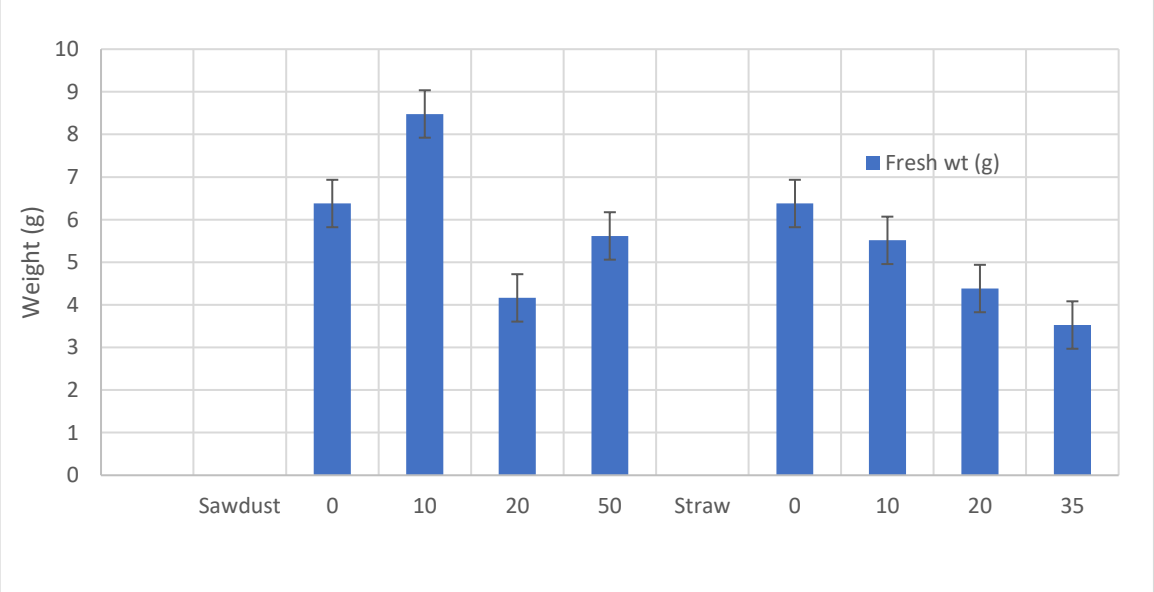

Figure 4.25: Fresh weight of the harvested plants over the treatments, Control 0%, Sawdust + Green Crab with the potting mix in the composition percentage (10, 20 and 50%) and Straw + Green Crab with the potting mix in the composition percentage (10, 20, 35%) (n = 4 with SD).

Figure 4.26: Determination of Moisture content using the gravimetric analysis in drying oven at 50ºC for both plants and compost potting mixes.

4.4.3.3. Plant Nutrient Uptake Based on Treatment

The addition of compost to the potting media significantly increased the nutrient uptake by the plants. After two weeks of growth, the biomass was harvested and analysed for nutrients using the dry yield by the process of digestion. The nutrient concentration remained higher in the SD+GC compost media than the SW+GC compost media.

The compost concentrations provided the cress plants different nutrients from each pot. Primarily P uptake, occurred in the plants during growth (Table 4.17). The highest increase in Mg, K, P, Na and S concentrations was observed with the SD+GC based compost plants (Table 4.17).

Table 4.17: Chemical compositions of the harvested garden cress (*Lepidium sativum)* used in the experiment (n = 4 per treatment; ±SD)

Compost (% by weight)	Ca	Mg	K	P	Na	S
	mg / g of total plant dry yield					
Sawdust						
Control	1.43±0.02	0.31±0.01	2.58±0.12	0.72±0.04	0.29±0.01	1.94±0.08
SD10	1.08±0.02	0.29±0.01	2.65±0.10	0.70±0.02	0.41±0.02	1.74±0.06
SD20	1.51±0.02	0.37±0.01	3.62±0.05	0.98±0.02	0.48±0.01	2.43±0.06
SD50	1.58±0.03	0.40±0.01	3.79±0.05	1.01±0.01	0.64±0.01	2.53±0.03
Straw						
Control	1.43±0.02	0.31±0.01	2.58±0.12	0.72±0.04	0.29±0.01	1.94±0.08
SW10	1.21±0.08	0.23±0.01	1.58±0.14	0.51±0.04	0.31±0.02	1.22±0.08
SW20	1.35±0.14	0.23±0.01	1.76±0.13	0.55±0.04	0.34±0.02	1.26±0.11
SW35	1.69±0.03	0.30±0.01	2.93±0.06	0.87±0.02	0.45±0.01	2.01±0.05

At a given percentage of compost (10 or 20%), the Ca concentration was observed to be higher in the SW+GC experiments compared to the SD+GC based compost amendment (Table 4.18). In contrast, the higher nutrient uptake was encountered in the SD+GC experiments for Mg (0.40mg/g), K (3.79 mg/g), P (0.98 mg/g), Na (0.64 mg/g), S (2.53 mg/g) compared to the SD+GC experiments. In most cases, the nutrient concentrations of the garden cress were increased by the concentration of compost. The nutrient concentrations also affected the chlorophyll content in the garden cress plants. Due to the high potassium content, the leaves turned pink. The nutrient concentration over the concentrations decreased concerning pH, and the SW+GC compost media was highly alkaline, which on the other hand determined that the calcium concentration higher. The initial mixes had a C: N ratio of 28:1 (Table 4.1) for the SD+GC composting study and 27:1 (Table 4.5) for the SW+GC composting study. The carbon (Figure 4.27) from the

plants was observed to be higher in the SW+GC experiments relative to the SD+GC experiments for a given percent of compost. Nitrogen concentrations in the plants are shown in Figure 4.28 with no significant trend evident.

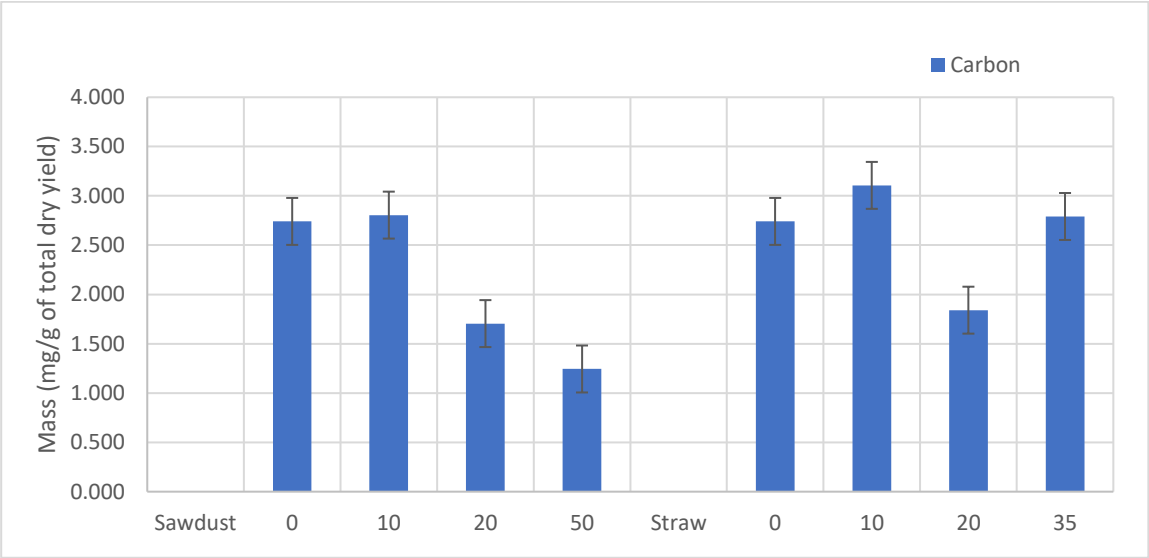

Figure 4.27: Mass of carbon concentration in plants over the plant dry yield, Control 0%, Sawdust + Green Crab with the potting mix in the composition percentage (10, 20 and 50%) and Straw + Green Crab with the potting mix in the composition percentage (10, 20, 35%) (n = 4 with SD).

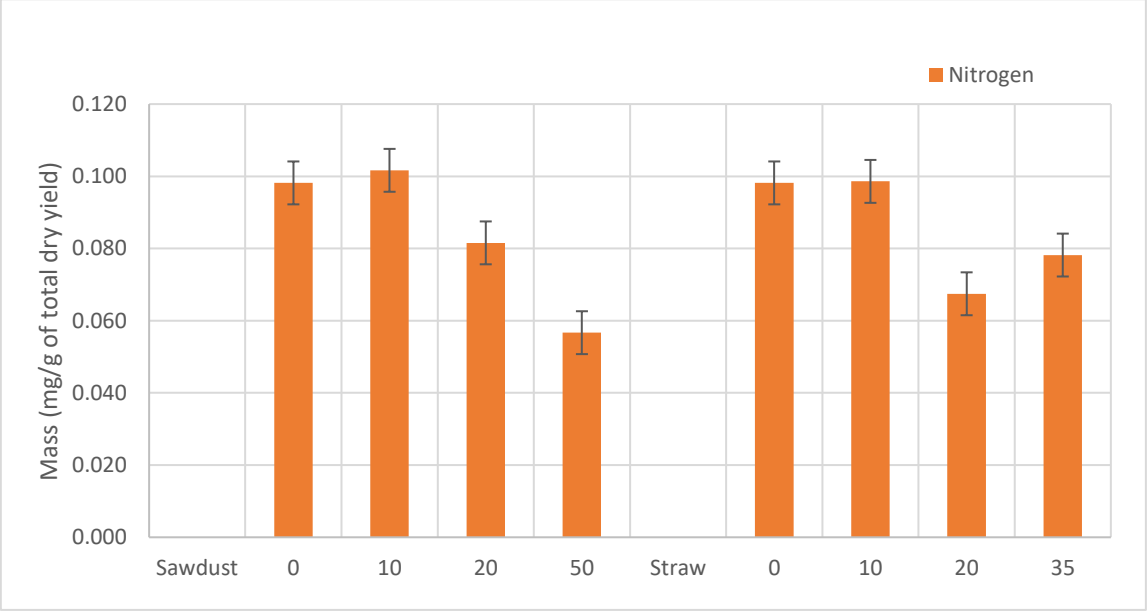

Figure 4.28: Mass of nitrogen concentration in plants over the plant dry yield, Control 0%, Sawdust + Green Crab with the potting mix in the composition percentage (10, 20 and 50%) and Straw + Green Crab with the potting mix in the composition percentage (10, 20, 35%) (n = 4).

When the nitrogen concentration obtained from the harvested plants have been statistically significant ($p < 0.05$) along the comparison with the controls, but the carbon concentration when compared against both the studies were not statistically significant against each other ($p > 0.05$), but the standard error associated is small, hence the compared carbon concentration between SD+GC medium and SW+GC medium are low statistically significant ($p = 0.07$), the studies require more number of samples (replicates) to indicate high statistical significance. The carbon concentration was statistically significant ($p < 0.05$) when compared against the controls and also when compared against both the studies (SD+GC media and SW+GC media).

The concentration of potassium (3.798 mg/g), sulphate (2.732 mg/g) and phosphorus (1.008 mg/g) were relatively higher along the harvested plants from the 50% of SD+GC based composting media (Figure 4.29a). On the other hand, the calcium concentration was higher along the plants harvested from 35% SW+GC composting medium in comparison with the plants harvested from SD+GC composting study (Figure 4.29b), which when compared with the pH also determined that the SW+GC compost media was alkaline in nature, which thus resulted in affecting the calcium concentration in plants. Similarly, the harvested plants from the SD+GC composting medium had higher concentrations of Magnesium (0.638 mg/g) and Sodium (0.403 mg/g) compared to the highest concentrations (Figure 4.30a) obtained from SW+GC composting media plants (Figure 4.30b). The SD+GC composting medium had a higher ratio of green crabs in the composting medium, which denotes that the marine organisms had a higher concentration

of sodium and magnesium in their composting medium when mixes with controls.

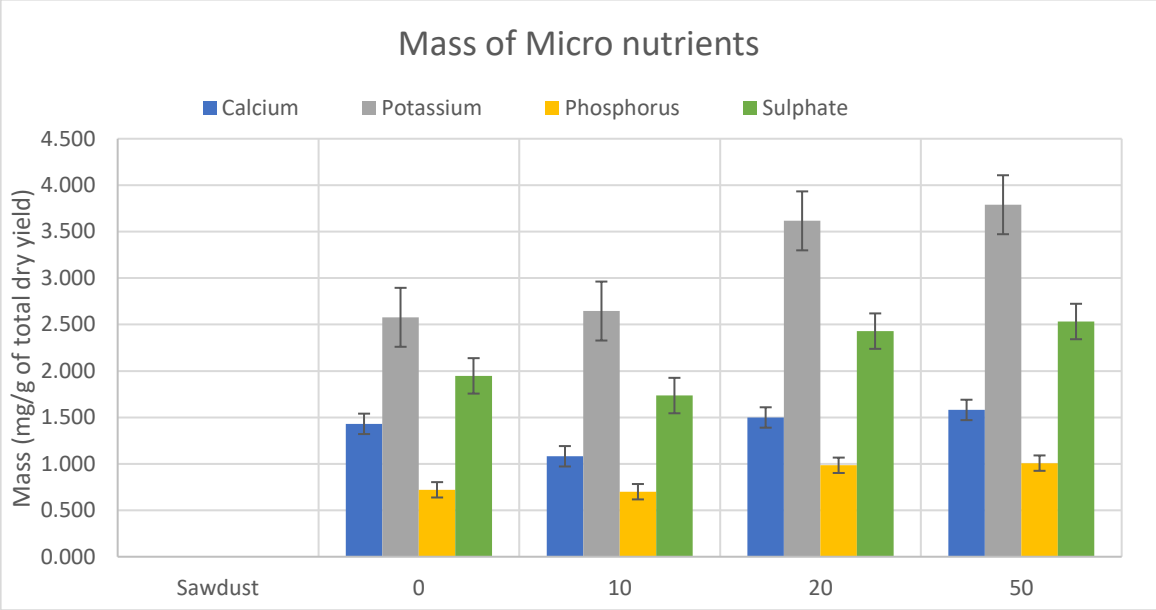

Figure 4.29a: Mass of Calcium, Potassium, Phosphorus and Sulphur concentration in harvested plants over the treatments, Control 0%, Sawdust + Green Crab with the potting mix in the composition percentage (10, 20 and 50%) (n = 4 treatments).

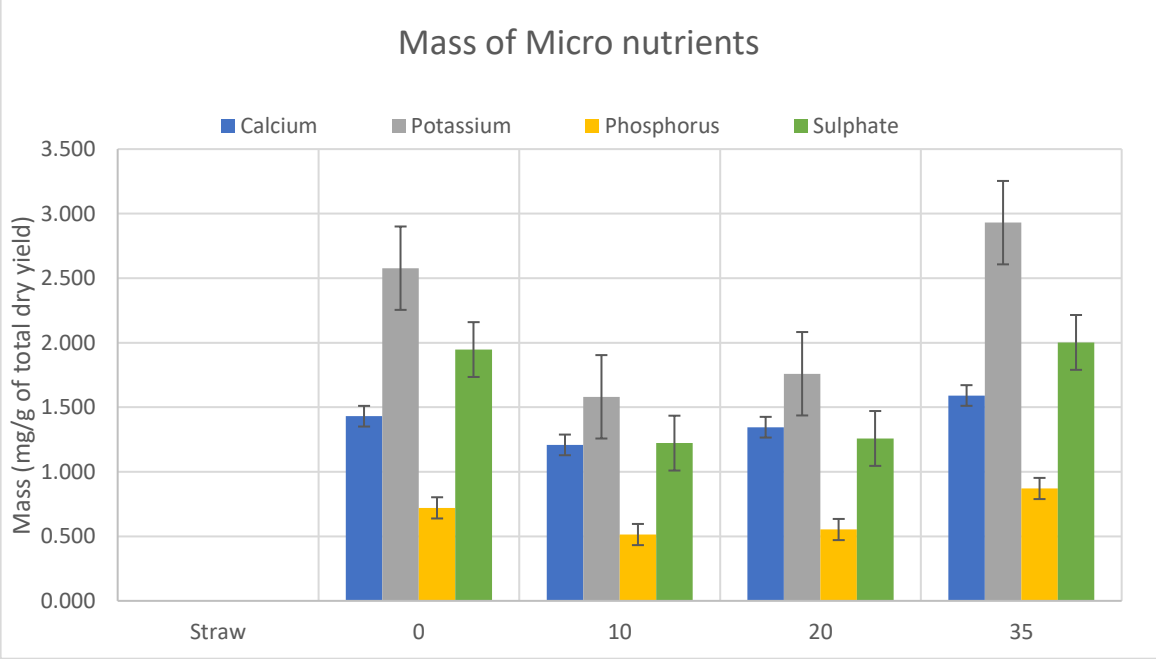

Figure 4.29b: Mass of Calcium, Potassium, Phosphorus and Sulphur in harvested plants concentration over the treatments, Control 0%, Straw + Green Crab with the potting mix in the composition percentage (10, 20 and 35%) (n = 4 treatments).

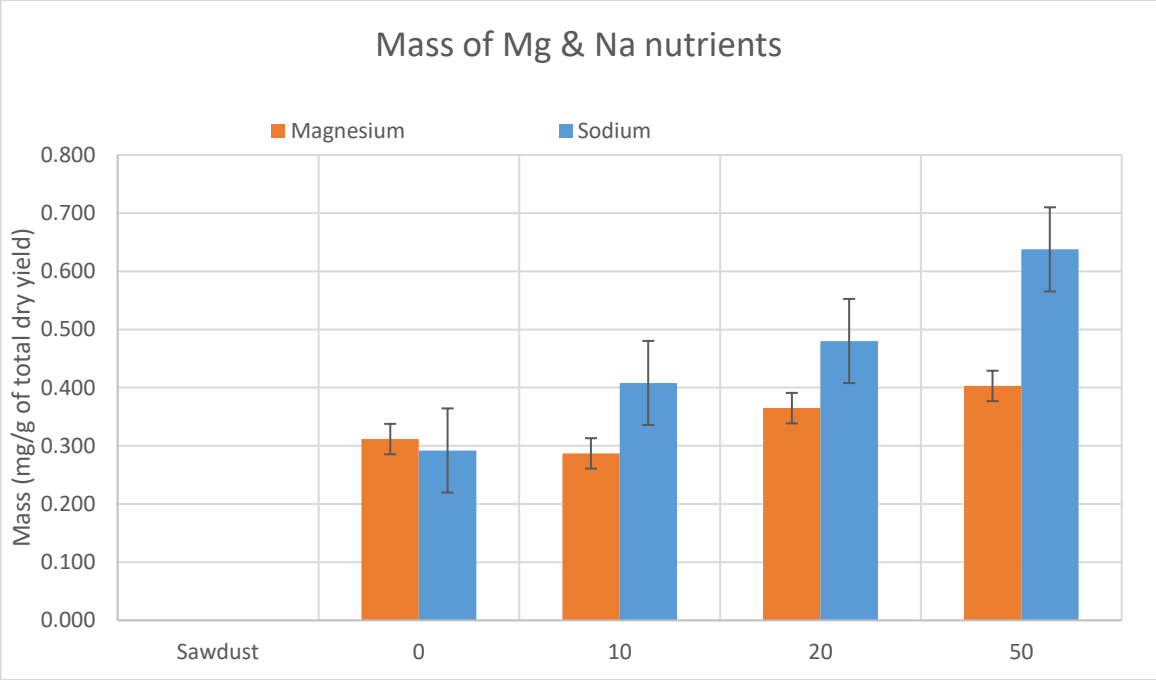

Figure 4.30a: Mass of Magnesium, and Sodium concentration in harvested plants over the treatments, Control 0%, Sawdust + Green Crab with the potting mix in the composition percentage (10, 20 and 50%) (n = 4 treatments).

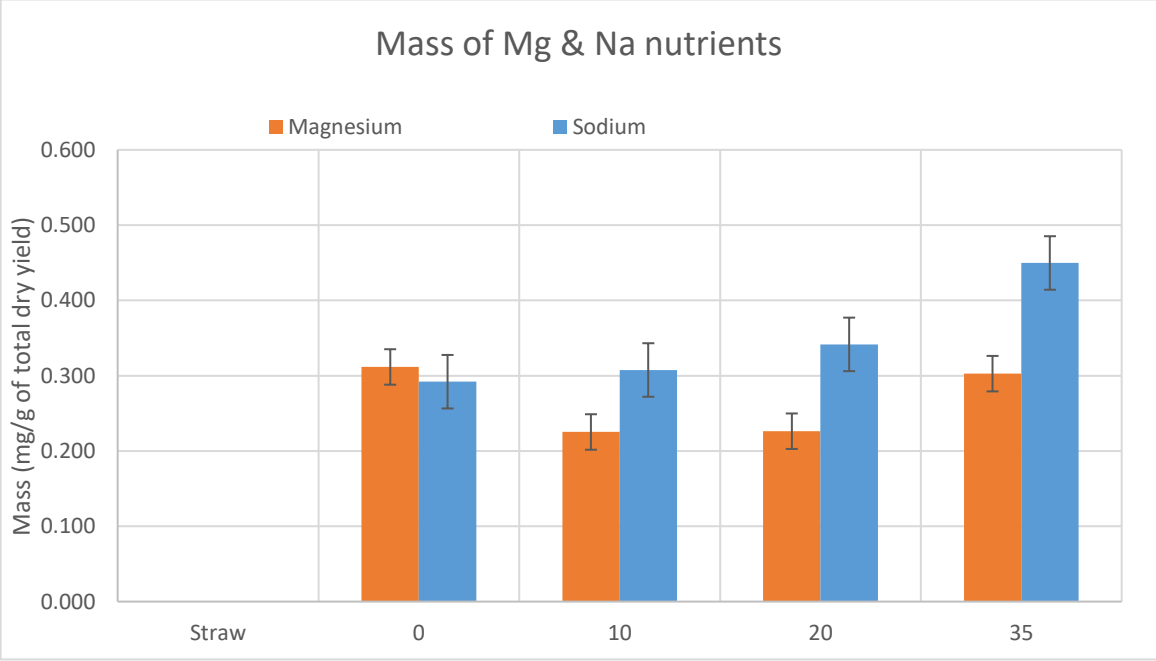

Figure 4.30b: Mass of Magnesium, and Sodium concentration in harvested plants over the treatments, Control 0%, Straw + Green Crab with the potting mix in the composition percentage (10, 20 and 35%) (n = 4 treatments).

4.4.3.4. Statistical Analysis of Nutrients from Harvested Plants

Calcium

The calcium concentration was higher along the yields obtained from the SW+GC medium compared to the SD+GC medium based on the mean data (n = 4). The SD 50% (0.97mg/g) had a higher concentration and SD 10% (0.63mg/g) were statistically different. Similarly, in the SW+GC composting study, SW35% (0.66mg/g) had a higher concentration than SW10% (0.52mg/g), which also indicated that the nutrient composition of the composts increased along the increase in concentration of compost media. The main significant difference between the groups (SD+GC & SW+GC) along the levels of composition was highly statistically significant ($p<0.05$) . The SD 50% media was significantly different when compared against the controls, similarly SW 35% had calcium concentration significantly different against the controls (Table 4.18).

Table 4.18: Least Square mean value of calcium concentration generated from SD+GC and SW+GC composting medium

Compost (% by weight)	Calcium Concentration (mg/g)	Compost (% by weight)	Calcium Concentration (mg/g)
Control	0.59±0.01	Control	0.59±0.01
SD10	0.63±0.11	SW10	0.52±0.01
SD20	0.78±0.15	SW20	0.60±0.21
SD50	0.97±0.16	SW35	0.66±0.25

Magnesium

Plant uptake of Magnesium was conveniently significant along with the SD+GC composting medium at $p < 0.05$, where $p = 0.0124$. The SD 10% (0.28mg/g) and SD 35% (0.30mg/g) were statistically different based on Tukey's comparison LSD test. As the composition ratio increased, the plant magnesium uptake increased along with the

SD+GC composting study. The harvest yield generated from SW+GC composting medium was not statistically significant since the data yields were much lesser. A high variation is observed along SW 10%. The SW+GC composting medium had a magnesium concentration simultaneously increasing, but the control is higher than SW 10%. The main significant difference was observed between SD 0 to 50% (Table 4.19).

Table 4.19: Least Square mean value of magnesium concentration generated from SD+GC and SW+GC composting medium

Compost (% by weight)	Magnesium Concentration (mg/g)	Compost (% by weight)	Magnesium Concentration (mg/g)
Control	0.31±0.01	Control	0.31±0.01
SD10	0.28±0.11	SW10	0.22±0.01
SD20	0.37±0.15	SW20	0.23±0.21
SD50	0.40±0.16	SW35	0.30±0.25

Potassium

Plant uptake potassium was highly significant ($p < 0.05$). As the ratio of the medium composting increased, the plant potassium uptake increased from SD 10 and 20%, but slightly increased along SD 50% (Figure 4.44). The potassium concentration when compared against controls and SD 10% were significantly different, but the SD 50% (3.79mg/g) had a higher nutrient concentration along with the study. There had been significantly different along SW 35% (2.93mg/g), the concentration had been increasing along the SW+GC media. When the SD+GC and SW+GC media were compared against each other they were statistically significant, but the concentration was higher along SD+GC media when compared with SW+GC media harvest. The initial potassium concentration of the SW+GC compost media was also lower than the controls, resulting in lower media concentration after the harvesting plants (Table 4.20).

Table 4.20: Least Square mean value of potassium concentration generated from SD+GC and SW+GC composting medium

Compost (% by weight)	Potassium Concentration (mg/g)	Compost (% by weight)	Potassium Concentration (mg/g)
Control	2.58±0.01	Control	2.58±0.01
SD10	2.65±0.11	SW10	1.58±0.01
SD20	3.62±0.15	SW20	1.76±0.21
SD50	3.79±0.16	SW35	2.93±0.25

Phosphorus

Plant uptake phosphorus was measured along smaller concentration, indicating statistically significance along with the SD+GC composting study at $p < 0.05$. As the sawdust concentration increases, the plant phosphorus uptake increased. The sawdust 50% (1.01 mg/g) significantly greater than the control (0.72 mg/g). The phosphorus concentration decreased along with the levels from the harvested plants, which correlates the potassium concentration direction along with the SW+GC composting medium. The SW 10% (0.51 mg/g) has a higher concentration; when the concentration of SW medium increased, the nutrient uptake decreased (Table 4.21).

Table 4.21: Least Square mean value of phosphorus concentration generated from SD+GC and SW+GC composting medium

Compost (% by weight)	Phosphorus Concentration(mg/g)	Compost (% by weight)	Phosphorus Concentration(mg/g)
Control	0.72±0.02	Control	0.72±0.02
SD10	0.70±0.01	SW10	0.51±0.01
SD20	0.98±0.21	SW20	0.55±0.21
SD50	1.01±0.25	SW35	0.87±0.25

Sodium

The sodium concentration was observed to be higher along the yields obtained from the SD+GC medium compared to the SW+GC medium based on the mean data ($n = 4$). The

SD 50% (0.26mg/g) had a higher concentration and SD 10% (0.41mg/g) were statistically different. Similarly, in the SW+GC composting study, SW35% (0.45mg/g) had a higher concentration than SW10% (0.31mg/g), which was also identified that the sodium concentration increased with increasing concentration of compost in the media. The main significant difference between the groups (SD+GC & SW+GC) along the levels of composition was statistically significant. The main statistical difference was observed between 0 to 50% composition along the plant harvested from SD+GC composting medium (Table 4.22). The main significant difference observed between the studies was significant at $p < 0.0001$ (Table 4.23) for the SD+GC composting study.

Table 4.22: Least Square mean value of sodium concentration generated from SD+GC and SW+GC composting medium

Compost (% by weight)	Sodium Concentration (mg/g)	Compost (% by weight)	Sodium Concentration (mg/g)
Control	0.29±0.01	Control	0.29±0.01
SD10	0.41±0.11	SW10	0.31±0.01
SD20	0.48±0.15	SW20	0.34±0.21
SD50	0.64±0.16	SW35	0.45±0.25

Sulphur

Plant sulphur uptake was only significant at $p < 0.1$ ($p = 0.077$) (Table 4.24). As the rate of SD increases, the highest concentration of sulfur was observed at SD 50% (2.53mg/g) and decreased along with the lower concentration SD 10% (1.74 mg/g), which had been weakly significant. But the SW+GC medium yielded a compost with a lower sulphur concentration of SW 20%. The Sulphur, Potassium, and Phosphorus, which were not highly significant, had lower SW 20% and 50% concentrations.

Table 4.23: Least Square mean value of sulphur concentration generated from SD+GC and SW+GC composting medium

Compost (% by weight)	Sulphur Concentration (mg/g)	Compost (% by weight)	Sulphur Concentration (mg/g)
Control	1.95±0.01	Control	1.95±0.01
SD10	1.74±0.11	SW10	1.22±0.01
SD20	2.43±0.15	SW20	1.26±0.21
SD50	2.53±0.16	SW35	2.01±0.25

4.4 DISCUSSION

Green crabs were amended with two different exogenous carbon sources (either straw or sawdust) which resulted in two different mature composts with chemical profiles that differed substantially, particularly with regards to the levels of nitrogen. A detailed physical and chemical description of the developing compost was carried out over the entire timeframe of composting. The sawdust based composting study reached the thermophilic phase of composting during the earlier stages of composting, since the ambient temperature was higher throughout this study, while the straw had a very short thermophilic phase of composting, the ambient temperature was very low, since the study was carried out in the winter and also the ratio of mass used in both the studies also influenced the temperature of the compost. The influence of change in moisture in both the studies were highly due to the ambient temperature conditions, where the drying out in the SD+GC study occurred initially as a result of the composting study, further the moisture was maintained for proper composting study. Earlier literature suggested that a sawdust-based compost maintained a higher temperature throughout the composting period, while the straw-based compost-maintained temperature peak for a significantly shorter period (Changa et al., 2003). In this study, the sawdust reached the thermophilic phase during the first week, but the straw required a longer duration to enter the

thermophilic phase of composting. Furthermore, the sawdust-based compost maintained a higher temperature (>40^{0}C), for a period of 45 days, but the straw temperature decreased after a period of 15 days. The composts were analyzed for total carbon, total nitrogen, organic carbon, and carbon dioxide evolution rate. Based on earlier studies, the CO_2 evolution rates for both sawdust and straw were measured to be ≤1.0 mg CO_2 g OM^{-1} d^{-1}, after 60 days of composting, suggesting that both composts were mature and stable (Stefan et al., 2004). In this current study the carbon dioxide evolution rate was observed to be 2.51 mg CO_2 g OM^{-1} d^{-1} for the SD+GC based composting study and 1.45 mg CO_2 g OM^{-1} d^{-1} for the SW+GC composting study. Based on the CCME guidelines the composts having CO_2 evolution rates less than 4.0 mg CO_2 g OM^{-1} d^{-1}, are considered mature and stable, hence both the studies were considered to have generated stable and mature composts.

In the study by Stefan et al. (2004), the composts were added with cow dung and two extraneous carbon materials like straw and sawdust which had a neutral pH. In the current study the SD+GC compost, had a pH of 6.65 and SW+GC compost had a pH of 8.13, indicating a higher alkaline in the SW+GC compost, which was generated due to the alkaline nature of the shells of the crabs. In earlier studies, the total carbon ratio was higher by 20% along the straw-based compost compared to the sawdust-based compost (Changa et al., 2003). Similarly, the current study which focuses on the measurement of total carbon in the compost showed that SW+GC had a 12% higher total carbon compared to the SD+GC compost, which was highly due to the ratio of SW+GC compost (1:4). The straw, one of the carbonaceous raw material had been used in a larger quantity in comparison with the SD+GC study.

The weight of SD+GC and SW+GC composting study were in the ratio 1:2 and 1:4 respectively, they had been adjusted so that the initial C:N ratio of both composting studies remained 25:1. Initially peak heating temperature and length of peak heating, the carbon dioxide evolution rate was higher in the SD+GC based composting study, which indicated the higher microbial activity along the initial stages of composting.

The SD+GC and SW+GC based composts with the potting media had different mix profiles compared to the original control potting mix. The physical parameters such as bulk density and water retention capacity were also one of the reasons for quantity of yield, hence lower the water retention capacity (12.21%) higher is the crusting associated with the straw. The SD+GC potting medium had a lower bulk density (450 kg dry m^{-3}) and higher water retention capacity (20.81%) in comparison to the SW+GC study, which resulted in higher yield.

The physical parameters of the plant growth study indicated that the SD+GC compost media showed a higher growth of 1.30 – 1.55 cm. Addition of compost to the control mixes in calculated proportions indicated increased yield along the SD+GC media after 14 days of harvesting. On SD+GC compost and control media in the ratio 50% showed a higher above-ground biomass than the SW+GC compost yield.

There was also another significant factor that played a role in the plant growth which included the pH (Luo et al., 2011). In the current study the SW+GC amended compost had high alkalinity due to the chitin content, which affected the plant growth when tried with higher concentrations. The higher concentrations of straw-based compost in the plant growth study had encountered top-layer crusting due to the mulching nature of the straw for an intertwined layer, which led to restricted plant growth over the higher

concentrations of compost. Due to the crusting of straw, they had been used as a barrier for sand control and vegetation restoration, but there was no proper experimental study carried out on the straw compost as a plant growth medium.

After harvesting, the potting media carbon and nitrogen concentration were generally lower compared to the initial compost nutrient composition in the medium. (Hardy et al., 2013). Similarly, the potting media with SD+GC compost in the percentages of 10%, 20% and 50% and SW+GC compost in the percentages of 10%, 20% and 35% found that the total carbon and nitrogen percentage along the experimental study had a slight increase after harvesting. The increase in carbon and nitrogen were also due to the fibrous nature of the roots in the harvested media.

The SW+GC composting study had a higher calcium composition in the harvested plants compared to the SD+GC compost, whereas the nutrient composition such as magnesium, potassium, phosphorus, sodium, and sulphur remained higher along the SD+GC composting study.

CHAPTER 5 CONCLUSION

Green crabs have played a prominent role in affecting aquatic species in the north-western Atlantic Canada since the 19th century. This species of crabs has flourished throughout Atlantic Ocean due to its ability to tolerate wide range of water temperature and salinity. They have been feeding on a variety of prey which include soft shell clams, quahogs, mussels, and oysters. They have also been competing with the other crustaceans for nutrient resources and habitats.

There have been various culling efforts to control the spread of this invasive species, which have not been very successful. Current methodologies to control the green crab population on the east coast of Canada included the process of trapping for several years. From an economic perspective there is no particular potential usage identified for the trapped green crabs. There is no current market for European Green Crabs in the Atlantic Canada. The green crabs are relatively small in size, from which meat cannot be extracted, hence the market is not strong in North America (Mary et al., 2013).

Composting is identified to be a useful and economic process adopted in the utilization of green crabs. The first objective of this research focused on the comparison of sawdust and straw feedstocks with the green crab with similar C: N ratio (i.e., SD+GC and SW+GC). Sawdust is a feedstock from the timber industry which has carbohydrates like cellulose (40%), lignin (30%), and hemicellulose (10%) (Muley et al., 2016). Whereas straw comprises of higher concentration of carbohydrates like cellulose (35%), hemicellulose (18%), and lignin (10%) (Gou et al., 2018), which indicated that the final SD+GC compost high carbon dioxide respiration rate.

The second objective focused on tracking the carbon and nitrogen dynamics associated with the composting system. The total carbon in the composting system was used in detailing the decomposition associated with the system, where the total carbon decomposition rate was higher along the SD+GC based composting study, compared to the SW+GC based composting study.

The carbon dioxide evolution rate used in the estimation of the maturity of the compost, was higher in the SD+GC based composting study, since the straw had readily available carbohydrates in a higher ratio (cellulose, hemicellulose, and lignin). The higher microbial activity occurred in the SD+GC based composting study, but the rate of organic matter decomposition was low. However, the evolution rate from both the composts suggest that the composts were stable and mature based on CCME guidelines (less than 4.0 mg CO_2 g OM^{-1} d^{-1}). Initially, the compost began with composting ratio of 25:1 where the raw materials were not evenly distributed in the compost, but the final compost generated from the SD+GC study generated a C: N ratio of 28.2:1, and the SW+GC study had a C: N ratio of 27.5:1, which indicated a small increase towards the end of composting, when the composts remained more homogeneous.

The third objective dealt with the utilization of the compost generated from straw and sawdust in the plant growth studies. The pH played a vital role in the growing media, since high chitin content from the crab shells and straw affected the growth media, resulting in a lower yield of harvest. The compost was added with the potting media, where the initial concentrations of the composting media had a higher concentration before plantation. After harvesting, the media was tested for nutrients, which were analyzed to be in a lower concentration, since the plants were evidently using the

nutrients from the media in growth. The SD+GC amended compost with a high concentration of nutrients like magnesium, potassium, phosphorus, and other micronutrients, which include the primary plant growth requirements. Similarly, the sawdust and potting media in an equal ratio (50%) showed higher growth of plants. The plant growth was higher, with the higher concentration of compost added to the medium. Also, the water retention capacity in sawdust had been observed to be higher compared to the straw-based composting study, based on the bulk density.

The potting media, a foundation for the plants, could be enriched by adding the compost mixes in various proportions into the potting medium, which increased the release of the nutrients in the harvested plants. Depending on the decomposition rate, carbon cycle, mineralization of nitrogen, the germination index, and yielding capacity of the compost, the SD+GC composting had been generating a higher yield. Since the sawdust is used in a ratio of 1:2, it could be easier to adopt the SD+GC-based composting easier than the other composting techniques. The waste generated as green crabs could thus be disposed of by carrying out this composting technique. There is various ongoing research related to green crabs and their application in chitin since they belong to the crustacean family. The composting procedure was one of the adopted procedures to reduce the damage made to the environment by green crabs. This technique could be more accessible once people are encouraged to perform commercial fishing and enable various techniques to improve the environmentally concerning factors. The composting study could be carried out with different carbonaceous materials like peat moss, corn stalks or wood chips in different ratio. The chitin-based composts could be utilized in pest management activities and also biological crop disease control medium. Regarding the plant growth study, different

species of seeds could be used to see huge variations in germination index, mineral concentrations for different proportions.

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APPENDIX I – TABLES AND FIGURES

COMPOSTING

1. Sawdust and Green crab-based composting

Table A.1: Quantity of Moisture Loss associated with Sawdust and Green Crab studies over the 125-day time-period over Fall 2019.

Sampling Days	Moisture Loss in SD+GC Study (in litres)
0	3.71
1	3.71
2	3.70
3	3.68
5	3.61
7	3.54
10	3.20
12	2.93
14	2.57
18	2.19
22	1.66
27	1.51
28	3.52
29	3.52
30	3.51
31	3.46
32	3.54
33	3.43
34	3.39

35	3.39
36	3.37
37	3.35
39	3.34
41	3.27
43	3.28
46	3.27
49	3.21
53	3.19
57	3.14
125	3.20

Table A.2: Amount of CO_2 – C mg/hr recorded over the Sawdust and Green Crab for a duration of 96 hours

	Hour (Cumulative amount of CO2-C in mg/hr)					
Days	**4**	**8**	**24**	**48**	**72**	**96**
1	1.79	3.06	1.50	0.71	0.81	0.70
5	3.26	5.59	3.00	1.10	1.27	1.09
14	4.70	8.06	4.50	1.43	1.67	1.38
29	6.47	10.68	6.00	1.87	2.14	1.74
39	7.99	13.22	7.50	2.27	2.57	2.05
46	9.51	15.73	9.00	2.63	2.99	2.35
57	11.03	18.24	10.50	2.98	3.40	2.63
125	12.58	20.72	12.00	3.30	3.77	2.91

2. Straw and Green crab-based composting

Table A.3: Quantity of Moisture Loss associated with Straw and Green Crab studies over the 57-day time-period over winter 2020.	
Sampling Days	Moisture Loss in SW+GC Study (in litres)
0	1.31
2	1.98
3	1.22
5	1.13
7	1.35
10	1.90
12	1.51
14	2.22
18	1.86
22	2.08
27	1.85
29	1.58
37	1.19
43	0.06
49	0.03
54	0.01

Table A.4: Amount of CO_2 – C mg/hr recorded over the Straw and Green Crab for a duration of 96 hours						
	Hour (Cumulative amount of CO2-C in mg/hr)					
Days	4	8	24	48	72	96
1	0.91	0.91	0.76	0.39	0.26	0.19
5	2.02	2.00	1.57	0.79	0.52	0.39

8	2.84	3.03	2.38	1.18	0.78	0.58
14	3.59	3.99	3.20	1.57	1.04	0.78
27	4.14	4.78	4.02	1.96	1.30	0.97
35	4.41	4.95	4.78	2.35	1.56	1.16
52	5.03	5.68	5.58	2.75	1.82	1.36

PLANT GROWTH STUDY

Table A.5: Number of seeds germinated, length of the plant, and germination index during the plant growth study carried out for the sawdust and straw based composting study

Treatment	Germinated seeds	Length of the plant	Germination Index
control	26	1.15	76.67
	27	1.15	79.62
	28	1.15	82.56
	25	1.15	73.72
sd 10	25	1.05	67.31
	23	1.05	61.92
	29	1.05	78.08
	29	1.05	78.08
sd 20	25	1.1	70.51
	25	1.1	70.51
	23	1.1	64.87
	24	1.1	67.69
sd 50	26	1.15	76.67
	22	1.15	64.87
	26	1.15	76.67
	26	1.15	76.67
sw 10	20	1	51.28
	17	0.9	39.23
	22	1	56.41
	20	0.9	46.15
sw 20	18	0.9	41.54
	12	0.9	27.69
	12	0.9	27.69
	22	0.9	50.77
sw 35	15	0.9	34.62
	15	1.1	42.31
	13	1.05	35.00

	14	1.05	37.69
sw 50	0	0	0.00
	16	0.8	32.82
	0	0	0.00
	0	0	0.00

COMPOSTING

1. Sawdust and Green crab-based composting

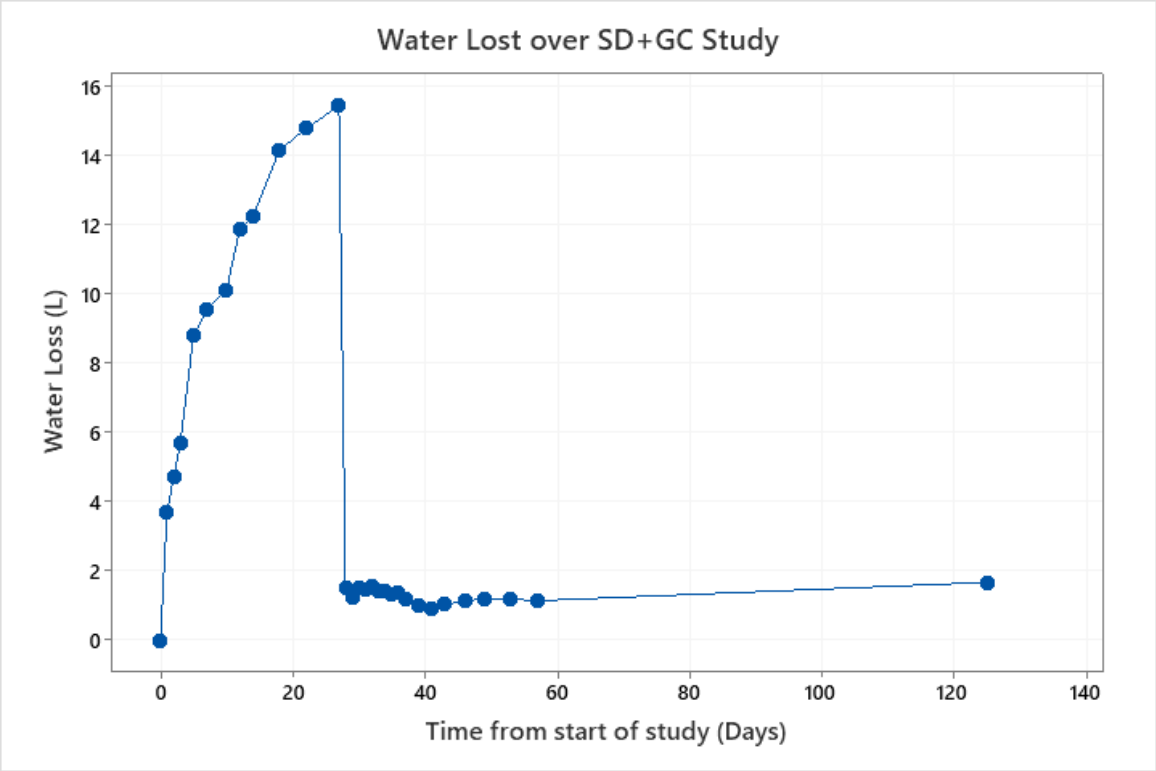

Figure A.1: Quantity of water loss associated with Sawdust and Green Crab (SD+GC) studies over the 125-day time-period over Fall 2019.

2. Straw and Green crab-based composting

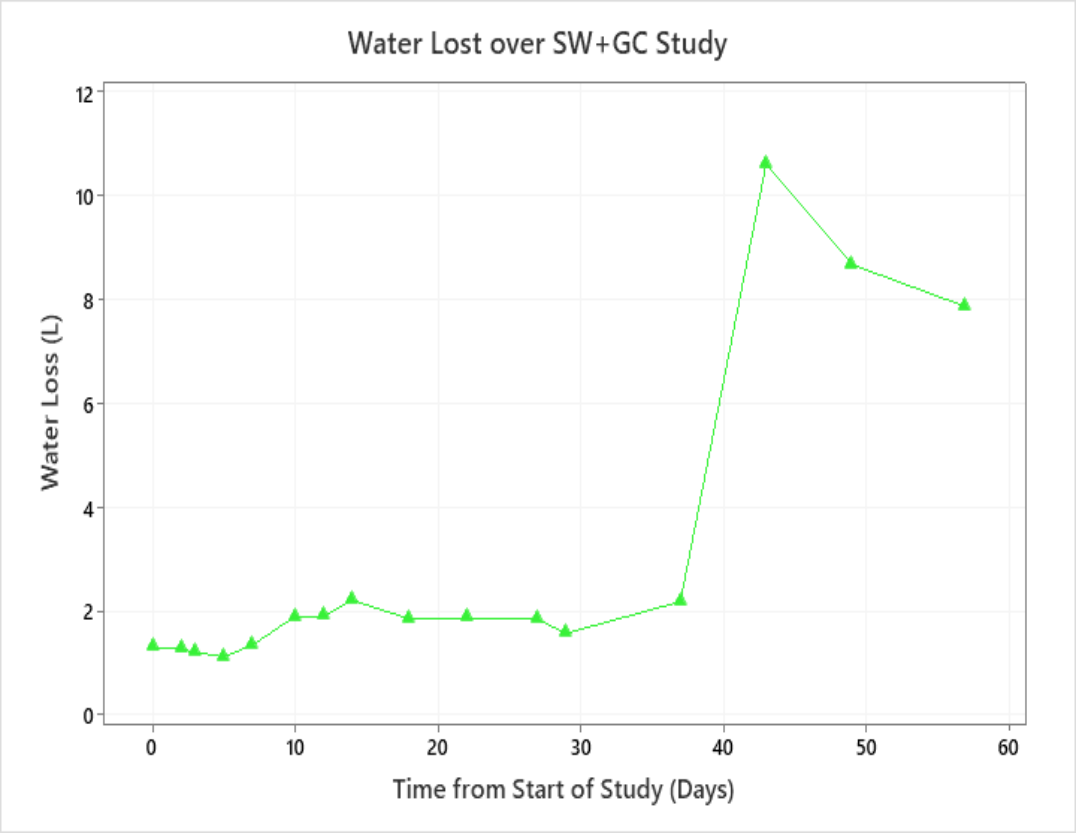

Figure A.2: Quantity of water loss associated with Straw and Green Crab (SW+GC) studies over the 54-day time-period over Winter 2020.

PLANT GROWTH STUDY

Figure A.3: Water seepage test performed in compacted compost SD+GC (on the left) and SW+GC (on the right) study.

Figure A.4: Harvested plants stored in the oven for the gravimetric analysis at 50º